

## Making Hydrogen a Safe Fuel

a report by

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When, in 1870, Jules Verne wrote *20,000 Leagues Under the Sea*, Captain Nemo fuelled the Nautilus with hydrogen. Verne understood that the fuel of the future was hydrogen. Perhaps he would question why it took so long for others to understand too.

Today, we know that the traditional fuel – oil – may last only 100 years at the current rate of consumption. Oil has become so valued that it has shaped governmental policies and politics worldwide. Industrial nations depend so heavily on ‘black gold’ that they see the need to conserve it to both stabilise prices and to protect future supplies.

Hydrogen may be the fuel that provides hope of independence from oil. This is the dawn of a new era in energy and a new business is being born.

Where will we see this new source of energy impact the world’s dependence on oil? Vehicles, heating systems, passenger aircraft, as well as electricity generators, are uses that are being adapted to hydrogen fuel. Vehicles will likely be the first to use hydrogen as a fuel on a wide-scale basis.

One consideration is the type of by-products that are generated from the use of hydrogen as a fuel. There will be no toxic emissions as with gasoline/petrol fuel. Instead, the only by-product is, quite simply, water. Water is the combination of hydrogen and oxygen.

There are challenges facing the engineers, scientists and even business leaders in the conversion from oil-to hydrogen-fuelled vehicles, two of which are major challenges. Unlike oil, which is a naturally occurring resource, hydrogen needs to be produced. An efficient process in which hydrogen is produced cost-effectively, needs to be commercialised.

Production is only one issue. Safety is the other major issue. Safe handling, safe storage and safe dispensing need to be addressed before the public will accept hydrogen as a fuel.

Hydrogen is often associated with explosion and fire. People still remember images of the

Hindenburg tragedy of 1937 and such images are reinforced by school science experiments performed using a hydrogen generator and a Bunsen burner. The explosion that so little hydrogen produces is memorable.

Education of the public about hydrogen will help in gaining its acceptance. The natural gas that many use in their own homes provides more explosive potential than hydrogen and, if natural gas has become accepted by the public as fuel, it is plausible to see that hydrogen-fuelled vehicles can also be accepted. The greatest factor in wide public acceptance will no doubt be that hydrogen can be produced, delivered and used safely.

To achieve a favourable safety record, some basic properties of hydrogen need to be taken into consideration. For instance, hydrogen is lighter than air and will rise when released. Hydrogen will diffuse four times faster than natural gas; in fact, it is the fastest diffusing gas. More importantly, the gas is made up of very small molecules. This property means that it will travel right through masonry, as well as many other construction materials.

Hydrogen is explosive if it reaches a concentration of 4%. At above a 77% level it is too ‘rich’ to be of any danger. Simply put, a means of preventing accumulating a concentration above 4% in an area must be implemented. Since hydrogen is invisible, odourless and tasteless, some form of sensing technology must be used to detect it. This requires a hydrogen sensor.

The design parameters for such a sensor:

- Specificity to hydrogen gas – it should detect hydrogen but not other gases. There are many gases and vapours that might trigger a false alarm that are available in the real world.
- Wide detection range – typical range from 100 parts per million (ppm) up to 4% hydrogen in air is required. This wide dynamic range would be able to detect low-level leaks before they are dangerous. It would also sense at the explosive threshold.



Table 1: A Comparison of Current Hydrogen Sensor Technology

	ATMI EC	ATMI MEMS-S	Standard Electrochemical	Pellistor	Semiconductor Sensor	ATMI Acoustic	Polymer Sensor
Selective to hydrogen	Yes <sup>1</sup>	Yes	Yes <sup>2</sup>	No	No	Yes <sup>3</sup>	Yes <sup>4</sup>
Able to detect 100ppm of hydrogen	Yes	Yes	Yes	No	No	No	Yes
Able to detect 4% lower explosion level	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Power consumption (including electronics) @ 12-volts direct current	1mA	10mA	4mA	300mA	200mA	500mA	200mA <sup>5</sup>
Standard temperature range	-40°C +85°C	-40°C +140°C	-20°C +40°C	-40°C +140°C	-40°C +140°C	0°C 40°C	N/A
Size including electronics 2.5 x 2.5 x 6cm or smaller	Yes	Yes	No	No	No	No	No
Calibration interval normally required	6 months	6 months	3 months	6 weeks	3 months	5 years	N/A
Poisoning danger	No	No	No	Yes <sup>6</sup>	Yes <sup>6</sup>	No	N/A
Expected life <sup>7</sup>	3 years	3 years	2 years	4 years	4 years	10 years	N/A
CE conformity	Yes	N/A	Yes	Yes	Yes	Yes	Yes
Self-test function <sup>8</sup>	Yes	No	No	No	No	Yes	No
Redundancy	No	Yes	No	No	No	No	No
Cost per sensor including electronics (<€20 with mass production)	Yes	Yes	Yes	Yes	Yes	No	Yes
Commercially available for automotive use <sup>9</sup>	Yes	Yes	No	Yes	Yes	No	No

- Key:
1. Selective with filter.
  2. Cross interference only if other gases are in very high ppm concentration.
  3. Senses only hydrogen and methane.
  4. Preliminary tests indicate good selectivity, more extensive testing needs to be carried out.
  5. Low-power polymer sensors are currently experimental.
  6. There are poison-resistant sensors that delay the poisoning of the sensor, but the protection is dose-dependent.
  7. Lifetime depends on environmental conditions. This information is based on 20°C and 40% relative humidity.
  8. There are other detectors with self-test for use with other gases and other industries.
  9. Mainly as prototype versions.

- Low maintenance – it should not need to be adjusted or calibrated for at least one year.
- Rugged – it should not be affected by ageing, loss of sensitivity or have zero drift. Since the sensor is a safety item, degradation from these causes is unacceptable.
- Supervision – it should have an internal supervision mode. This feature ensures that the sensor will always be functional and verifies whether it is performing within tolerances.
- Redundancy – this feature provides tolerance to a single failure while still providing protection with a back-up if the main sensor should fail.
- Price – although there are a great number of features and high reliability is required, the sensor needs to be inexpensive. It is possible that some applications, such as automobiles, could require up to 20 sensors each. Hydrogen is not feasible as a fuel if it is too expensive to use safely.
- Low power consumption – for the automotive industry, power consumption is a high-priority item. Detection is required when the vehicle is off as well as when it is running. For example, a sensor drawing 200 milliamperes (mA) would drain a battery in a few days. Twenty sensors would yield a dead battery in less than one day.
- Wide temperature range – the sensor will need to operate normally over a wide temperature. An automobile sensor, for example, would be expected to operate in a range of -40°C up to +120°C.
- Small size – the size has to fit in areas that are extremely small. A size of 2.5cm x 2.5cm x 6cm is ideal.
- Radio frequency interference suppression – there are many radio frequency sources that a sensor will be exposed to. The sensor will have to perform perfectly and not trigger any non-hydrogen alarms. While the sensor needs to not be affected by radio frequency, it is equally important that it not be a source of radio frequency interference. It is not permissible to have a sensor that interferes with other sensors or sensitive control electronics either.

A single sensor is inadequate to provide a safe detection system for hydrogen in a vehicle. Imagine the reaction of a single sensor to the detection of hydrogen. If installed in an automobile, the system would immediately shut down the vehicle. It would certainly be dangerous to lose all power from the detection of one sensor. Instead, a system comprising multiple sensors, redundancy and intelligent control electronics is required.

A sensor needs to be placed near the point of a leak for quick detection. The further away the sensor, the slower the response. Also, as the distance increases, the amount of hydrogen is less due to its rapid dissipation in air.

A configuration that includes multiple sensors would likely be configured into a system of zones, each with its own sensor(s) and electronics. There would be zones for the petrol tank, filler, boot, interior, engine and anywhere else that hydrogen could leak and build up dangerous concentrations. These zones would have three or four sensors each, some of which would be set for very low ranges (e.g. ppm levels). Others will be set for high, almost explosive ranges. The ranges are based on the potential for a leak to occur in that particular zone.

A detection of hydrogen at ppm levels might be mitigated by having the vehicle's airflow system

safely 'vent' it off. A more significant leak might cause a portion of the fuel system to shut down. A large leak might shut off all fuel and even switch over to an alternate fuel. The vehicle could then vent off the leaked hydrogen to the atmosphere. It is safe to vent off hydrogen into the air as long as there is no source of ignition between a leak and the outside air. Remember that hydrogen diffuses quickly, and it will achieve a very safe level in the atmosphere.

The fantasy that Jules Verne imagined in his famous tale has not quite been achieved. However, we are on the verge of realising hydrogen as a new source of fuel. Hydrogen creates challenges to address, but the largest by far is its safe production, handling and use in our everyday lives. New and promising technologies in sensing and controls will make hydrogen a safe fuel; one that will eventually be accepted by consumers worldwide. ■

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