HOW HYDROGEN-CARS CAN BE SAFELY FUELED

On Swiss roads only a few dozen passenger cars use hydrogen as fuel. But the CO_2-free drive technology has great potential. To enable hydrogen cars to be more widely used, a nationwide network of fueling stations is required. The Swiss Federal Laboratories for Materials Science and Technology (Eidgenössische Materialprüfungs- und Forschungsanstalt, Empa) is currently investigating technical and legal issues to facilitate the construction of hydrogen fuel filling stations. First solution concepts are on the table.

The three fuel dispensers of the “move” project at Empa provide different fuels: methane (front), a methane-hydrogen mixture (middle) and hydrogen (rear). Photo: Empa

A technical report about the results of a pilot and demonstration project in the field of hydrogen, which is financially supported by the Swiss Federal Office of Energy. The report has been published on www.ee-news.ch (29.03.2018).

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Today, battery-powered electric cars have become a usual street ocurrance. Hydrogen vehicles, on the other hand, are still a rarity—only a few dozen such cars are traveling on Swiss roads. There was a pilot program with hydrogen-powered postal buses. But it ended after five years in 2016. A hydrogen-powered truck from Coop, however, is still in use. Reasons for the low prevalence of hydrogen powered vehicles are the lack of available vehicles and the lack of publicly available hydrogen fueling stations—there are only two of them in Switzerland: one in Hunzenschwil (AG), the other at Empa in Dübendorf (ZH).

Countries such as Japan and South Korea and Germany and also some states in the USA, such as California, and Scandinavia, are driving the development of hydrogen technology forward. Switzerland is also active in this area through support of innovative projects. There are good reasons for this: The corresponding vehicles are CO_2-emission free if they are fueled with hydrogen produced using renewable electricity. A fuel cell in the vehicle converts the gaseous fuel back into electricity, which drives an electric motor. The only thing that escapes from the vehicle's exhaust pipe is water vapor. Hydrogen has a high energy density. Cars easily reach a range of 500 kilometers or more in real-time operation with one tank of fuel. A new model from Hyundai ('Nexo'), which will be available in Switzerland in summer of 2018, will increase this value by a further 30% thanks to improved fuel cell technology.

Focus on Refueling Passenger Cars

If hydrogen cars are to make a successful breakthrough, a secure filling station infrastructure is paramount. Three years ago, scientists at the Empa campus in Dübendorf built a demo unit called "move." This research and development platform provides hydrogen at a nominal pressure of 350 bar, which is used to refuel hydrogen trucks and buses (see the technical article 'Sonnen- und Windtreibstoff tanken,' available at www.bfe.admin.ch/CT/H2). A current project concerns hyrdogen-powered cars, which are refueled at a nominal pressure of 700 bar. For this purpose, the move system was upgraded with an additional compressor and a pre-cooling system for the hydrogen. "Our project aims to clarify various technical and legal questions for the reliable and safe operation of filling stations for passenger cars," says Urs Cabalzar,

TRANSPORT WITH HYDROGEN

The names vary—Hyundai ix35 FCEV, Toyota Mirai or Honda Clarity Fuel Cell—but they all share one thing in common: powertrain driven by hydrogen, which they hold in a tank and that is converted into electricity via a fuel cell to drive the car's electric motor. A Hyundai ix35 FCEV - to give an example - can hold up to 5.6 kg of hydrogen fuel in its tank and thus can travel a distance of up to 600 km, according to the manufacturer (equivalent to the range of 30 l of diesel in a mid-range car). Since the hydrogen is gaseous, a tank with 140 l is significantly larger than that of a diesel car with the same range. The tank is also heavier because it must withstand a high pressure of 700 bar. Adding the weight of the energy storage system and drive train, the electric car performs the worst, followed by a hydrogen car and then the classic internal combustion engine.

When refueling hydrogen cars, the fuel in the tank is brought under high pressure (depending on the ambient temperature and refueling amount above 700 bar); this creates compression heat. For this reason, among other things, without precautions the tank can become overly heated, causing damage. To prevent this, the hydrogen is cooled to -40 °C before refueling. This keeps the heat during refueling within certain limits and depending on refueling conditions, reaches 40 to 50 °C. Over time, the temperature goes down.

At the Coop hydrogen refueling station in Hunzenschwil, one kilogram of hydrogen costs 10.90 Fr–thus, per kilometer traveled, costs about as much as gasoline or diesel. At Empa, 1100 kg / year of hydrogen was tanked in 2017, and in Hunzenschwil 3000 kg / year (excluding hydrogen powered trucks). Commercially interesting would be a facility at the 200 to 300 kg / day, experts estimate (considering current costs). Thanks to economies of scale, however, this number may decline significantly in the future. BV

The compression of hydrogen to 700 bar produces noise that can affect the neighborhood. This noise can be shielded through a suitable sound insulation device. In the picture right: a device for sound measurement. Photo: Prose

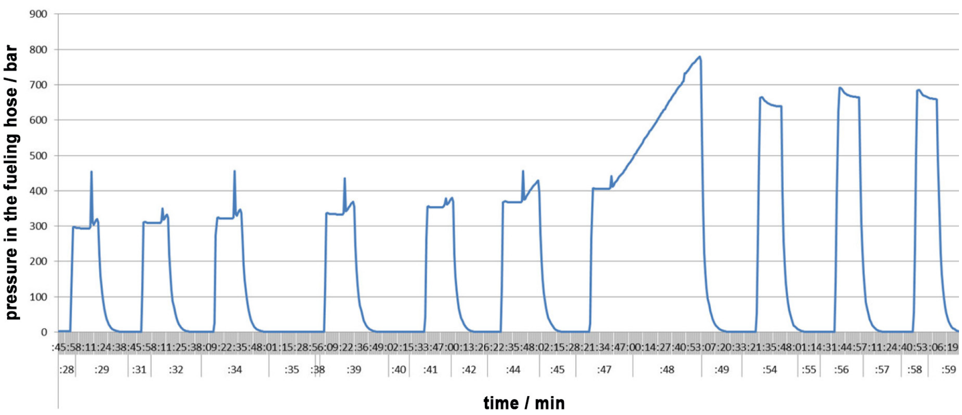
responsible for research in the area of synthetic and electricity-based fuels at Empa. The project, in which H2 Energy AG (Glattpark / Opfikon) and Hyundai are involved as technology partners, receives financial support from the Swiss Federal Office of Energy as part of its pilot and demonstration program.

From a technical point of view, there are no major hurdles to the construction of hydrogen fueling stations. However, the fueling stations at Empa and in Hunzenschwil have had a few teething issues since they came into operation during the second half of 2016 (for example, noise from compressor pistons and high-frequency whistling from its electric drive motor). These shortcomings were eliminated with little effort. One problem scientists are still working to fix, however, is icing. In cold and humid weather, the fuel nozzle can feeze onto the fuel tank inlet of the vehicle, although this happens rarely. The reason: The hydrogen must be pre-cooled -40 °C for refueling to (see text box p. 2). According to the researchers, shortened lubrication intervals of the fuel nozzle or suitable covers could help.

Safety Thanks to Leak Analysis

For ease of use and economy, it is desirable to integrate hydrogen dispensers into existing gas stations. This is not readily possible because, for safety reasons, a safety clearance area must be maintained around hydrogen fuel pumps in which there is no ignition source and no second fuel dispenser (gasoline, for example). Experts call this safety area the 'Explosion Protection Zone,' or shortened 'Ex-Zone.' Empa researchers are now working on an alternative safety concept in cooperation with the Swiss Accident Insurance Institute (Schweizerischen Unfallversicherungsanstalt, SUVA). The basic idea: if hydrogen is released into the environment during refueling, the refueling process is immediately stopped thanks to leak analysis.

Technically, leak analysis works as follows: At the beginning of the fueling process, the pressure inside the filling hose is measured twice within few seconds. If the determined pressure difference is greater than a predetermined tolerance value (for example 5 bar), a leak is to be assumed - the refueling process stops automatically.



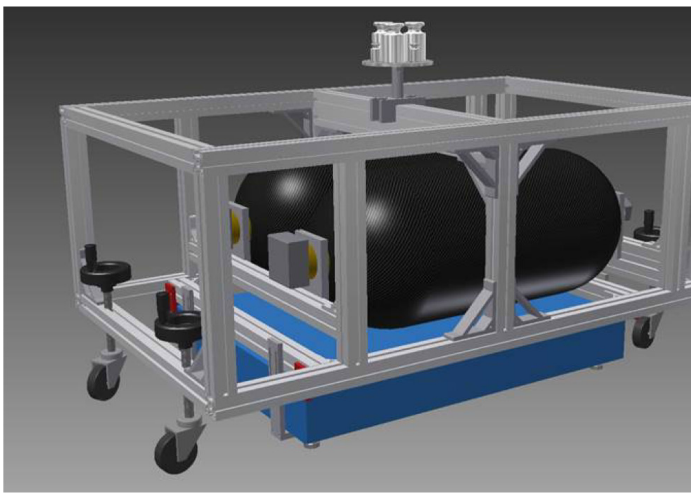
The graph shows ten leak tests carried out at Empa over a period of a half hour. During the first seven tests, there is no pressure drop in the fueling hose during refueling - so there is no leak. The last three tests are different: after the start of refueling the pressure drops, which suggests the presence of a leak. In this case, the refueling process would be automatically stopped to prevent the escape of hydrogen. While the first six tests were carried out with approximately half a tank and the refueling stopped manually after the leak test, the diagram shows that the vehicle was completely filled in the seventh test and the subsequent tests were carried out with a full tank. Graphic: Empa

Existing fuel dispensers for hydrogen are already standardly equipped with the described leak analysis system. The Empa researchers now want to use a specially developed leak test device to provide the proof required by SUVA that the leak analysis system works robustly. If this proof is acceptable, the Ex-Zone area could be reduced or even abolished - thus eliminating an important obstacle to the integration of hydrogen fuel dispensers in existing gas stations.

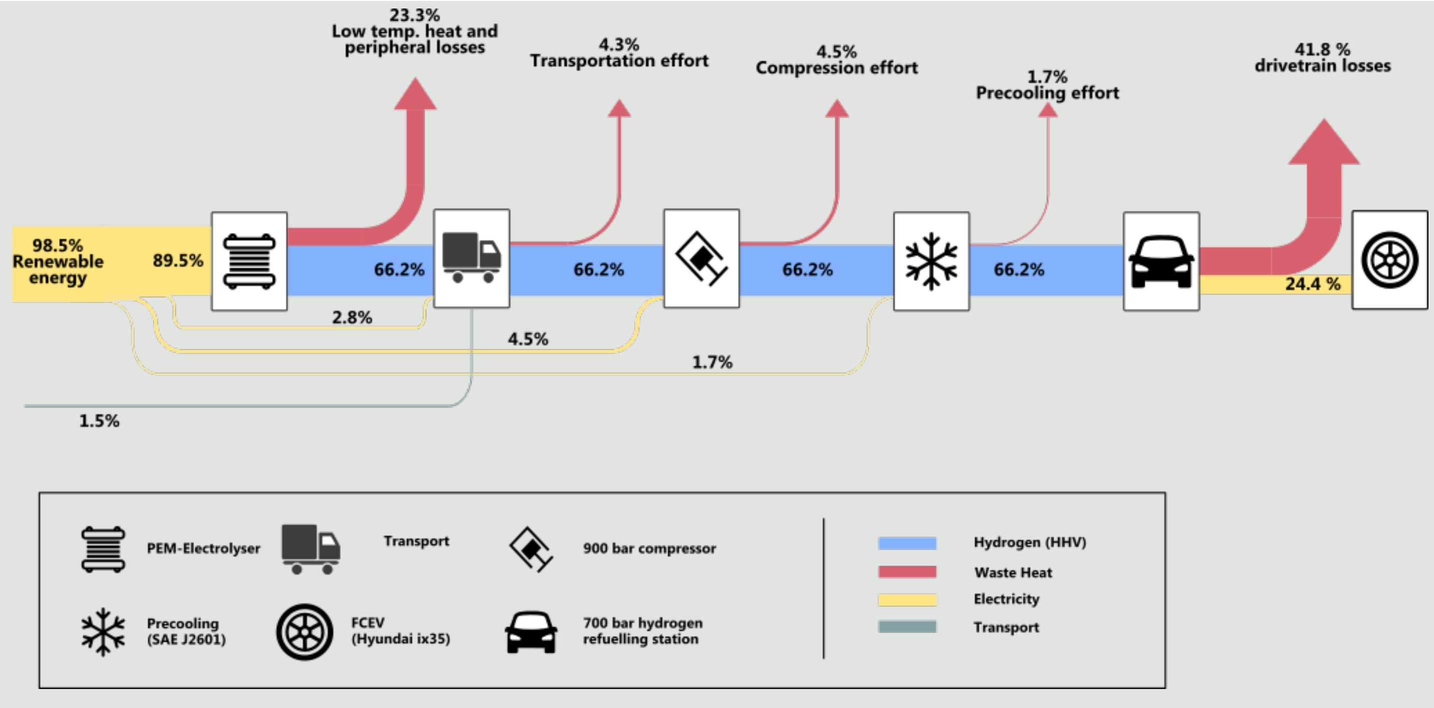
Measurements with Calibration Device

The Empa researchers' work reaches beyond technical questions: the scientists also aim to clarify legal issues in a written guide. In the future, this will serve as a working guide for petrol station manufacturers as well as licensing authorities in the Swiss Cantons. The Empa researchers are also focusing on the reliability of the fuel dispenser displays. For drivers to only pay for as much hydrogen as they have fueled, the pumps must be calibrated. For this purpose, the Swiss Federal Institute of Metrology (Eidgenössische Institut für Metrologie, METAS) developed a calibration device in 2017. This consists of two high-pressure tanks that can be used to check the mass of the hydrogen used by weighing (gravimetric method). Measurements with this calibration device are planned for the current year.

In 2019, Empa's scientists and their partners plan to conclude the research project on hydrogen fueling stations for passenger cars. Their work provides an important foundation for the future use of hydrogen-powered vehicles in Switzerland. Whether or to what extent the drive technology will prevail in the end depends on additional influencing factors. Electric vehicles convert renewable electricity directly into power of motion via the electric motor and achieve an efficiency of 50% to 75%, depending on the charging speed and secondary power consumption in the vehicle (well-to-wheel analysis). For hydrogen cars, the electricity is converted into hydrogen and then converted back into electricity, whereby in real-time operation per wheel, about 25% of the originally mobilized electrical energy is available. "An electric vehicle, depending on the charging time, travels two to three times as far as a hydrogen car with the same amount of electricity," says Cabalzar. "Nevertheless, the hydrogen technology has great advantages: With hydrogen, one can store a lot of energy with low weight, which favors solutions for long-



The mobile calibration device for hydrogen dispensers, as developed by the Swiss Federal Institute of Metrology in Wabern near Bern. The two tanks (black) are 91 cm long and have a diameter of 32 cm. In blue: the scale that can be used to precisely determine the weight of hydrogen in the two tanks. Illustration: Metas



If solar power is used to drive a hydrogen car, 24.4% of the output energy is converted into the energy of motion, as illustrated by this Sankey diagram: when converting the electricity into hydrogen, 23.3% is lost as heat (this can be used as waste heat if possible). 4.3% is lost due to the energy required to transport the hydrogen, another 4.5% is needed to the compress the hydrogen to 700 bar, 1.7% is required to pre-cool the hydrogen. The drive train uses another 41.8% of the energy (the greater part of it in the fuel cell, the smaller part for the energy conversion in the electric motor). The values in the diagram refer to a hydrogen production system on an industrial scale. Graphic: Empa

haul, heavy transport, aircraft or ships, for which pure battery-electric propulsion systems are not suitable."

- Empa offers **guided tours** of the "move" pilot system to interested groups. Register with Urs Cabalzar (urs.cabalzar [at] empa.ch)

- **Information** about the project is available from Dr. Yasmine Calisesi (yasmine.calisesi [at] bfe.admin.ch), responsible for pilot and demonstration projects of the SFOE section Cleantech, and Dr. Stefan Oberholzer (stefan.oberholzer [at] bfe.admin.ch), head of the SFOE research unit Hydrogen.

- Further **technical papers** on research, pilot, demonstration and flagship projects in the field of hydrogen can be found at www.bfe.admin.ch/CT/H2.

PILOT, DEMONSTRATION AND FLAGSHIP PROJECTS OF SFOE

The Empa project to clarify technical and legal issues surrounding hydrogen fueling stations for passenger cars is one of the pilot and demonstration projects with which the Swiss Federal Office of Energy (SFOE) promotes the development of economical and rational energy technologies and the use of renewable energies. The SFOE sponsors pilot, demonstration and flagship projects with 40% of non-amortizable, chargeable costs. Applications can be submitted at any time.

- **Informationen**:
  www.bfe.admin.ch/pilotdemonstration
  www.bfe.admin.ch/leuchtturmprogramm

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