Boil-off Systems crucial for safe hydrogen use

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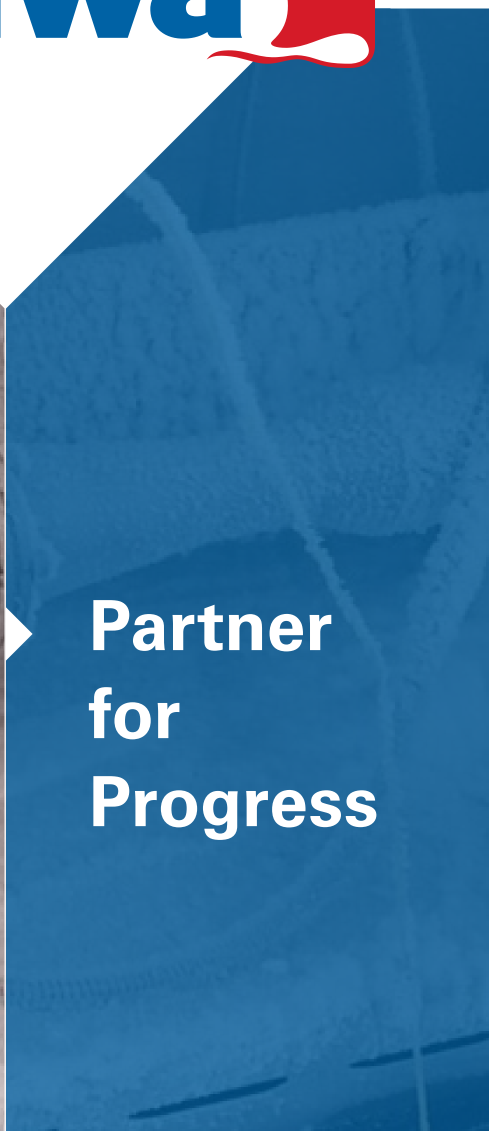


Partner for Progress

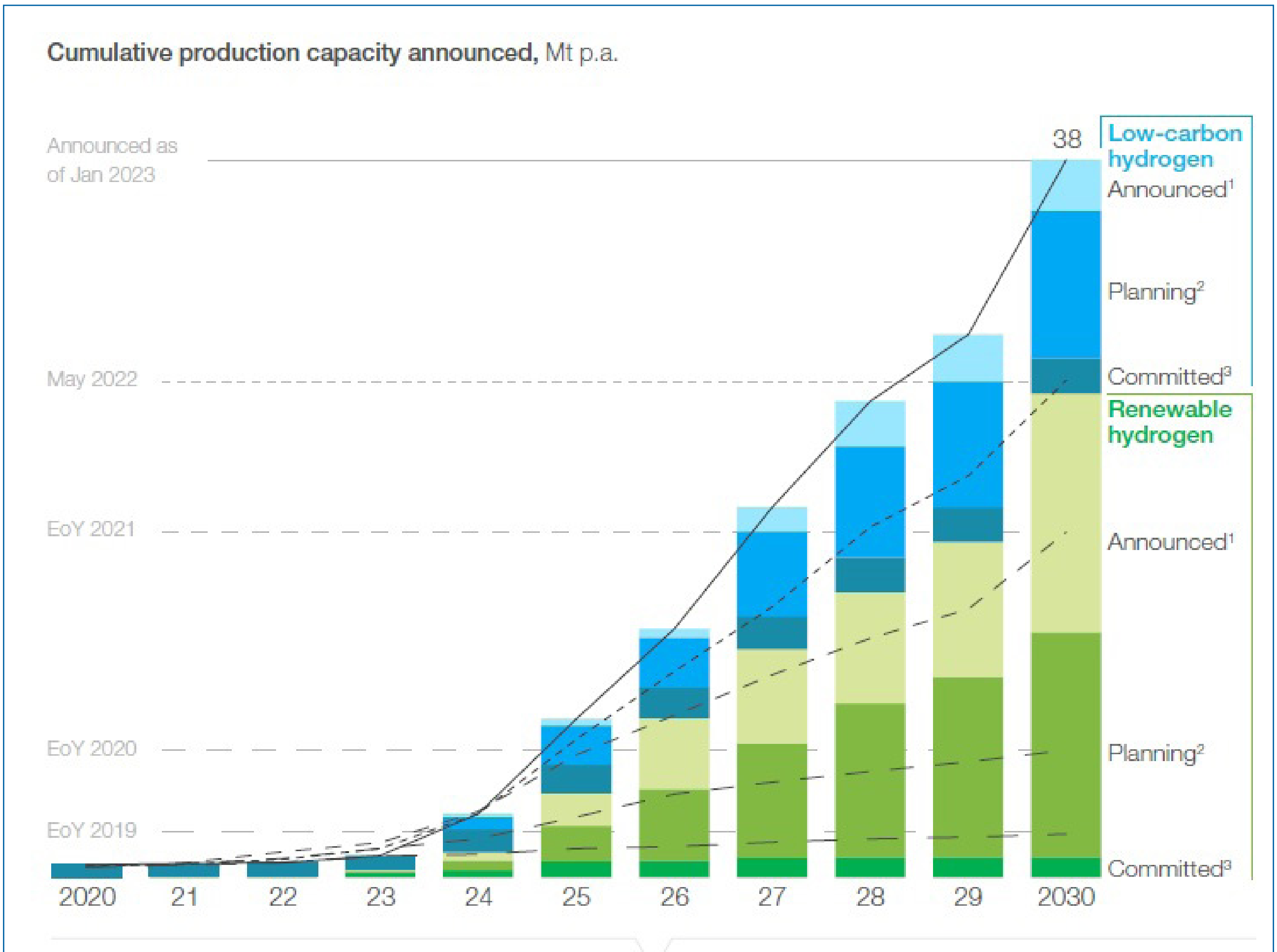
Boil-off Systems crucial for safe hydrogen use, by Hans de Laat

Hydrogen is widely regarded as an environmentally friendly alternative to fossil fuels. However, it is flammable as well as a greenhouse gas. In the application of hydrogen, such as in vehicles, and its transportation through pipelines, excess hydrogen inevitably occurs. To prevent its release, it is essential to equip vehicles and hydrogen networks with a Boil-off Management System (BMS) capable of efficiently venting excess gas. Kiwa Technology's hydrogen expert, Hans de Laat, has written this article on the subject.

The market for sustainable hydrogen for stationary applications, hydrogen networks and hydrogen mobility is growing globally. The Hydrogen Council expects a significant increase in hydrogen production capacity in the coming years, reaching 38 Mton per year by 2030, a multiple of the production in 2023 and previous years (see the figure below).

Tighter emission standards for hydrogen

Cryogenic hydrogen storage is expected to play a crucial role in the hydrogen economy due to its high energy density. Networks are also being established for hydrogen transport. The expected growth in the hydrogen market [1] has prompted Kiwa Technology to share its knowledge about safely evacuating excess hydrogen from systems. We aim to serve the global hydrogen market with our systems for the safe conversion of hydrogen into water.
Hydrogen is flammable and a greenhouse gas and international guidelines, including those from the World Bank [2] and the United Nations [3], are imposing stricter standards on hydrogen chain emissions. In the long term, very little or no hydrogen emission will be allowed. However, market players are dealing with excess hydrogen in their products or operations. This includes boil-off gas from cryogenic hydrogen or degassing pipeline sections in a hydrogen network. A summary of hydrogen storage methods is provided in the table on the next page.



Hydrogen storage method	Storage density relative to high pressure at room temperature	Pressure (bar)	Application
Medium pressure at room temperature	50%	350	Utility vehicles such as buses
High pressure at room temperature	100%	700	Passenger cars
Cryogenic liquid hydrogen	125%	5- 5.5	Stationary tanks and transport by hydrogen trucks
Cryogenic low-pressure gaseous	125%	15-20	Heavy vehicle propulsion
Cryogenic high-pressure gaseous	150%	300-350	Heavy vehicle propulsion

Table: Hydrogen storage methods with storage density, pressure and application

Between 2001 and 2015, Kiwa Technology developed the first Hydrogen Boil-off Management System (BMS) for BMW vehicles using cryogenic hydrogen. A BMS has a catalyst that reacts excess hydrogen with ambient air to form water. No spark is needed for ignition. The advantage of the Kiwa BMS is that the tank pressure alone is sufficient to convert hydrogen to water. It is a passive safety system that requires no maintenance.

Photo: BMW Hydrogen 7 with 5-bar liquid hydrogen tank and BMS

Photo: The BMW 5GT fuel cell vehicle and a mobile filling station for 350-bar cryo-compressed hydrogen gas. The 'CC' on the license plate refers to the storage method. The BMS's air inlet and water vapor outlet are highlighted in blue and integrated into the black rear bumper.

The BMS for BMW passenger vehicles had a thermal capacity of 30 g/h of hydrogen, equivalent to 1 kW. Recent prototype construction for heavy-duty vehicle applications has shown that Kiwa technology can be increased by a factor of 10 without technological changes while maintaining performance. A BMS contains no moving parts or electrical circuit, making certification for a specific application relatively straightforward.

Developing a BMS

Kiwa Technology has a unique combination of expertise that positions it strongly in the development of a BMS:

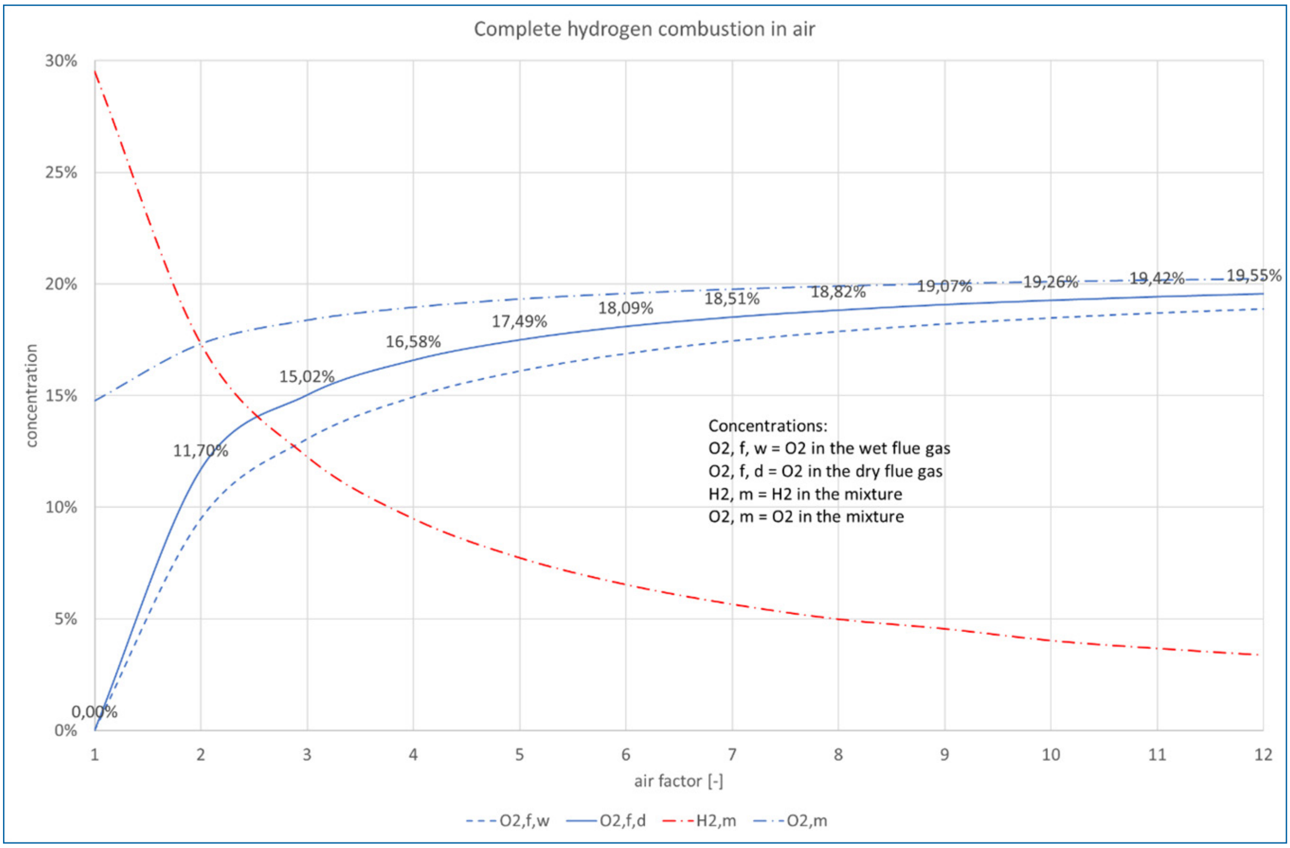
- Independent;
- Fifteen years of experience with BMS for various forms of hydrogen storage systems: liquid, cryogenic gas and cryo-compressed gas;
- Test setup for measuring the performance of hydrogen catalysts and the air factor of a BMS;
- License to work with hydrogen under (very) high pressure, up to 150 MPa;
- Strong relationship with Kiwa Nederland N.V. and other test houses, enabling testing under extreme conditions;
- Contacts with various major catalyst suppliers.

This allows Kiwa Technology to provide solutions for diverse emission situations.

Operation of a BMS

Hydrogen, in the presence of a catalyst, reacts with oxygen from the air at room temperature, forming water. Kiwa's systems have been tested in a climate chamber at low ambient temperatures up to-40°C. The BMS exhibits low emissions during start-up and continuous loading under any condition, meeting the requirements set by the United Nations [3]. Low emissions are achieved through a fast-reacting catalyst.

The outer surface of Kiwa Technology's BMS remains cool. Our BMS distinguishes itself with a low combustion temperature achieved with a high air factor. Typical air factors are 6 to 7 times the required amount of air needed to convert hydrogen. Due to air cooling, the BMS temperature is low, between 400 and 450°C.



Graph: Composition of the hydrogen and air mixture in the BMS and exhaust gases as a function of the air factor.

Only the hydrogen pressure in the tank or the hydrogen network is sufficient to allow the BMS to convert hydrogen. In a vehicle, the tank pressure is almost constant, determined by the tank's relief valve. The pressures for which our BMS is suitable range from about 5 bar for liquid hydrogen to 350 bar for cryo-compressed hydrogen.

Hydrogen network operators depressurize pipeline sections to perform safe work on their network. It is crucial that no hydrogen escapes into the environment. The pressure in the hydrogen network will decrease from an initial pressure to eventually the ambient pressure. The pipeline section is then flushed with nitrogen. Kiwa's BMS creates a mixture of air and hydrogen/nitrogen from the pipeline. This mixture is converted by a catalyst into water without releasing hydrogen into the atmosphere. The mixture contains less than 4% hydrogen in air, making it non-ignitable by a spark.

Regulations for hydrogen vehicles require that a BMS operates at-40°C. Kiwa's BMS is tested in a climate chamber where it is cooled to this temperature and the air drawn through the BMS is at this temperature.

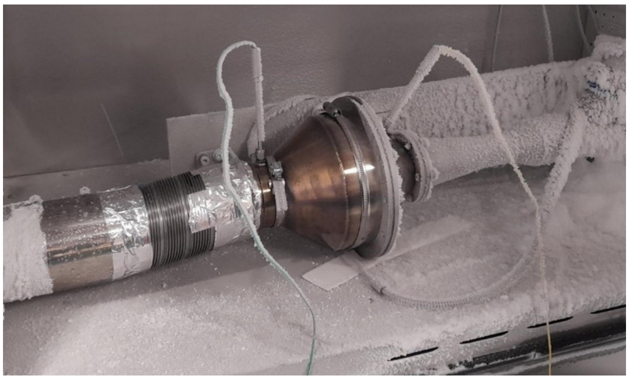


Photo: A BMS after a cold start in the climate chamber. The catalyst and exhaust have melted the ice on the outside.

Our BMS has a compact design and is lightweight. The noise production is limited to the sound of the flowing gas. In most cases, ambient noise ensures that an operational BMS goes unnoticed.

Dialogue with clients

A phased development process for a BMS is undertaken in collaboration with the client, with dialogue to establish a comprehensive set of requirements being the guiding principle. The development process starts with defining the BMS. It is always apparent that there are diverse requirements a BMS must meet:

- **Vehicle manufacturer requirements:**
  The vehicle manufacturer requires a BMS to fit in the car, with surface temperatures not affecting nearby components and the system not being too heavy. Additionally, the system must withstand conditions that may occur in a vehicle, such as mechanical loads, extreme ambient temperatures, dust and vibrations. Internal standards are available that distinguish the car brand from its competitors.
- **Network operator requirements:**
  A hydrogen network operator will require the BMS to work from network pressure to almost atmospheric pressure. To work safely, the hydrogen concentration in the mixture must not exceed 4% in air. This translates to an air factor of at least 10. Kiwa's catalysts can convert all hydrogen at a multiple of 10. Due to flushing the pipeline with an inert gas, the fuel composition is not constant but a mixture of nitrogen and hydrogen with varying proportions.
- **Requirements from standards and guidelines:**
  International agreements in standards and guidelines for vehicles specify safety and environmental impact. Minimizing hydrogen emission plays a crucial role. Another essential aspect is the behavior of a BMS at tank pressures higher than the nominal tank pressure that can occur during operation. A Kiwa BMS is designed to handle overload due to increased hydrogen pressure as an extreme condition.
- **Requirements from the hydrogen storage system:**
  For applications of a BMS in cryogenic storage, the supplier of the hydrogen storage system is often the client. The main parameter for design is the nominal capacity of the BMS in grams of hydrogen per hour. This capacity is determined by the insulation quality and the volume of the hydrogen tank. A Kiwa BMS has been supplied in the power range of 30 to 300 grams per hour at nominal tank pressure. We expect to scale our technology to higher capacities, for example, for maritime applications. Another parameter is the temperature of the hydrogen expected at the BMS connection to the fuel line. The colder the hydrogen, the faster it flows through the BMS. We can use simulations of gas temperature or practical values from experiments.
- **Kiwa Technology requirements:**
  Kiwa Technology also imposes requirements on the integration of a BMS into the vehicle. These requirements ensure that the BMS reliably functions in all conditions. Wind influence is minimized, precipitation cannot come into contact with the inside of the system and objects cannot unintentionally enter the gas lines.

Building the solution

To determine if the system meets the set requirements, a prototype is built and tested. Kiwa Technology has developed a special BMS test setup for this purpose. It imposes a programmed hydrogen load on the BMS in g/h. This results in hydrogen pressure in the fuel line. The BMS's response to the load is recorded with continuous analysis of the composition of the exhaust gases. The analyzed components are oxygen for determining the air factor and hydrogen. Two separate hydrogen analyzers are used, one for registering short peaks up to 10% and one for detecting hydrogen traces at ppm levels. Extreme tests such as salt spray, vibrations and varying temperatures are conducted in collaboration with colleagues within the Kiwa Group or other test houses.

Products and markets

In addition to applications in hydrogen vehicles and hydrogen networks, cruise ships are also equipped with hydrogen tanks. When docked at the pier, hydrogen is used for onboard power to avoid emitting smoke from traditional fuel stocks and prevent dependence on shore power, offering an environmentally friendly alternative.

With our test setup, we can test the quality of hydrogen catalysts on behalf of various parties. Kiwa Technology then provides an independent judgment. In the coming years, small series BMS demand is expected for the first generations of hydrogen trucks. Safety and functionality testing is central to their production. Kiwa Technology expects to play a significant role in the mass production of BMS with its testing facilities.

Potential markets and products are listed in the matrix below.

Conclusions

A BMS will become a mandatory component of a cryogenic hydrogen vehicle. Also, for the safe degassing of a hydrogen network, catalytic conversion of hydrogen into water is a logical element for safe and emission-free operation. A BMS can play a significant role in limiting the emissions of a hydrogen network.

References

[1] The World Bank, "Zero routine flaring by 2030," 21 06 2023. [Online]. Available: https://www.worldbank.org/en/programs/zero-routine-flaring-by-2030/about.

[2] McKinsey & Company, "Hydrogen insights may 2023," The Hydrogen Coucil, North America, 2023.

[3] United Nations, "UNECE adopts global technical regulation on the safety of hydrogen and fuel cell vehicles," 15 6 2013. [Online]. Available: https://unece.org/DAM/trans/doc/2013/wp29/ECE-TRANS-WP29-2013-041e.pdf.

Market	Suppliers of Cryogenic Hydrogen Storage Systems	Catalyst Suppliers	Transmission Network Operators	Distribution Network Operators	Maritime
BMS prototypes	X		X	X	X
Catalyst testing		X			
Small series BMS	X		X	X	X

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