

## P21 White Paper

# HYDROGEN FACTS AND SECURITY CONCEPT PREMION T FUEL CELL SYSTEM

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## Summary

P21 is well aware that the operational security of the system is as important as the reliability of power supply. That's why special attention was paid to the development of a security based operating system for the Premion T Fuel Cell System.

Furthermore P21 knows about prejudices and fears concerning hydrogen and it is one goal of this document to give objective information about the risks and opportunities connected with the use of hydrogen.

## Hydrogen as a fuel

Hydrogen is not more or less dangerous than any other energy carrier, furthermore hydrogen has properties that in certain areas make it safer than other energy carriers.

## Usage yesterday and today

For the past 50 years, gaseous hydrogen has been used in large quantities as a feedstock in petroleum refining and the chemical and synthetic fuels industries. Hydrogen is used in the food processing, semiconductor, glass, and steel industries, as well as a coolant for large turbine generators.

In 1996, the total world-wide consumption of hydrogen was more than 14 trillion cubic feet per year. Almost all of the hydrogen used is captive. It is consumed at the refinery or chemical plant where it is produced.

Nevertheless, a safe and reliable hydrogen

distribution network, consisting of liquid hydrogen delivery trucks, gaseous hydrogen tube trailers, and dedicated hydrogen pipelines, has been developed over the years. [U.S. Department of Energy, 2004]

## Hydrogen facts

Hydrogen makes up to 75% of the known universe. It is not an energy source like oil, coal, wind, or sun. Rather, it is an energy carrier like electricity or gasoline – a way of transporting useful energy to users. Hydrogen is an especially versatile carrier. Like oil and gas, but unlike electricity, it can be stored in large amounts, and can be made from almost any energy source and used to provide almost any energy service.

- **Density:**

Hydrogen is the lightest of all the elements; it is eight times lighter than natural gas.

- **Buoyancy:**

At room temperature, gaseous hydrogen has a very low density compared to air and to other fuels. If it were to leak from a container, it would rise more rapidly than methane, propane, or gasoline vapour and quickly disperse.

- **Diffusion:**

Although gas transport from diffusion is much less than gas transport due to

buoyancy, hydrogen diffuses through air much more rapidly than other gaseous fuels.

- **Colour, Odour, Taste and Toxicity:**

Hydrogen is a colourless, odourless, tasteless, and non-toxic gas.

- **Flammability and flame characteristics:**

The flammability of hydrogen, as a function of concentration level, is higher than that for methane, propane, or gasoline vapour.

However, if there is a brief leak, hydrogen will rise more rapidly than methane or propane and will disperse quickly. Hydrogen's rapid dispersion rate is its greatest safety asset.

- **Ignition energy:**

Hydrogen can be ignited by a very small amount of energy if its concentration is neither lean nor very rich, and the humidity is low.

Outdoors, an explosion is not likely, except in the rare case of a large hydrogen accumulation and a high-energy ignition source (such as a lightning strike or a chemical explosion). However, a hydrogen cloud is highly unlikely to occur because hydrogen (unlike other conventional fuels) dissipates rapidly in unconfined areas.

- **Detonation limits:**

Hydrogen is detonable over a very wide range of concentrations when confined. However, unlike the other common fuels, it is difficult to detonate when unconfined.

[US Department of Energy, 2004]

## Excursion:

In 1958 the company Arthur D. Little carried out a series of detonation tests involving discharges of LH2 in quantities ranging from 5 litres up to almost 20,000 litres. The tests confirmed that hydrogen never detonated from impact – not even when bullets were shot through the tank. Comparison tests were also made against various hydrocarbon fuels, clearly showing the much faster combustion process of hydrogen:

Fuel	Combustion time
Liquid H <sub>2</sub> (LH <sub>2</sub> )	27 sec
Propane	4 min
Petrol	5 min
Jet fuel (JP-4)	7 min

Combustion time calculated from 121 litres of fuel. Calculations based on a conventional car accident show that a fire will last for 20 to 30 minutes, while a comparable hydrogen vehicle would burn for 1 to 2 minutes. [Hart, 1997]

## Vis-à-vis other energy sources

There are quite a few different energy sources, electrochemical, gaseous and liquid, all with different properties. Common for all fuels is their flammability. This is in the nature of fuels owing to their high energy per volume ratio. Consequently, all fuels are more or less dangerous under different circumstances, and therefore they call for specific care and handling depending on their individual properties. So it is a quite difficult issue to compare the safety of fuels due to their varying physical and chemical properties. Hydrogen-air mixtures, when compared to similar fuels, have wide flammability range and low minimum ignition energy. These are disadvantages for hydrogen. [SFK-GS-37 2002]

But there are also advantages to these characteristics. Hydrogen-mixtures between 4 and 75% are flammable, and mixtures between 18 and 59% are explosive. [Brewer 1991] Likewise, gasoline is explosive between 1.1 and 3.3 % - in other words a much lower burning point than for hydrogen. In the majority of accidents it's the lower burning point that is decisive.

It is very difficult to detonate hydrogen in open air. This has to do with the fact that hydrogen is much lighter than air (14.4 times) and rises at a speed of 20 m/s. [Swain 1998]

When a fuel ignites, the emission influences the total flux of heat radiated. Hydrogen slow emission reduces the heat transferred by

radiation to objects near the flame, thus reducing the risks of secondary ignitions and burns.

The average emissive of a flame is a more significant factor than flame temperature when considering thermal radiation damage from fires. Hydrogen flames radiate less heat than do natural gas, propane, gasoline, and kerosene, although the flame temperatures of hydrogen and the other common fuels are comparable. Because of their higher lean limits of flammability, both hydrogen and natural gas are less likely than gasoline or propane to ignite in the case of a small leak discharging into a closed area with a nearby ignition source. [IAEA-TECDOC-1085]

Per unit of energy contained, hydrogen weighs 64% less than gasoline or 61% less than natural gas: 1 kilogram (2.2 lbs) of hydrogen has about the same energy as 1 U.S. gallon of gasoline (3.8 litres), while gasoline weighs not 2.2 but 6.2 pounds. [Amory B. Lovins, 2003]

## Demonstration



Hydrogen car



Gasoline car

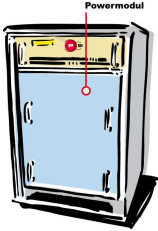
The fire from a leak in a gasoline engine car and the same kind of leak from a hydrogen car compared. The pictures are taken at one minute after ignition. The hydrogen flame has begun to subside, the gasoline fire is intensifying. After 100 seconds, all the hydrogen was gone and the interior of the car was undamaged. The gasoline car continued to burn for a long time and was totally damaged. [Swain 2001]

## Characteristic compared

Characteristic	H2	Natural Gas	Gasoline
Lower heating value kJ/g	120	50	44,5
Self-ignition temperature (°C)	585	540	228-501
Flame temperature (°C)	2.045	1.875	2.200
Flammability limits in air (vol %)	4-75	5,3-15	1,0-7,6
Minimum ignition energy in air (uJ)	20	290	240
Detonability limits in air (vol %)	18-59	6,3- 13,5	1,1-3,3
Theoretical explosive energy (kg TNT/m <sup>3</sup> gas)	2,02	7,03	44,22
Diffusion coefficient in air (cm <sup>2</sup> /s)	0,61	0,16	0,05

Batteries (energy storage) are comparable to H<sub>2</sub>, because they emit H<sub>2</sub>, their storage rooms need ventilation. The difference to H<sub>2</sub> storing technology is that batteries emit H<sub>2</sub> at any time uncontrolled, while H<sub>2</sub> based technology like Premion T Fuel Cell Systems are developed and standardised for maximum on security and control.

## Security Premion T



Safety has top priority for P21 GmbH. All used components in the production as well as in the development and maintenance are standardised products from highly qualified supplier, which undergo a multitude of quality and functional tests during the construction and afterwards.

P21 GmbH works according to quality management system ISO 9001:2000. Furthermore all products are constructed and tested according to type examination test Machine Directive 98/37/EG and are certified according to CE.

### Technical Implementation Safety Concept

The most important safety measure within in Premion T is the close hydrogen loop. Once the hydrogen has passed the pressure unit (which under normal circumstances is outside or is connected with the outside) no hydrogen can leak uncontrolled under regular operation conditions. The hydrogen is conducted directly to the stacks, which enclosures are gas proofed.

Within the stacks most part of the hydrogen reacts and produces the required energy. The

small amount of hydrogen which passes through the stack without a reaction is collected and conducted into a surge tank.

This surge tank is the only place within the loop where hydrogen can leave the loop in a controlled way into the exhausted air of the system. A valve guarantees that the hydrogen concentration discard to the air stream is always less than 1%. Within the air stream the hydrogen is instantly diluted. There is no risk of ignition at any time.

The whole hydrogen loop is monitored through the redundant security based operating system in 100ms intervals. If any value is out of the given security levels the system shuts down immediately and the hydrogen supply is interrupted.



## Hydrogen Storage

The hydrogen storage unit normally consists of two hydrogen bottles. The cabinet is placed outside or has a connection to the outside environment. The whole storage system is certified according to the stringent guidelines of the German TÜV. If nonetheless a leak occurs, the safety zone (the zone with no source of ignition) is dimensioned in a way that even in a worst case scenario the hydrogen is diluted under the ignition level.

Hydrogen bottles are in use for over 120 years and the development of safety issues goes on for the same time. Today a wide range of testing procedures is implemented into the manufacturing process as well as in the maintenance. [puefraum-online]

### Ultrasonic test procedure:

An ultrasonic test signal is emitted into the bottle by a multitude of sensors. The signal is reflected and gives a detailed picture of the bottle up to the detection of capillary cracks.

### Water pressure test procedure:

Water is pressed into bottles with a 1,5 time higher pressure than the nominal pressure that means 300 bar for a 200 bar bottle. The bottle has to withstand this pressure for at least 30 seconds.

## Conclusion

**1. Hydrogen has been used as energy carrier and fuel. It offers a sustainable energy supply; it is clean, efficient, and safe. It can be produced large-scale by water electrolyser using electricity from renewable energies.**

**2. Safety technical aspects of hydrogen appear to cause risks of the same order of magnitude as for other fuels. Handling experiences with hydrogen in industrial scale showed that hydrogen has good safety records.**

**3. Considering all facts and having the restriction of fossil energy sources in mind, it is obvious that hydrogen will be one column of the energy supply of tomorrow.**

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