Safety systems for hydrogen

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Hydrogen will be here for centuries in chemical and industrial applications. The need to mitigate climate change is making hydrogen potentially relevant for domestic, commercial, and consumer applications where it has not been used before.

Safety is, therefore, of paramount importance in industrial and domestic applications. Nobody should get hurt, and assets must be protected. Sensors, equipment, procedures and smart controls exist for the safe use of hydrogen. When these are properly implemented by people with appropriate training, each economically viable hydrogen application can be implemented without concern.

Chemical processing

In industry, engineering practices and reliable equipment exist to mitigate the two risks of hydrogen gas: pressure and flammability.

Over-pressure in equipment can lead to catastrophic failure and a massive release of hydrogen. Powerful explosions and intense fires can be the result. Avoiding over-pressure is achieved using mechanical relief valves which vent hydrogen to prevent mechanical damage. In the vent header, hydrogen must not be allowed to mix with air or other oxidant gases before it is released to the atmosphere either directly or through a flare or gas scrubber.

If hydrogen does leak from a high-pressure source, it can be detected rapidly using various techniques. Fixed gas detectors use sensors to identify the presence of a flammable gas and are located close to likely leak points such as valves and pipe flanges. However, the gas detector relies on the leaked hydrogen gas passing over the sensor. Wind direction changes can suppress the signal meaning potentially explosive hydrogen gas leaks are not detected.

To support gas detection, flame detectors can be installed. They are immune to wind direction changes, but are only activated after a leak has been ignited. Hydrogen burns with an inorganic flame: no CO_2 is present. Furthermore, the unburned hydrogen is also an inorganic molecule. This means that conventional flame detectors which rely in the Infra-Red (IR) signatures of methane and CO_2 molecules are not suitable for hydrogen. Innovative flame detection equipment operating in other IR and ultraviolet (UV) wavelengths is required for hydrogen flames.

Pipelines

Moving hydrogen from an industrial production location to end-user application locations can be achieved in many ways. The most cost-effective mode for high volumes of hydrogen is to use a pipeline network. The same concept is true for natural gas transmission and distribution.

Hydrogen is a tiny molecule and has the ability to attack and embrittle steel in ways that methane cannot. The grade of steel, pressure of the pipeline and the operational regime of the pipeline pressurisation and depressurisation are all governed by this property of hydrogen to embrittle steel.

Safety precautions begin with the selection of an appropriate grade of steel, or by coating the internal walls of the pipeline to avoid direct contact of hydrogen with the pipeline material. Additionally, mechanically activated overflow protection valves are used. These automatically close if a pipeline is ruptured to minimise the amount of flammable gas that will be released.

In addition to good engineering practices and mechanical devices, smart controls are also used. High-tech sensors can detect sudden pressure drops and send signals through digital control systems to close valves in the pipeline network.

Mobility

Pressure is a major risk in hydrogen mobility applications. To ensure there is sufficient fuel storage capacity on a fuel cell electric vehicle (FCEV) or vehicle with a hydrogen-fired internal combustion engine, hydrogen is stored at 700 bar in carbon-fibre tanks.

In the event of a fire the pressure in the storage tank will increase. If it explodes due to overpressure, it will seriously injure, or kill the occupants of the vehicle. To prevent this, the hydrogen storage tanks are fitted with a thermal pressure relief device (TPRD) which vents hydrogen in a safe direction away from the vehicle occupants. The TPRD operates in a similar way to water sprinklers in a hotel or commercial building.

To decant hydrogen into vehicle's tank, hydrogen is stored at the refuelling station (HRS) at up to 1,000 bar. A release of hydrogen from this pressure will heat the gas instantaneously to above its auto-ignition temperature due to the Joule-Thomson effect. This heating will result in a flame or explosion. Joule-Thomson expansion of natural gas and air are used to liquefy these gases. On the other hand, when hydrogen is released from a very high pressure to the atmosphere it heats up, rather than cooling down.

Power generation

Modern data-centres which enable the internet, cloud computing and AI are keen to decarbonise their operational footprint. Some are looking to use large hydrogen-fed fuel cells for this purpose.

Hydrogen can be delivered to these end-user locations by truck. These trucks store up to one tonne of high-pressure hydrogen. It is common for the hydrogen trailer to be de-coupled from the tractor unit and be connected to the end-user site by a high pressure hose. When the trailer is empty, a full trailer of hydrogen is delivered and the truck tows away the empty one for refilling.

The consequences of towing a hydrogen trailer away whilst it is still connected to the data centre would be catastrophic. To mitigate this, there is an electronic cable attached to the gas hose. If the trailer is erroneously towed away whilst it is still connected to the data centre, the electrical cable is broken. The loss of this electrical connection drives smart control systems to close valves on the truck and the end-user site to minimise the amount of flammable hydrogen that can leak.

Technical training

Training is essential for mechanical, electrical, instrumentation, process and civil engineers involved in designing hydrogen systems. They must understand the unique properties of hydrogen such as its very high flame speed, low ignition energy, and low density to design appropriate installations and equipment.

Blast walls must be built with appropriate civil engineering standards to contain the energy of an explosion. Electrical equipment must be spark free to avoid introducing an ignition source. Processes and operations must be designed to minimise the amount of hydrogen stored at a location.

Experts from the industrial gases sector, energy, chemicals plants and power generation will have a good basic foundation in safe engineering practices. However, they must be trained in the specific hazards and mitigation techniques related to hydrogen.

Standards and good practices

Multiple standards exist in this area, such as the ISO 22734-1:2025 which covers 'Hydrogen generators using water electrolysis'. This standard makes recommendations about parameters to measure and the corresponding smart controls and safety measures that can be invoked.

Industrial gases experts have united in their efforts to maintain rigorous safety standards to protect employees, hydrogen users and the public. Their collective expertise has been consolidated by EIGA into various documents. For example, EIGA Doc 247/24 refers to 'Hydrogen Overview – Distribution, Storage, Applications'.

Robust standards are in place to ensure the integrity of functional safety systems. For use in industrial settings with hydrogen, they are generally rated to safety integrity level 2, or 3. The highest SIL, level 4, is typically used in nuclear power plants and aircraft. A higher SIL rating refers to a lower risk ▸

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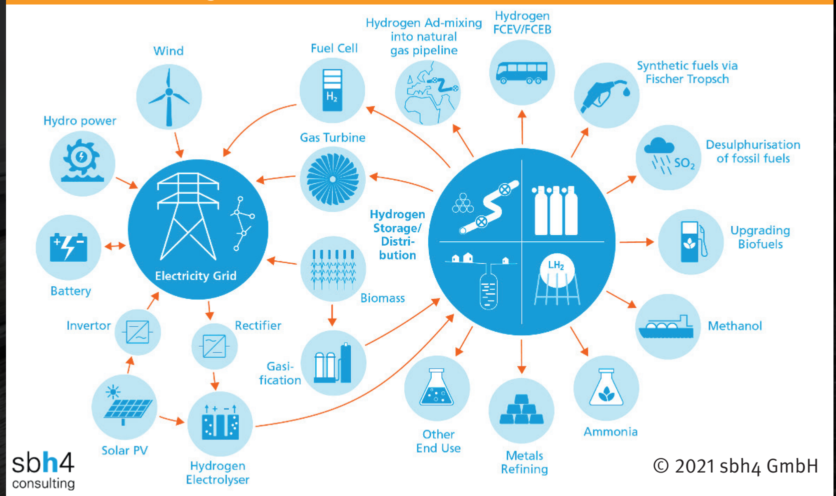
Figure 1. Renewable Hydrogen Production, Distribution, Storage and Utilisation Value Chains



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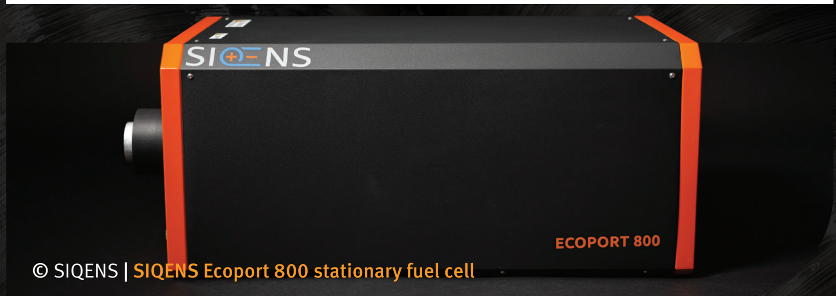

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of a functional safety measure failing, when it is required. However, there is a high price to pay for the high-level SILs.

Hydrogen sensor innovations

Early hydrogen leak detection on board buses, trucks, trains and cars will mitigate the hazard of using hydrogen as a fuel. To achieve this, a specification for an onboard hydrogen sensor has been proposed which specifies that the sensor react to the leak within seconds.

Sensors to achieve this ultra-fast response are being developed. A smart control system incorporating such a device can respond to a leak and automatically close valves on the hydrogen storage tanks to minimise the amount of gas that has leaked.

Many leak detection systems rely on chemical reactions in sensors to identify a leak. However, many different gases can trigger a response. For example, a catalytic bead sensor will detect many flammable gases including methane, carbon monoxide and hydrogen. In some use-cases, such as an industrial steam methane reformer, or a domestic boiler running on a blend of natural gas and hydrogen, these three gases can present at the same location.

A limitation of the commonly used, and cost-effective catalytic bead sensor is that it requires a reaction between the fuel gas (hydrogen) and oxygen (from air). To detect a hydrogen leak in an inert background gas such as nitrogen, sonic leak detection or a different type of sensor technology must be used.

Sonic hydrogen leak detection listens for the characteristic signature of a gas as it rapidly flows from high to low pressure. These devices are increasingly being integrated into smart control systems along side chemical gas detectors and flame detectors.

Speciation of the hydrogen leak, separate to the other flammable gases is complex. A new generation of MEMS-based sensors is being developed precisely of this purpose to enable a higher degree of granularity in smart control systems. gw

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