UNDER POWER

Huge amounts of green hydrogen will be needed to create a sustainable economic system. As a result, Evonik is working together with partners to develop a new membrane that will make environmentally friendly water electrolysis competitive

TEXT **GEORG DAHM**

“This technology combines the advantages of previous electrolysis processes”

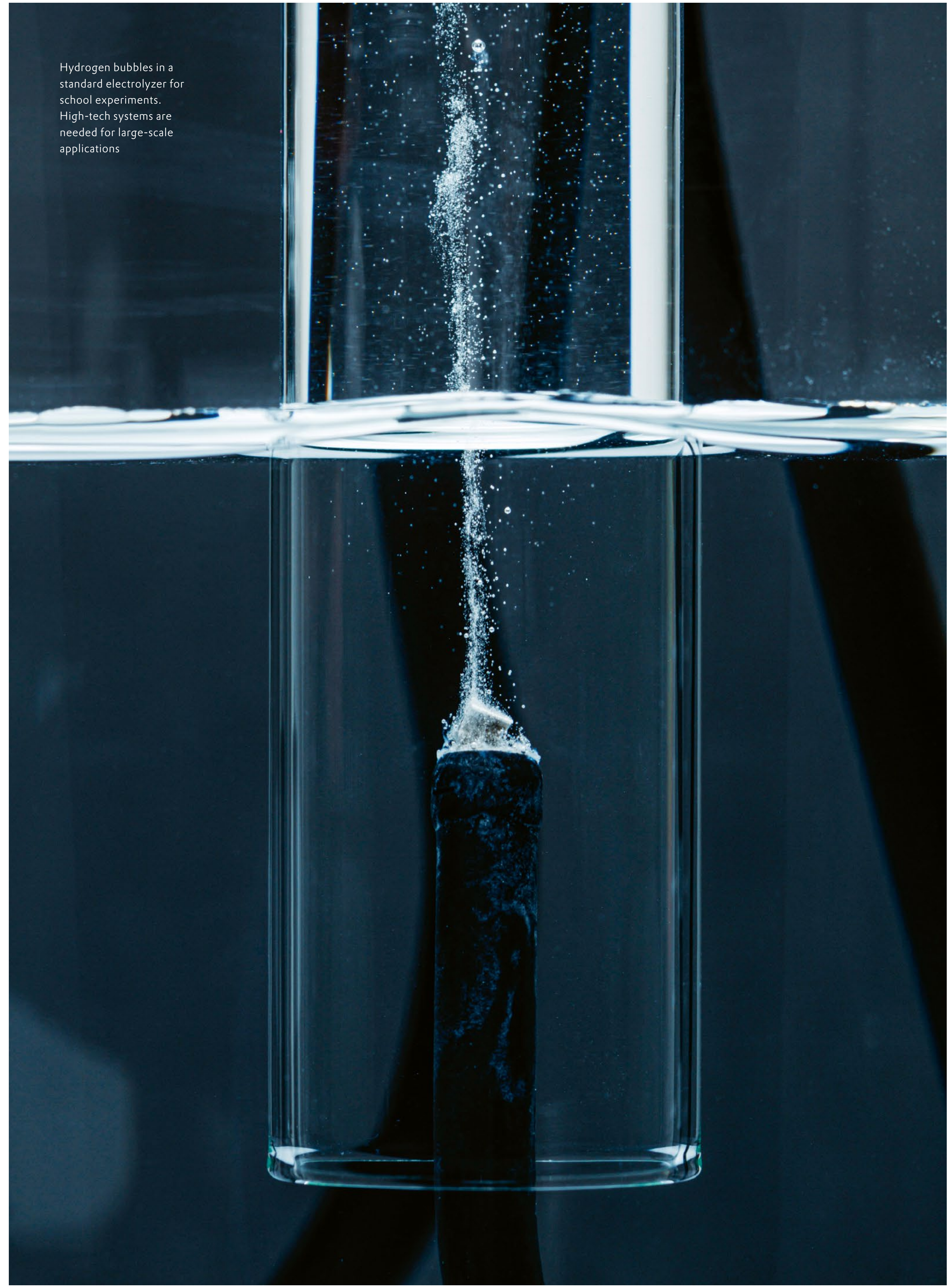
OLIVER CONRADI, CREAVIS

Sebastian-Justus Schmidt became an energy entrepreneur by accident. Since 2014, Schmidt, who owns an IT firm, has been supplying his sustainable estate in Thailand with hydrogen that is produced with green electricity. The associated electrolyzer comes from the Italian startup Acta. Although the system worked wonderfully, Acta’s German parent company went bankrupt in 2017. “So we bought up the technology, took over the team, and created our own startup, Enapter,” recounts Schmidt’s son, Jan-Justus, Chief Operating Officer of the young family-run enterprise.

This step not only enabled the Schmidt family to safeguard the energy supply of its property but also to take a leading role in a technology that could make entire sectors carbon-neutral in the coming decades. According to experts, AEM (anion exchange membrane) electrolysis could make the production of hydrogen from renewable electricity feasible on a large scale.

“This technology combines the advantages of the previous hydrogen electrolysis processes,” says Oliver Conradi, who is in charge of the Membranes innovation field at Creavis. This strategic innovation unit at Evonik is cooperating with Enapter in an EU-funded research project in order to develop new membrane materials for AEM electrolysis. “If it works as well as it already has in the lab, we will make the industrial-scale production of environmentally friendly hydrogen economically viable,” says Conradi.

The collaborative project is called CHANNEL. Besides Evonik and Enapter, the participants include the energy company Shell, Forschungszentrum Jülich, and the Norwegian research institute SINTEF. Their goal is to create a demonstrator by 2022 that will prove AEM’s capabilities. The project’s main feature is a new ion-conducting membrane from Evonik, which is being tested in Enapter’s facilities. →



Hydrogen bubbles in a standard electrolyzer for school experiments. High-tech systems are needed for large-scale applications

Enapter still makes its electrolyzer modules in Italy. However, plans call for series production to start soon in Germany

The electrolyzers can be combined into bigger systems as needed

“We have learned that we greatly benefit by working together with small companies such as Enapter because they are flexible and can very quickly try out new things,” says Conradi. “Moreover, having direct contact to the people involved is very helpful when you want to validate and implement a technology.”

Enapter’s AEM electrolyzers aren’t big systems. Instead, they look rather like server cabinets with slide-in modules arranged one on top of another. Each of these modules is a separate unit that produces half a cubic meter of hydrogen per hour. “This makes the technology so easily scalable,” says Jan-Justus Schmidt, who studied aerospace engineering and is now setting up series production in Germany.

In water electrolysis, electricity is used to split water into oxygen and hydrogen. However, most hydrogen is currently still produced from carbon-based sources such as methane by means of steam reforming. This is mainly due to the fact that this traditional process is much less expensive than electrolysis (see the article on the hydrogen energy economy, beginning on page 10). “One of the reasons for this is the relatively high price of electricity,” says Conradi. “Another reason is that electrolysis systems require a very high level of investment.” Evonik wants to help reduce the cost of the equipment by introducing an innovative membrane technology.

PROVEN TECHNOLOGY WITH SOME WEAKNESSES

The workhorse of the established processes is alkaline electrolysis (AEL). It is the method that is most like those illustrated in schoolbooks, consisting of two electrodes that are inserted into a highly concentrated potassium hydroxide solution (pure water is not conductive enough). At the cathode, the water molecules split into hydrogen and hydroxide ions. The hydrogen rises as a gas while the hydroxide ions move through the alkaline solution to the anode, where they react to create water and oxygen. To ensure the products of the reaction remain apart and don’t recombine with a bang, a porous membrane—a diaphragm—separates the anode side of the electrolyzer from the cathode side.

“The technology is robust and the cell material is pretty inexpensive,” says Conradi. For example, the catalysts that cause the reactions to start at the electrodes include nickel, cobalt or iron, while the housing components are made from stainless steel. The investment costs amount to about €800 per kilowatt of power and experts think that the amount will drop to as low as €600 by 2025.

AEM technology is already being used at a residential site in Thailand

“Our technology is easily scalable”

JAN-JUSTUS SCHMIDT, COO ENAPTER

One problem with AEL is that the diaphragm is porous. This means that it lets gases through so that the possibility of operating the facility under pressure is limited. As a result, the hydrogen has to be compressed so that it can be stored and transported further, consuming a lot of energy in the process. In addition, the porous membrane can only be operated at low power densities: The diaphragm can handle a maximum of 600 milliamperes per square centimeter of membrane surface. The other well-established method, PEM (proton exchange membrane) electrolysis, can operate at three times the current density, or 2,000 milliamperes per square centimeter of membrane surface. In practice, this means that a much smaller electrolyzer can be used to produce the same amount of hydrogen.

In PEM electrolysis, membranes are more than just separators. They replace the entire bath because they consist of an electrically conductive polymer that ions can move through. The electrodes lie right on top of the membrane. In this system, the water to be split flows across the anode. The hydrogen ions that are released move from the anode through the membrane to the cathode side, where they combine to form hydrogen molecules. A PEM electrolyzer is not only operated at higher current densities than an AEL system, it can also handle greater load fluctuations. And because it can be operated under pressure, less energy is subsequently needed for hydrogen compression.

However, despite its technological advantages, the high investment costs of PEM systems pose a considerable barrier to market entry. “PEM cells operate in an acidic environment, which means that the materials need to be very robust,” says Conradi. “The catalysts have to be made of precious metals such as platinum and iridium, while the cells have to consist of titanium or even of platinized titanium. Investment costs are calculated to be €1,000 or more per kilowatt of power using today’s technology.”

HIGHER OUTPUT, LOWER COSTS

This is where the promising AEM process comes into play. Over the medium term, Evonik hopes to develop a system that costs €500 to €600 per kilowatt. An AEM cell has the same structure as a PEM cell. It can also be operated under pressure and with a high level of power output. The centerpiece of this system is also a membrane made of an ion-conducting plastic known as an ionomer. Electrodes lie on both sides of the membrane. They are also made of an ionomer and are permeated with catalyst particles. “However, AEM lets us use non-precious metals such as nickel for this purpose, which is significantly less expensive,” says Conradi. This is possible because the process operates in an alkaline environment. As is the case with the AEL process, the water is split on the cathode side. Two H_2O molecules give rise to one hydrogen molecule and two hydroxide ions (OH^-). The hydroxide ions then move through the membrane to the anode, where they react to form oxygen and water (see the illustration on page 33).

To achieve such a combination is a real challenge. “An alkaline environment is aggressive as well,” says Alejandro Oyarce Barnett from the Norwegian re- →

First it's solid, then liquid, then flexible: In the Creavis laboratory, researchers create a polymer powder (top right), which is then turned into a liquid (bottom right) that is cast into endless membranes (above)

search institute SINTEF, which chose the partners for CHANNEL and coordinates the consortium. "Developing a membrane that can operate under such conditions is no trivial matter. Only a few companies in the world can do this and Evonik is one of the key players in this field."

SINTEF operates similarly to Germany's Fraunhofer Society: The government supplies only some of its budget, as the society's business model focuses on partnerships and funded projects that produce commercially exploitable intellectual property. SINTEF now wants to forge ahead with the construction of a two-kilowatt system. It would be a first step, says Barnett: "If it works, it would be only logical to think about building a 100, 200 or even 500-kilowatt facility."

Although the membranes from the Creavis laboratory already exceed most of the team's targets, the teams are still working with prototypes about the size of an A4 format sheet of paper. Before the material can be series-produced in endless sheets, the team at Creavis will have to optimize the coating process, among other things. Before the year is out, the team plans to conduct tests in a pilot plant in order to determine how a constant level of quality can be ensured in a roll-to-roll process. Creavis has been working together with experts from High Performance Polymers to research ion-conducting membranes for electrochemistry for several years now, enabling it to amass extensive know-how in this field. "Our knowledge of polymer chemistry in this field ideally supplements our expertise with membranes for separating gases and liquids," says Goetz Baumgarten, who is responsible for the Membranes innovation growth field at Evonik.

A great deal of preparatory work was done during the development phase. Creavis has been researching ion-conducting membranes for electrochemistry for several years—it's another promising field for the company besides the hollow-fiber membranes that have been the mainstay of the business to date. "We need completely new methods and skills for measuring the properties of the membranes, for example," says Conradi.

DEVELOPMENT TARGET: AN ENTIRE SYSTEM

The focus is currently still on optimizing the membrane's formulation. "An important factor for its efficiency is the contact resistance between the membrane and the electrode, for example," says Conradi. "To make it as small as possible, we need a good ion connection between the two. As a result, we not only have to continue optimizing the polymer formulation for the membrane but also develop a custom electrode paste that is then applied to the membrane." The aim is to develop an entire system that can be supplied to electrolyzer manufacturers such as Enapter.

Project manager Barnett expects that a whole series of membrane and electrode formulations will have to be tried out until an optimal combination is found. It will include the right catalyst systems, which are currently being developed by Forschungszentrum Jülich and the Norwegian University of Science and Technology (NTNU). Experts at Evonik will develop further generations of catalysts once the new membrane technology goes into commercial series production.

"For the formulation of the electrode pastes, we are benefiting greatly from the fact that the colleagues at Evonik know a lot about polymers and their properties," says Barnett. This means that the team doesn't have to start from scratch, but can instead use proven components to quickly develop and test new materials.

Each new formulation of the membrane electrode assembly (MEA) affects the design of the cell. The ultimate aim is to combine five of these cells into a stack. The cells' components include the bipolar plates—solid metal structures that enclose the membrane electrode assembly on both sides in order to channel the inflow and outflow of liquids and gases. The porous transport layers at the electrodes, through which the gas from the electrodes is led off, are another example. "These are a key component that isn't yet available on the market," says Barnett's colleague Thulile Khoza. "Although we are building on the experience gained from the production of PEM cells, we are working with completely different materials and have to continuously compare costs and performance."

The new modules are being tested in Enapter facilities. "We can test new materials on a small scale before quickly using them on a larger scale," says Jan-Justus Schmidt. In this way, a private technical pastime could turn into a product that will take the world by storm.

The AEM water electrolysis

High pressure and an aggressive environment: The AEM process puts great demands on the material. To enable hydrogen production to take place under controlled conditions, electrolyzers consist of many individual cells that are connected in series to form stacks. These cells harbor the actual reaction that splits water into hydrogen and oxygen.