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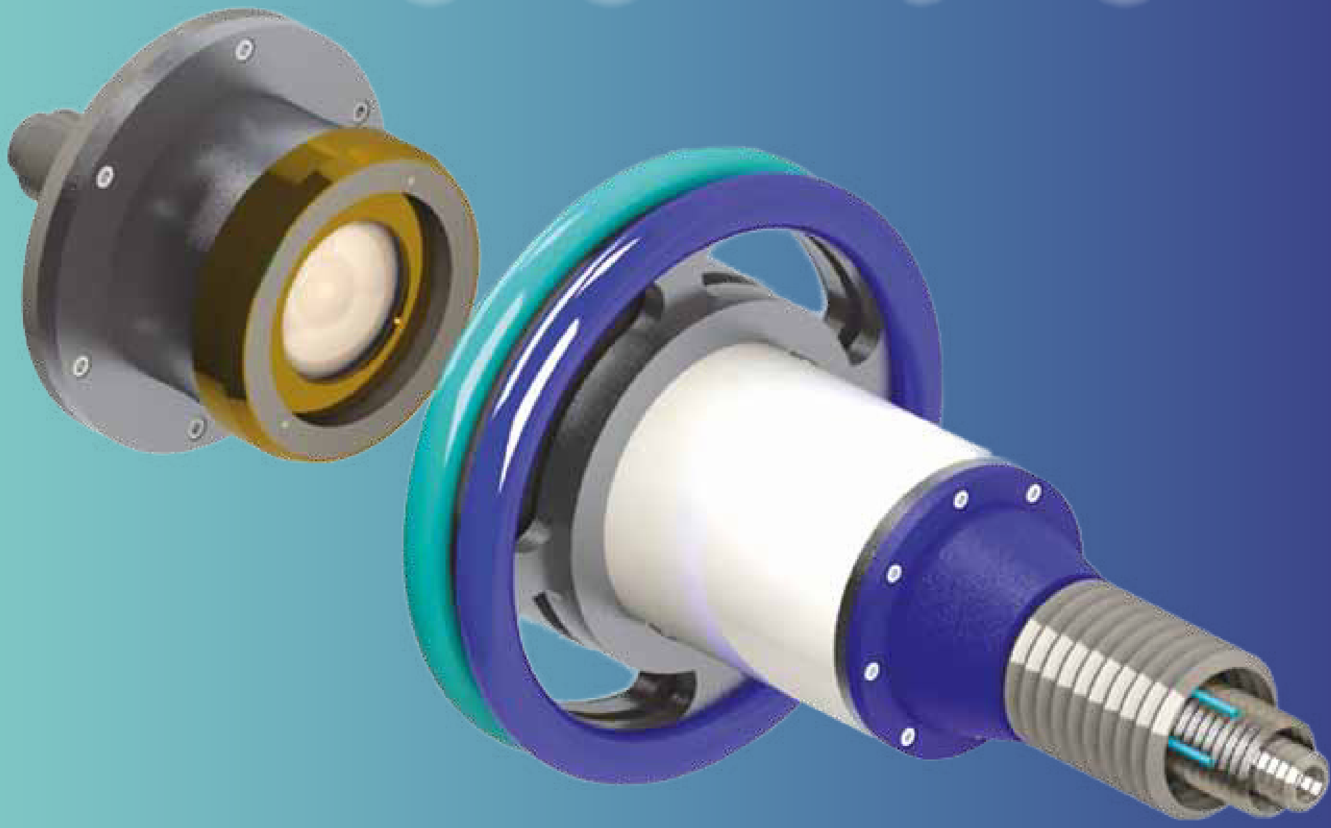
cover story

BUTTING CryoTech: contributing to green hydrogen



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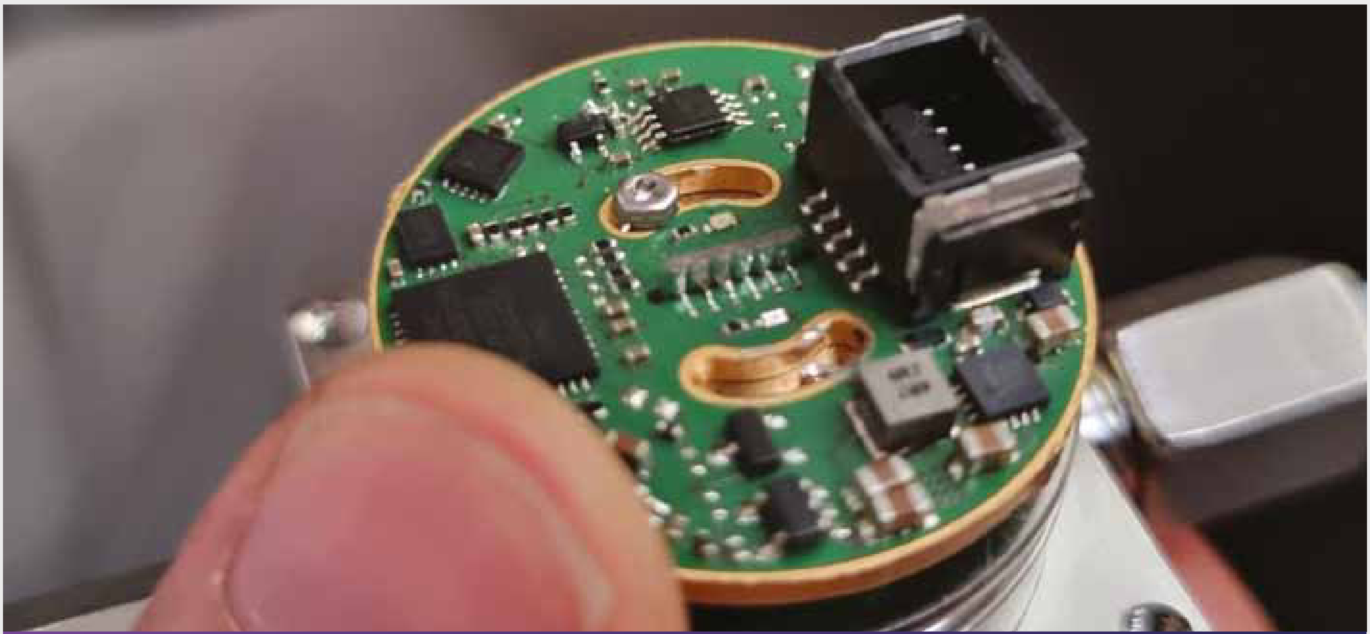


Small is the new big: the sensors require little space. All images © Archigas

Combination of TCD and MEMS technologies: the silver bullet in hydrogen measurement

To be able to use hydrogen safely and on a large scale, high-quality and quantitative production is required on the one hand, and reliable monitoring of the combustion processes on the other. This in turn urgently requires gas measurement systems based on sensors that are particularly sensitive, stable, compact and – since they are required in large quantities – as cost-effective as possible. New, innovative combination solutions from TCD and MEMS technologies meet these requirements exactly.

By Illya Kaufman and Wladimir Barskyi, Archigas

The well-known science-fiction author and visionary Jules Verne called water the 'coal of the future' 150 years ago and talked about the decomposition of water by electric current. Now, the time has (finally!) come. If we look at the entire hydrogen value chain (production, distribution, storage, and combustion), it becomes clear that sensors are needed at all stations in this chain. Thus, the measurement of hydrogen concentration plays a decisive role in the process control of many technologies handling hydrogen. Precise measurement of concentration is also essential for adding hydrogen as an energy carrier to existing gas networks. Last but not least, precise and reliable sensor systems are needed for safety engineering when using explosive gas mixtures with hydrogen content. In short, complete and always reliable transparency is needed for the safe and effective production and use of hydrogen. What sounds banal at first turns out to be a complex task when it comes to implementation.

No lack of challenges

This is because, upon closer inspection, claims and reality are still – more or less – far apart. Currently, there are the following possibilities for detecting hydrogen:

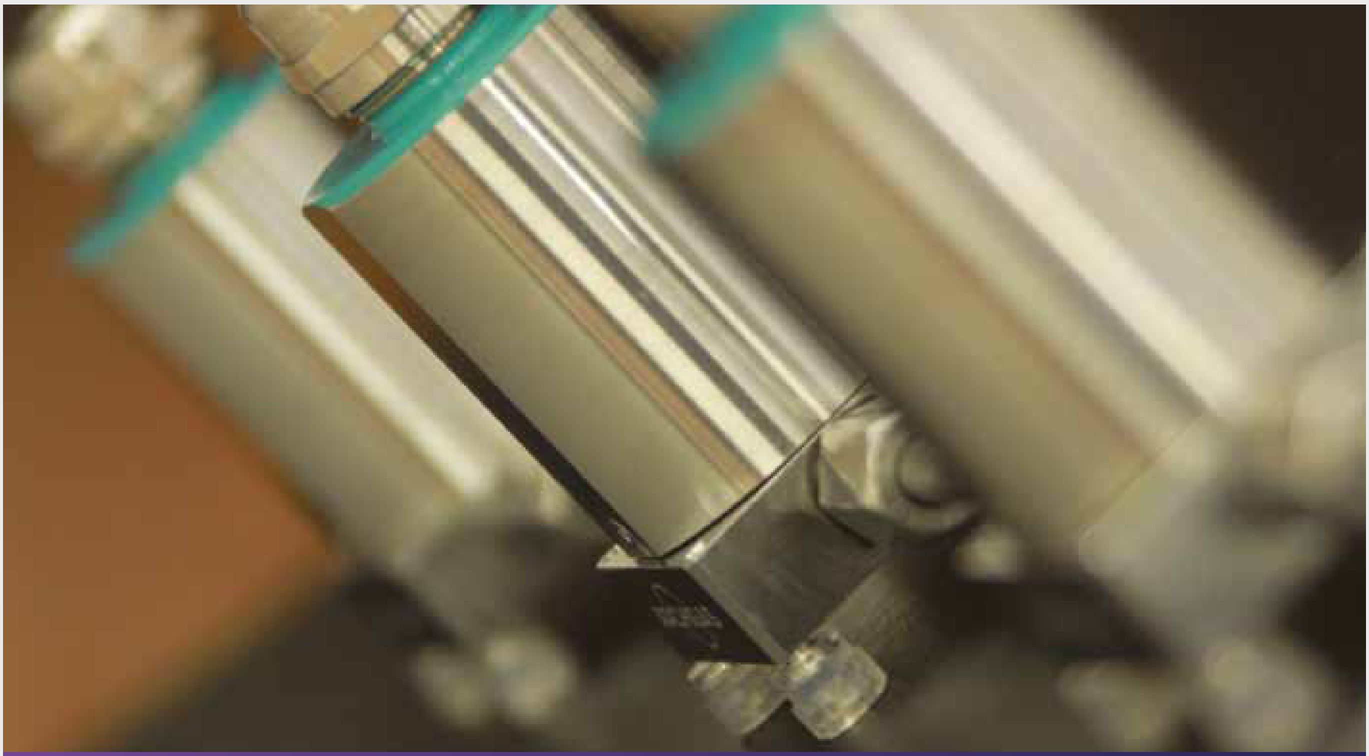
- **Electrochemical method**: These sensors consist of an electrode that reacts to hydrogen.
- **Catalytic**: Here, the combustion energy is measured at the surface of the sensor, and a concentration is determined from this.
- **Optical**: The hydrogen molecule interacts at a specific wavelength.
- **Thermal**: Here, the specific thermal conductivity of the gas is determined.

However, most hydrogen sensors are impractically large, show signs of aging that destroy calibration over time, and are usually extremely expensive to purchase and maintain. These are just three of the challenges that need to be addressed, especially since there is a great ambition to bring about an energy turnaround, also and especially with the help of hydrogen. What is needed is an optimized measurement technology that can measure precisely and reliably while being cost-effective and ideally comes in a plug-and-play solution for easy handling. The specifications of technology providers are therefore well filled and are being further expanded by the legislators through additional regulations and requirements.

Companies that are highly specialized in gas analysis, with a focus on hydrogen measurement and close involvement of scientific experts, have a clear advantage here, as they are fully oriented to the specific needs of the hydrogen industry.

In order to meet customer requirements without compromise, attention must be paid, for example, to the special effect of hydrogen on many material properties (e.g., as a result of hydrogen diffusion), since the functional elements of the sensors must not irreversibly change their physical properties and thus the sensor parameters, such as sensitivity, as a result of contact with hydrogen. Degradation of the sensors due to exposure to hydrogen must therefore be ruled out.

Central examples of the measurement challenges can be found in electrolysers. This is because moisture in the process gas can falsify measurements, which is why cross-sensitivity compensation or gas dehumidification is required. Reaction times (t90) in the process should also be kept as low as possible. Some manufacturers expect a measurement time of 100 milliseconds.



Fine microsensors in stainless steel dress

Production under strict laboratory conditions

Corrosive gases are present in certain processes, which must also be taken into account. Additionally, extra sample preparation due to, for example, high operating pressures, humidity or process temperatures, may also be needed.

The importance of measurement precision and speed in the hydrogen process chain mentioned above cannot be overstated. The same is true for a compact design of the sensor systems for flexible plant construction and, of course, their sheer number. The demand for these sensors is enormous if one really wants to achieve a move away from fossil fuels with the help of hydrogen. Quality and quantity are both essential, so what is the ideal way to meet both with the help of new or optimized measurement technology? Innovative developers have found the answer.

Precise, fast and reliable

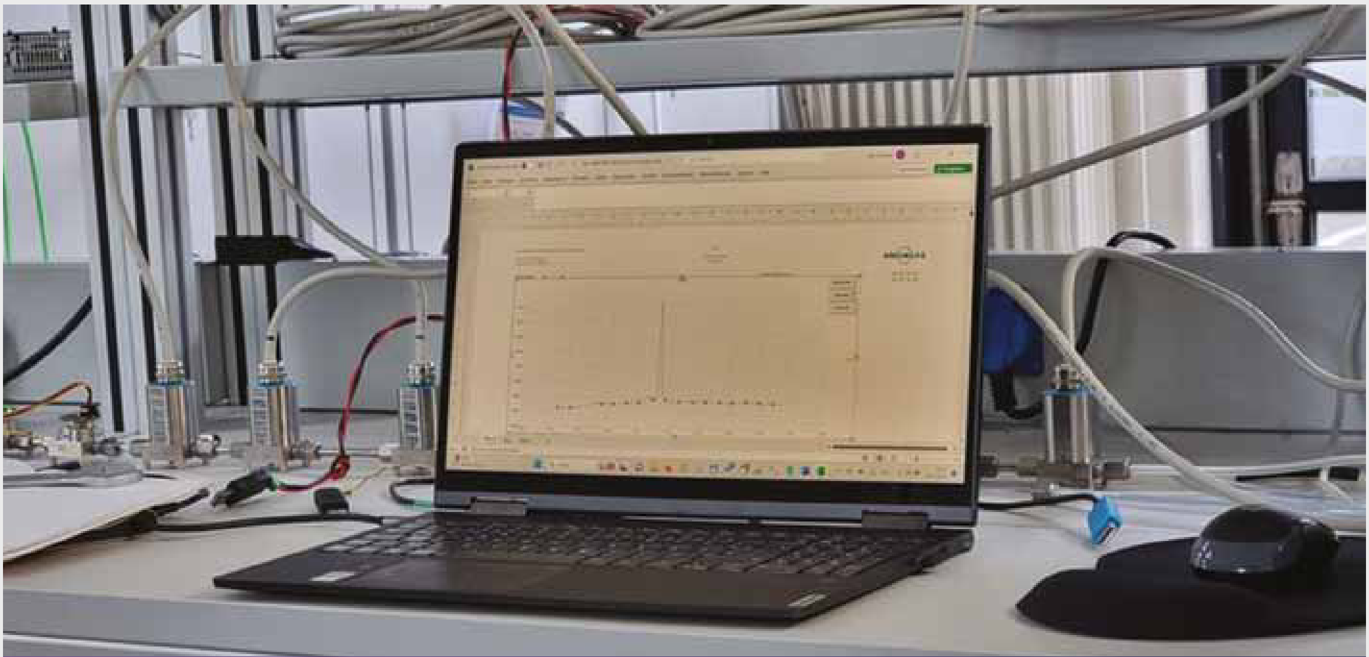
Due to the wide range of applications for hydrogen technology, sensor systems with the largest possible dynamic range are required. Very importantly, the sensors should be able to detect both relatively high hydrogen concentrations in the percentage range and extremely low concentrations in the ppm range in gas mixtures. Sensor solutions based on the thermal conductivity measurement principle seem well-suited, since hydrogen has a significantly higher thermal conductivity compared to other gases (only helium is comparable). Innovative solutions based on the proven thermal conductivity detector (TCD) sensor technology make use of the thermal conductivity in an optimized form and can determine the hydrogen concentration in gas mixtures extremely precisely. High precision of the thermal conductivity of gas measuring instruments is only possible if the temperature is under control. And this is only possible if the sensors and the evaluation electronics interact extremely finely and quickly.

Answers to these challenges have been found, for example, by Archigas GmbH (Rüsselsheim, Germany) with their new developments. In cooperation with the RheinMain University of Applied Sciences (HSRM), they realised a novel design of MEMS (see below), whereby the thermal changes can be detected exceptionally well due to the low thermal dimensions of the sensors by the micromechanical structures. Proof of a large dynamic range has already been provided beyond doubt for this sensor principle. Thus, the same sensor can measure low hydrogen concentrations in air for room monitoring, some vol% hydrogen in oxygen for lower explosion level monitoring, high up to upper explosion levels, as well as quantitative hydrogen purity. Research on the micromechanical solutions also led to the development of sensors that enable the inherently difficult delineation of hydrogen and helium with similar thermal conductivity (a pilot project funded by the German state of Hesse, currently in the prototype phase).

In addition, innovative measuring systems, such as those from Archigas, have other properties that make them well-suited for specific industry needs, thanks to their meticulous design and construction. For instance, let us consider hydrogen measurement in electrolysers with its typical requirements. The sensor units not only have a compact design, but they are also completely equipped with metal-to-metal connections. This feature ensures high leak tightness and chemical resistance. Additionally, process gas temperatures of up to 100°C are possible, and in some cases even higher. Thanks to stainless steel housings and IP67 protection, the devices can also be used safely in harsh environments, and the gas-carrying parts and the sensor itself are corrosion-resistant. The gas path is made of high-quality stainless steel, and the sensor is completely glazed on the gas side. Furthermore, these devices enable continuous online quality monitoring of hydrogen. An internal memory can store measurement parameters for a wide variety of gas pairs, so that the devices can be easily adapted to changing measurement requirements. In short, sensor solutions of this design are excellently equipped for increasingly precise, reliable, safe, and extremely easy-to-perform hydrogen measurement.

Cost-effective

Modern sensor systems now meet the metrological, or qualitative, requirements better than ever before. However, the industry also faces significant quantitative challenges in the broad-based development of hydrogen as an energy carrier. There is a growing need for corresponding sensors everywhere, including in the increased exploration of (natural) hydrogen



Precise measurement provides safety

deposits, hydrogen production by electrolysis, gas analysis for determining purity, and monitoring the tightness of the systems and the combustion process.

Let's take a hydrogen-powered truck as an example. Here alone, there must be sensors on the tank, in the engine and passenger compartments, and on the 'exhaust'. Considering the future importance and spread of hydrogen technology, the sensor solutions must be made available in considerable numbers and, consequently, at particularly low cost, as the 'small-scale' example just mentioned shows.

This is now succeeding, thanks to the development of solutions based on so-called MEMS (micro-electromechanical systems). The advantages are obvious: the production of MEMS sensors is established and a mass market. Each of us permanently has a dozen of MEMS sensors with us, namely in our cell phones. This shows that the technology enables large quantities with excellent reproducibility. The intelligent use of proven semiconductor technologies based on silicon wafers allows cost-effective mass production in a so-called batch process of exactly identical sensors without time-consuming calibration (also a cost factor that should not be underestimated). This form of manufacturing numerous, stable, and compact sensors is tantamount to a true revolution – it can make a significant, perhaps even decisive contribution to the energy transition with the aid of hydrogen. To put this into perspective, around 1,200 sensors can be produced from a silicon wafer measuring 4 inches (about 10 centimeters)!

Flexible and fast implementation

Due to the small dimensions of the sensors as well as the provision in compact modular units, gas measuring systems can be designed and manufactured to be precisely installed in plants of the most diverse shapes and dimensions. The TCD-OEM modules can be quickly implemented in customer plants, such as gas chromatographs and synthesis gas plants, without any issues due to the easy handling of the devices. Additionally, individualization options are available, allowing for use in a wide variety of applications, such as hydrogen production by electrolysis, admixture of hydrogen in natural gas (H_2 in CH_4), monitoring of the lower and upper explosion limits of hydrogen in fuel cell exhaust gases (LEL and LEL for H_2 in O_2/air), and input quality control and process gas monitoring for monitoring the gas purity (for example, hydrogen 5.0), to name a few. It is clear that the combination of TCD and MEMS may indeed be the silver bullet in hydrogen measurement, as evidenced by the enormous interest shown by numerous companies from a wide range of industrial sectors even after the first presentation.

About the authors

Illya Kaufman (left) and Wladimir Barskyi (right) graduated with an M.Sc. in applied physics from RheinMain University of Applied Sciences (HSRM) near Frankfurt am Main, Germany. After stints as employees in industry, they jointly founded the company Archigas in 2020. In close collaboration with experts from the university, they are developing innovative sensor technologies for particularly precise, stable and safe hydrogen measurement. The goal is to offer complicated measurement tasks as a reliable and cost-effective plug-and-play solution. One of their projects for the detection of natural hydrogen deposits is funded by the state of Hesse as part of the LOEWE program – State Offensive for the Development of Scientific and Economic Excellence.