Running on sun

Empa is in the midst of establishing the Future Mobility Demonstrator on its Dübendorf campus. Various technologies should reveal how excess electricity can be economically converted into fuel in the most sensible way. After all, this could save considerable amounts of fossil fuels.

TEXT: Christian Bach & Rainer Klose / PICTURE, ILLUSTRATION: Empa

The Future Mobility Demonstrator will be built on the Empa campus in Dübendorf, and it will look like this. The project is planned to start in autumn 2014.

Just how much one terawatt hour is

Switzerland's entire energy consumption in 2010 amounted to 253 terawatt hours (TWh), almost 60 TWh of which went on electricity. Just for comparison: the Leibstadt nuclear power plant produces around 10 TWh a year.
1 TWh of renewable excess electricity converted into methane could replace almost 60 million liters of petrol, and 70,000 gas vehicles could thus run CO_2-neutrally.

Switzerland has a substantial amount of "fallow" energy reserves. For instance, around half the local biomass (primarily slurry, dung, waste wood and bio-waste) goes unused, as an Empa study reveals. Converted in biogas plants, this would yield around 6 terawatt hours (TWh, see box) of bio-methane per year. On top of this there will be another 5 to 9 TWh of temporary excess electricity in the spring and summer months through the scheduled expansion of solar and wind-power until 2050. Photovoltaic plants, however, primarily produce maximum amounts of electricity at lunchtime and in good weather. And these electricity supply peaks can't always be put to good use.

With the large-scale project Future Mobility, Empa is looking to demonstrate how these home-grown energy can be used to replace imported fossil energy sources. A demonstrator will be constructed on Empa's Dübendorf campus that enables Empa and its industrial partners to develop the necessary concepts and test their practicality by working with real-world users.

Future Mobility – what exactly is it all about? The mobility of the future will increasingly have to rely on renewable energies, which is why drive concepts capable of using this energy are now in the spotlight: gas, electric and fuel-cell vehicles – all drives that Empa has been investigating and developing for years together with its partners in the ETH Domain and in industry. The idea behind the large-scale project: if the unused "domestic" energy could be exploited systematically, way over 1 million gas, electric and fuel-cell vehicles could drive around practically CO_2-neutrally, which would slash Switzerland's carbon dioxide emissions by over 4 million tons, which would match perfectly the Swiss contribution to the Kyoto-protocol.

The main challenge here isn't to process this energy and make it available; it's the economics of the entire system. Future Mobility should reveal how such plants have to be sized and operated, and which applications they need to be combined with to become a success – both in ecological and economic terms. After all, if the idea is also supposed to catch on in the real world one day, both of these requirements need to be fulfilled. //

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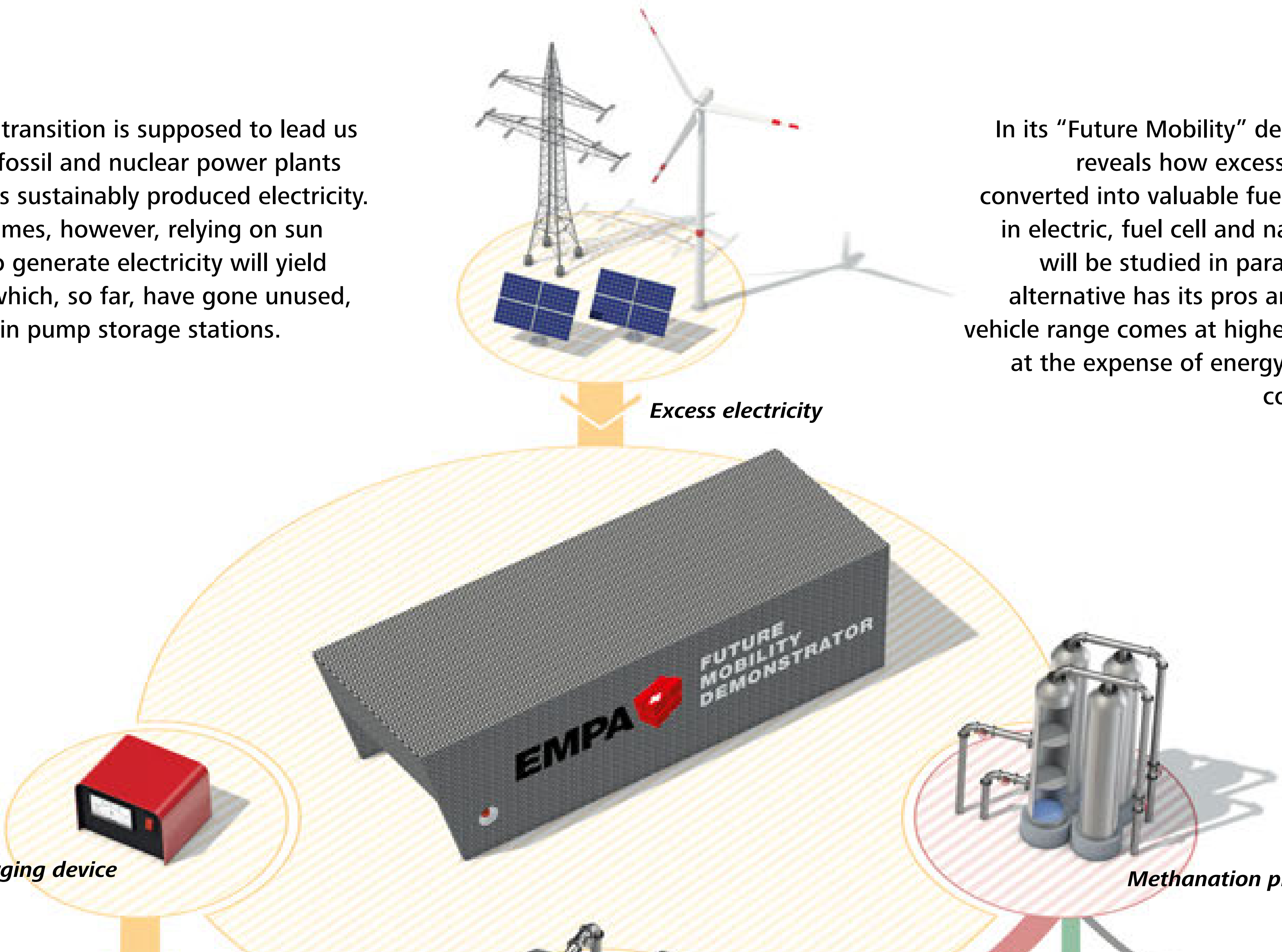
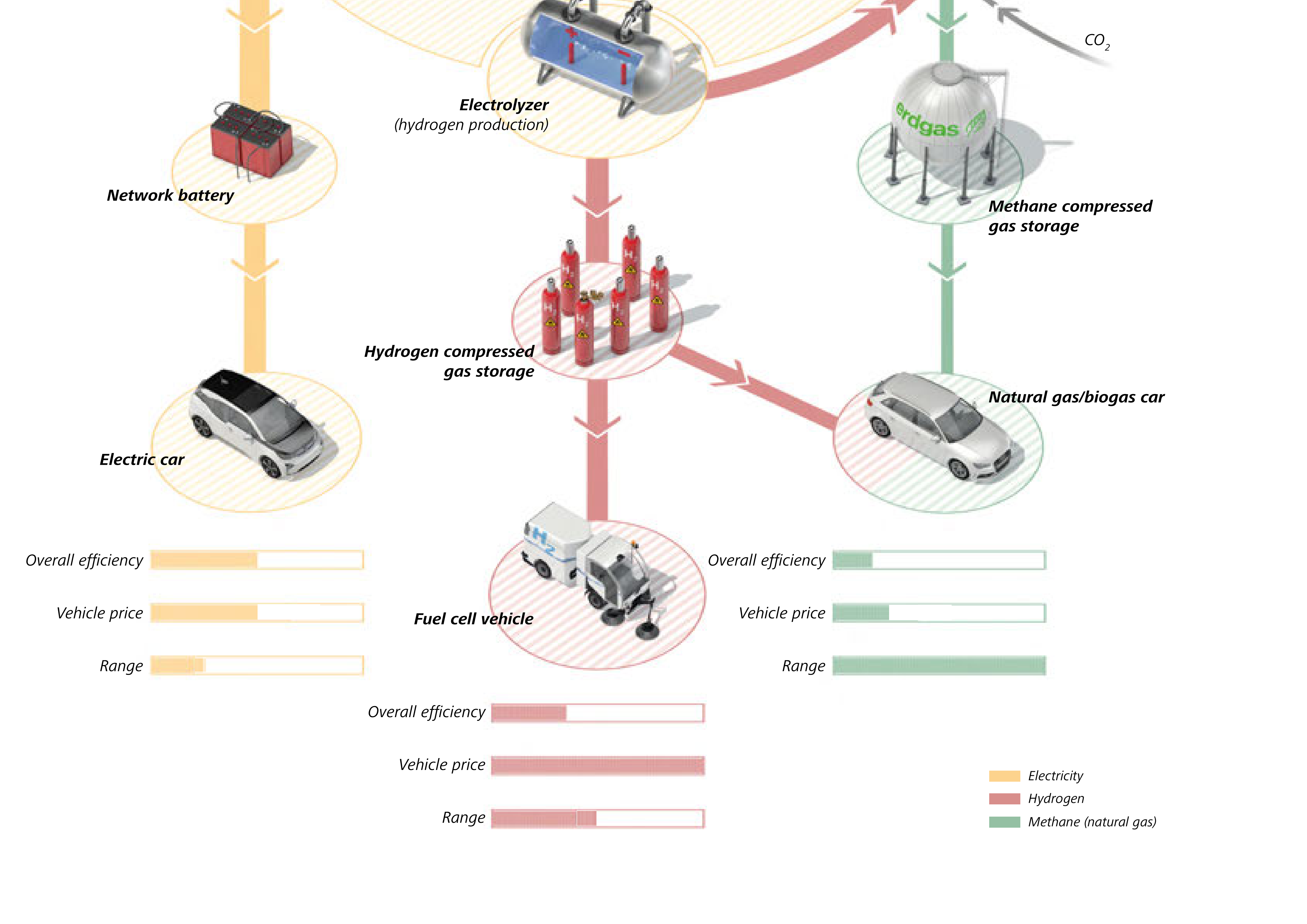
Turning excess electricity into fuel

The energy transition is supposed to lead us away from fossil and nuclear power plants and towards sustainably produced electricity. At certain times, however, relying on sun and wind to generate electricity will yield surpluses, which, so far, have gone unused, or retained in pump storage stations.

In its "Future Mobility" demonstrator, Empa reveals how excess electricity can be converted into valuable fuel. Its consumption in electric, fuel cell and natural gas vehicles will be studied in parallel. Because each alternative has its pros and cons: a greater vehicle range comes at higher vehicle prices or at the expense of energy losses during the conversion process.





CO_2
Electrolyzer
(hydrogen production)
erdgas
Network battery
Methane compressed gas storage
Hydrogen compressed gas storage
Natural gas/biogas car
Electric car
Fuel cell vehicle
Overall efficiency
Vehicle price
Range
Overall efficiency
Vehicle price
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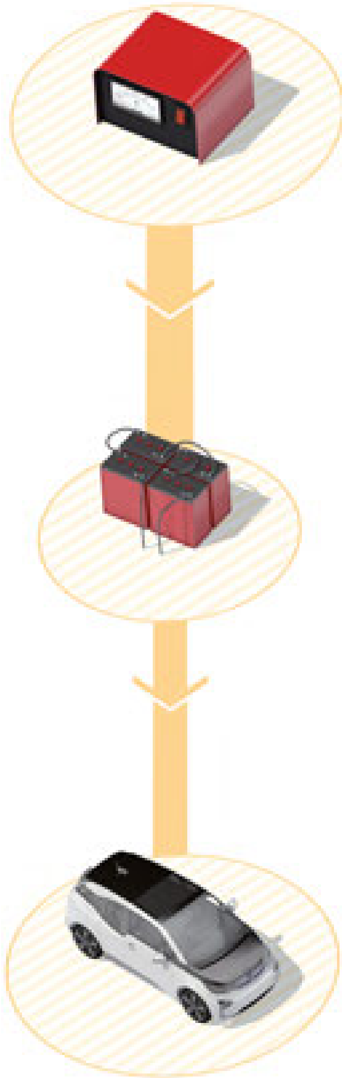
Hydrogen
Methane (natural gas)



Midday sun for the rush hour: electric cars

Theoretically, the easiest option would be to power electrical vehicles with excess electricity. Especially in the spring and summer months, large amounts of temporary excess electricity will already accumulate in the near future – unfortunately, mainly during lunch break, when far less electricity is consumed in Switzerland than photovoltaics, wind energy or hydropower plants provide. In other words, the electricity needs to be stored or it will fizzle out unused. In principle, electric vehicles (or their batteries) are just the ticket for the direct storage of excess electricity. However, as many as possible with as empty a battery as possible would need to be hooked up to a charging station precisely at lunchtime – and as few as possible should be driving around, which is hardly possible. Within the scope of Future Mobility, a permanent network battery assumes the role of temporarily storing the excess electricity that typically accumulates during the day. It can then be used to recharge the empty vehicle batteries at night. Batteries have an efficiency level of over 75 % and can also help stabilize the power grid – in other words, smoothen differences between the supply and demand within seconds. The biggest problem right now is the cost of the network batteries, which is why Empa is researching and developing new, cheaper batteries with a higher storage density and lower losses together with ETH Zurich and the Paul Scherrer Institute (PSI).

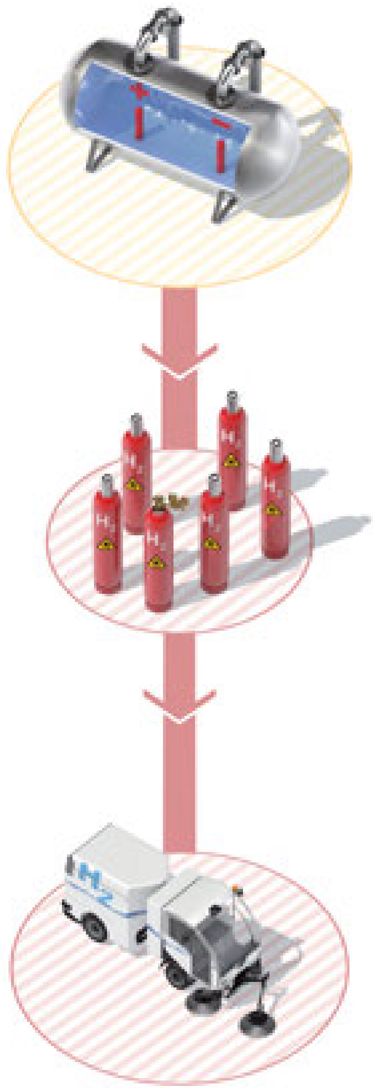
The Swiss Federal Office of Energy (SFOE) predicts a 28 % to 46 % proportion of electric and plugin cars and delivery trucks in Switzerland by 2050, 28 % for heavy utility vehicles and 70 % for motorbikes. These electric vehicles would consume a total of 11 TWh in electricity – the lion's share, namely 6 to 10 TWh, would have to be covered by fossil power plants or energy imports. There would be no advantage compared to using gasoline or diesel powered cars. Within the scope of Future Mobility, Empa researchers are looking to study whether and how the proportion of renewable energy can be increased by using network batteries for Switzerland's future electric fleet.

Catching and storing peak electricity: hydrogen vehicles

An energy transition is inconceivable without hydrogen for electricity storage. This makes hydrogen vehicles interesting. These vehicles have an electric drive, a hydrogen accumulator and a fuel cell that generates power from hydrogen and thus recharges the battery while it is on the move, thus combining rather long ranges with short refueling times. However, the complex technology sends the vehicle prices sky-high. On the flipside, hydrogen-powered cars do not emit any exhaust gases or CO_2, only steam. Empa is developing drive concepts for hybrid vehicles with integrated fuel-cell systems and conducting research into new technologies for hydrogen storage to replace pressure storage and increase the range of hydrogen vehicles even further.

The new Swiss energy strategy assumes that the electricity obtained from today's nuclear power plants will be halved by 2050, with the other half covered by renewable energies. Around 10 TWh should come from photovoltaics – the equivalent of an installed output of around 10 gigawatts (GW). However, Switzerland only needs 6 to 8 GW. In other words, on nice summer's days photovoltaics alone provides between 2 and 4 GW more electrical output than the country's overall demand. One possible solution that is being looked into within Future Mobility is decentralized chemical electricity storage devices: wherever excess renewable power accumulates, hydrogen (H_2) is generated directly through water electrolysis (splitting). A rough calculation shows that this is absolutely realistic: assuming electrolysis plants with an individual output of 1 MW, 2,000 to 4,000 such plants throughout Switzerland would be enough. These hydrogen plants would be conceivable at gas stations, bus depots or municipal facilities.

From today's perspective, hydrogen is the cheapest form of energy storage – with efficiency levels comparable to those of batteries. But since they are expensive, hydrogen vehicles are not suitable for all user groups. They primarily make sense where vehicles are driven a lot and hardly stand around, and where as large a reduction in CO_2 as possible is desired, such as public buses and larger passenger vehicles, which serve as shuttles or taxis, regional delivery vans and municipal vehicles. Within the scope of Future Mobility, a hydrogen-powered road sweeper co-developed with PSI and Bucher Schörling is being used to clean the roads in Dübendorf for two years.



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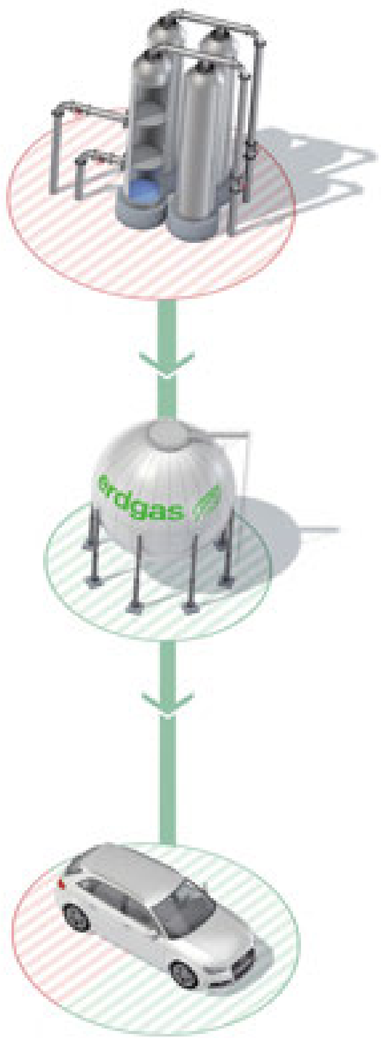
Summer energy for the winter: synthetic natural gas

It would be a nice idea, if we could "put aside" solar energy from summer months for the dark, cold wintertime. A concept called "power-to-gas" provides one possible solution: first, the excess electricity is converted into hydrogen via electrolysis and then into synthetic methane (CH_4) in another chemical process with CO_2. This synthetic methane produced in the summer can then be stored – together with biogas – in the natural gas grid for months on end and converted back into electricity in gas-fired combined-cycle or combined heat and power plants (CHP) during wintertime. However, the power-to-gas idea does have a drawback: as every step "costs" something in terms of energy, the overall efficiency of this form of storage is a mere 25 to 35 %. In other words, the electricity converted back would be very expensive and unable to compete with fossil energy sources.

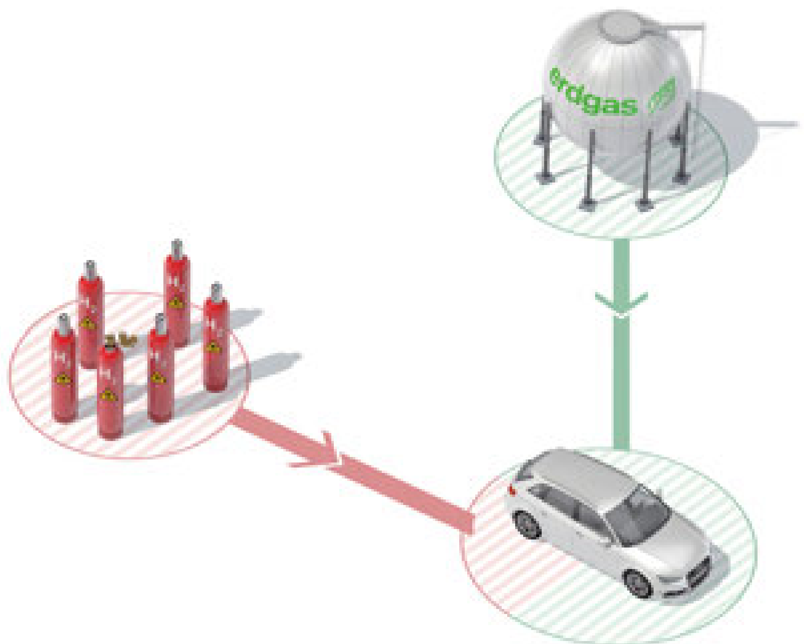
A way better alternative would be, the production of synthetic methane as fuel for gas vehicles – which is definitely economical. On the one hand, it avoids the losses incurred during the reconversion into electricity; on the other hand, fuels are generally more expensive than electricity. Of course, you also "pay" for the conversion of solar power into methane with higher energy losses, and the efficiency levels of power-to-gas plants are considerably lower than those for batteries and hydrogen plants. On the flipside, however, all industrial countries already have gas grids that are nowhere near stretched to capacity in the summer (when electricity excesses occur) and could easily accommodate and distribute the energy surpluses.

Another (presumably more surprising) advantage of gas mobility: although a combustion engine still powers the vehicle, gas vehicles that run on biogas or synthetic methane boast the lowest CO_2 emissions of all vehicle concepts. The reason: vehicles exclusively powered by renewable energy sources cause by far the most CO_2 pollution while being produced (not while being operated). Gas vehicles have the upper hand here compared to alternative vehicle concepts as the bodywork and engine can be produced economically and with a relatively efficient use of resources. Empa is working with ETH Zurich and the automobile industry to develop new combustion processes for gas engines. Methane's high knock resistance of up to 130 octane will facilitate completely new engine concepts in the future with considerably higher efficiency levels than today.



The right car for frequent drivers

Electric cars and fuel-cell vehicles only partly make a suitable replacement for today's cars. Due to their short range, for instance, electric cars are a no-go for the "frequent driver" group – around 20 % of all car-owners, who are actually responsible for half the kilometers travelled. And fuel-cell cars aren't much better, either, as there is no network of hydrogen filling stations (yet). Only gas vehicles are able to hold a candle to diesel and gasoline cars: they can be refueled in a matter of minutes and boast a range of up to 700 km to the tank. Plus, the network of filling stations within Switzerland and in neighboring countries is extensive.



Ecofuel ignitions: hydrogen in natural gas engines

Hydrogen can be used not just in (expensive) fuel-cell vehicles hydrogen but also in (cheaper) natural gas cars. Due to its high knock resistance, synthetic methane, treated biogas or natural gas are nigh-on perfect fuels for combustion engines. Modern turbo- or compressor-charged gas engines increasingly exploit these advantages. These days, natural gas engines are considerably more powerful than even ten years ago. As nice as this high knock resistance is, however, it is equally challenging for the fuel ignition and "flame nucleation" before the actual combustion. Consequently, intensive research is being conducted all over the world – including at Empa in collaboration with ETH Zurich and the automobile industry – to optimize the ignition process for gas engines and gain a better understanding of the processes that go on during the inflammation phase.

A considerably more effective ignition can be achieved in gas engines if hydrogen is mixed with bio- or natural gas. After all, hydrogen can be ignited very easily. In test series with a hydrogen admixture of up to 25 % by volume, Empa researchers managed to increase the engine's efficiency level significantly while reducing its exhaust-gas emissions – and all without technically altering the engine.

The Future Mobility Demonstrator has a natural gas/biogas filling station complete with a hydrogen admixture facility. It is currently being used to refuel three gas-powered Schweizerische Post delivery vans with a hydrogen-methane mixture and study them in routine operation. As hydrogen burns to steam in the engine, while increasing the efficiency level, substantial amounts of CO_2 can be saved with even a relatively low hydrogen admixture. Gas vehicles are thus the most cost-effective option for the sensible use of hydrogen from excess electricity.