Fuel cells

In the end only hydrogen remains

For those car manufacturers that have not invested in fuel cell technology, it may already be too late. Nevertheless, it is still too early to forecast when fuel cell propelled cars will be an important part of the market. Even if the strategy is feasible, until its positive effects come into being, adversity looms. An Analysis by Gottfried Ilgmann.

10th of January 2010. At Stuttgart, which is widely known as the capital of the German dream-car industry, a conference took place at the end of September last year with an accompanying technical fair entitled "f-cell". Fuel Cells were the general subject: those devices which produce electricity directly from air and hydrogen gas, one application of which is the powering of electric cars, a means of ensuring individual mobility in the post fossil era. Instead of a rechargeable battery such a vehicle has a hydrogen tank as a sole or additional source of energy.

During the "f-cell" fair, one could test-drive an electric car equipped with such cells: the HydroGen4 of Opel. This hybrid, in size between that of a medium-sized saloon car and a sport/utility vehicle, obtains 93 kilowatts from its fuel cell and a further 35 kilowatts from a nickel-metal-hydride battery which serves as a power buffer. This has the same characteristics as those of an electric power train in that its maximum performance is always available, irrespective of whether the number of revolutions per minute is high or close to zero. Thus the two ton vehicle accelerates faster than a gasoline or turbo Diesel car of the same power rating. Its maximum speed is 160 km/h and its tanks, pressured to 700 bar, accommodate 4.2 kg hydrogen, which is sufficient for 320 km of travel. An even longer cruising range can easily be obtained by fitting additional tanks.

A “serial hybrid”

But why use hydrogen tanks if one can store the necessary energy in batteries alone? In two years time the Opel Ampera will enter European markets. With regard to its weight and performance and in terms of its maximum speed it is comparable to the HydroGen4. With a range of 60 km its electric engine draws its energy from a 180 kg Lithium-Ion battery which can be charged with 16 kWh using ordinary domestic power sockets. In order to guarantee an economic life-span (ten years and at least 240,000 km) the battery discharges only up to half of its capacity and then has to be recharged, a process which takes three hours. Hence the usable stored energy amounts to only 8 kWh.

But who would buy such a high-speed limousine, with a cruising range of only 60 km? As a "city only car" it is oversized, but at the same time, for obvious reasons, it is also unsuitable for longer journeys. Therefore Opel has built "a range extender" into the Ampera, an auxiliary unit (a 55 kW-Corsa engine which produces electricity for the electric power train through a generator) which extends the cruising range if needed. In the specialized language of the industry, this is labelled a "serial hybrid", while cynics prefer calling it "an electric car with emergency back-up generator".

The battery is essential

Perhaps this cynicism is inappropriate, because Gherardo Corsini, development engineer at Opel, knows, "how depressing the thought of an empty tank can be", and 80 per cent of Europeans do not drive more than 50 km per day. For them a 60 km cruising range would thus be completely acceptable. Nevertheless, the market for "city-only cars" is small, while the market for cars with a longer range, even if that is only an occasional requirement, is considerably larger. However, if the Opel Ampera had to run only on stored electricity for 320 km, the battery alone would weigh about one ton. Such a battery-driven three-ton vehicle would be unaffordable and the normal domestic power socket would no longer be suitable for recharging it.

Thus an electric car may not be independent of fossil fuels. A technical break-through that would considerably increase the capacity of batteries could change that, but whether this will happen is more than questionable. One might ask therefore, despite all our hopes to the contrary, whether the concept of the electric car is already dead and buried.

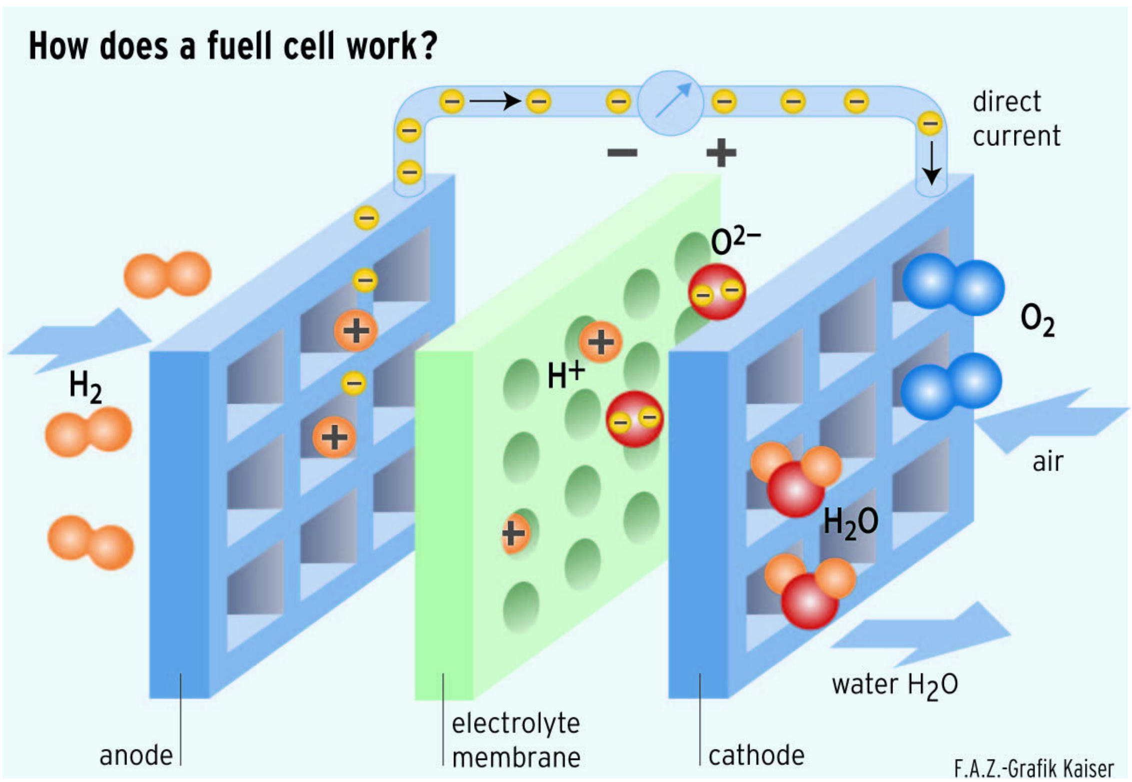
The answer would appear to be " yes", at least if the demands made of electric cars are similar to those made on gasoline and Diesel powered cars, which are true all-rounder. The strengths of battery-driven cars lie within the need for only small travelling distances, with small vehicle weights and in situations in which stop-and-go driving patterns prevail. This combination applies only to pure city cars.

A comeback thanks to the space programme

Nevertheless, electric power trains can do more if the energy comes from fuel cells instead of batteries. The technology is not by any means new. The chemist Christian Friedrich Schönbein discovered the principle that hydrogen can be burned quietly as early as 1838. Contrary to an explosive reaction, where the energy is mainly released as heat, here the energy is released as electric current (see the diagram "How a fuel cell functions").

One year after Schönbein's discovery the British scientist William Grove undertook the first practical experiments. However, the fuel cell fell into oblivion and experienced a comeback only thanks to the development of technology required for space travel.

Today the term "fuel cell" is generally used for hydrogen cells, although other materials, e.g. Methane or Methanol can also be converted with the help of atmospheric oxygen, thereby releasing electrical energy. However, cells processing these fuels today play hardly any role in research into electrically propelled vehicles.



Working on efficiency

In contrast hydrogen fuel cells already play a role in the development of vehicles powered by electricity. Electric vehicles equipped with such cells have already been developed not only by GM/Opel, but also by other large car manufacturers, such as Toyota, Honda, Nissan and Daimler. "We are already entering the home straight for commercialization", says Andreas Truckenbrodt of the Automotive Fuel Cell Corporation, a development initiative in which Daimler holds a majority interest. The introduction of such vehicles into the commercial marketplace is foreseen for the year 2015 - that sounds as if we are about to maintain our familiar mobility in the future by means of alternative technology. But is that really true?

At the "f-cell" conference in Stuttgart Ikuo Kasahara, manager of Toyota Motor Europe, highlighted what a Herculean task is still in store for developers. The costs would have to be forced down a hundredfold compared to those of the reference year 2005. The first cost reduction, to one tenth of current costs, is the most difficult one. How does one get along without the need for expensive platinum which, as a catalyst, helps to break up the gas molecules within the electrodes? What is needed is the same catalytic effect using only a tenth of the platinum required in 2005, and at the same time with the achievement of higher efficiency and longer durability.

Reality by 2015?

Kasahara calls this task a "trilemma", since the achievement of all three of the required goals is mutually contradictory: all things being equal, the reduction of the amount of platinum within the catalyst leads to less output and shorter battery life. Hence only the use of another catalyst might solve this predicament. Kenichiro Ota of the Yokohama National University for example is experimenting with niobium and titanium oxides, which are extremely cheap compared to platinum. Nevertheless, the belief that we can reduce the costs by a factor of ten involves an element of insanity, although strangely enough many developers are crazy enough to try. What makes them so confident is the fact that there is an existing potential - in stark contrast to the non-existent potential savings in battery development.

The second source of cost reduction will be mass production, decreasing overall costs by another tenth. If Kasahara's goals are achieved, this would mean the end for most combustion engines. Not even city cars running only on electricity from rechargeable batteries could compete. But are the goals of the Toyota manager not too ambitious? Can they become reality by 2015? Traditionally Toyota is rather over-modest, and than astonishes the public with an unexpected market launch. Charles Freese of General Motors states bluntly how quickly progress in fuel cell technology is being made. The latest generation of General Motors' fuel cell cars requires only 30 grams of platinum compared to 80 grams in 2005. The volume and weight of the fuel cell unit have been halved - and this at a 20 per cent increase in power output. The production model post 2015 should function efficiently with only 10 grams of platinum.

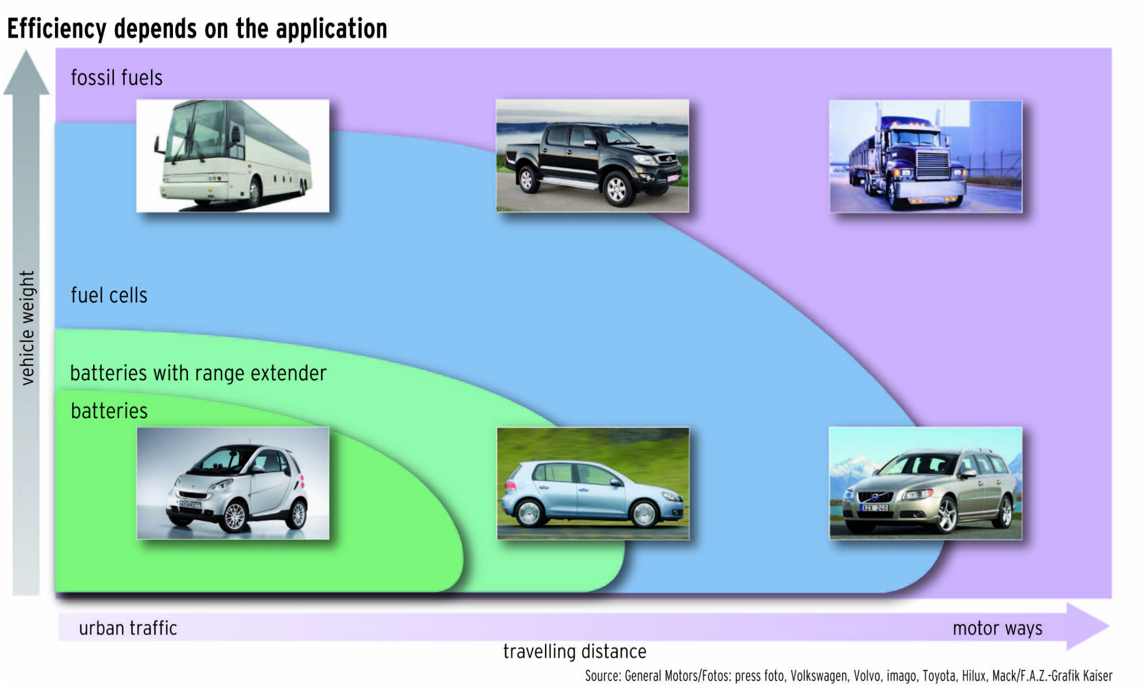
The German development plan

Today these forecasts may still sound audacious; nevertheless it is very likely that cars propelled solely by fossil fuels will be a product of the past. The car manufacturers are aware of this. Accordingly there is a deep fear of being left behind in the competitive race. Germany would be particularly affected, since no other industrial nation has such a high value added per capita in the automotive sector. Among the big car manufacturers a race for competence in electric mobility has begun. Much in demand are alliances with firms which have appropriate technical knowledge, for example those specialising in the production of electric motors and their control, but also batteries, fuel cells, and hydrogen storage devices. Those car manufacturers married to the most productive brides will eventually win the race. However, the most attractive brides might already be married!

Meanwhile, in the first half of 2009, the German Federal Government submitted the "national development plan for electric mobility", a 500 million Euro research and investment program within the framework of the economic stimulus package II. Its declared goal is "to ensure as quickly as possible the technological advancement of German industry to match the world-leaders in the field of electric mobility". This in a way sounds as if the German automobile industry already lags behind. At the same time, there is also a national investment program in hydrogen and fuel cell technology (NIP), launched in mid 2008, amounting to 700 million Euros and which is to generate a further 700 million Euros from the industry itself. The program will continue until 2016.

What are the other advantages of the fuel cell?

Other nations are also making serious efforts. The United States for example will expend a total of $ 2.4 billion over ten years for fuel saving vehicles, in addition to the $ 25 billion in loans to the car manufacturers and suppliers. China, a country which presently receives € 68 million of German development aid per year, wants to spend € 2 billion from 2009 to 2011 on pilot experiments with 10,000 vehicles.



According to the type and scope of the German Government's funding, more resources are channelled into research on fuel cells and hydrogen technology than into the development of batteries. Can that be taken as an indication of the fact that research into fuel cells is strategically more important?

At the "f-cell" conference in Stuttgart, the speakers referred to the preceding diagram ("it depends on the application"). It shows why fuel cell technology is so much less talked about in public than lithium ion batteries. Fuel cell propelled vehicles cover a far wider range of requirements than battery-propelled vehicles, and they are suited not only for short-distance passenger transport, but also for light commercial transport over short and medium distances - a segment conspicuously ignored in public debate. Why? The answer is quite simple: hardly any politicians and only a minority of voters drive delivery vans.

Text: F.A.S.
Pictorial material: F.A.Z.
Translation: R. Wurster, LBSt, Ottobrunn, and C. Ilgmann, CAWM, Univ. Münster

Where does the good gas come from?

Fuel cell vehicles are well suited to the vision of a post-fossil electricity industry

By Gottfried Ilgmann

15th of January 2010. Hydrogen gas can be produced by using fossil energy, for example from natural gas, which consists of up to 98 per cent methane. For this purpose it is converted into hydrogen and carbon monoxide by means of a so-called steam reformer and with the help of water vapour. In the next stage the carbon monoxide is processed with more water vapour to produce carbon dioxide und more hydrogen again. However, this type of hydrogen production is of no benefit to the climate. If natural gas was simply burned in a converted gasoline engine the same energy and CO_2 balance would result. Nevertheless, it may be useful to allow such a use for hydrogen in the short term. Introducing fuel cell cars into the market place only after we are able to synthesize the complete hydrogen chain from non-fossil energy sources will hamper the process of changing to electric transport.

Perhaps green algae will be the future

Hydrogen can also be produced from biomass, since biogas likewise consists mainly of methane. But it is more economical and thus more environmentally friendly to use locally available biomass such as liquid manure or straw for electricity production, especially as the residual heat could be used for heating purposes in the same locality. The idea of cultivating biomass (for example in the form of fast growing timber) in order to produce electricity or fuel in large, centrally located plants has been criticised due to the fact that it competes with the production of food for humans and animals. Fascinating, but still a future dream, is biotechnical hydrogen production from green algae. Using photosynthesis sunlight splits water into hydrogen and oxygen. Admittedly algae have high demands with regard to their upkeep. Researchers at the Max Planck Society are therefore trying to replicate artificially the process of biochemical photosynthesis.

Today "green hydrogen" is mainly produced by electrolysis, the splitting of water into hydrogen and oxygen using electricity produced from renewable sources - as for example in the hydrogen refuelling station of the "Hamburger Hochbahn". The potential for expanding this hydrogen source is considerable. In Europe it is a larger source than all the fossil fuel energy sources currently used for transporting passengers and goods, be it by car, truck, train or plane. The largest potential German renewable energy source is to be found in wind energy from off-shore generators, world-wide it is solar thermal energy, particularly in Africa. Here solar radiation is concentrated by mirrors and then used to produce steam which generates electricity using turbines. If the vision of the Desertec Project, which was initiated last October, becomes reality solar power plants in the Sahara would meet up to 15 percent of Europe's demand for electricity until the year 2050 while at the same time supplying the needs of northern Africa.

Wind - electricity - hydrogen?

Without such a source of solar energy like Desertec (and without nuclear energy), only wind energy remains as the source of non-fossil fuel electricity production in Germany. The question with regard to climate protection is whether it would be more efficiently to produce hydrogen for electric transport from North Sea wind power or to feed electricity directly into the grid in order to eliminate the need for conventional fossil fuel power plants? In the first case wind generated electricity would be sent to an electrolyser. The hydrogen produced by this means would subsequently be sent to the refuelling stations via pipelines and intermediate buffer storages. Compressed to 700 bar it would then be available to fill the pressure tanks of vehicles and, via fuel cells, would be converted into electricity for the engine and finally into mechanical energy. In the second case wind-generated electricity would be fed into the public electricity grid at the coast thereby replacing a natural gas power plant with an efficiency of 58 per cent. The natural gas thus saved would then be used as fuel for natural gas passenger cars.

Which of these two possible uses of wind electricity for individual passenger transport would result in less CO_2 emission? On the one hand through the hydrogen chain some 25 per cent of the initial energy would arrive in the form of mechanical energy at the car wheels. On the other hand if the wind-generated energy is fed into the grid, one could produce more than 30 per cent of mechanical energy with the natural gas saved at the gas turbine power plant. Consequently, from an ecological perspective, this means that each kilowatt-hour of wind-generated electricity produced belongs to the grid first.

When the wind blows

However, this calculation is not entirely correct. Wind does not blow in accordance with electricity demand. It blows as strongly at night as during the day. Germany however already has too much electricity at night because the output of existing base load power plants, for example coal and nuclear power plants, can only be slightly reduced at night.

Furthermore, wind blows twice as strongly during the winter months as it does during the summer, whereas the demand for electricity in the winter is not twice as high as that in summer. In Germany, and across Europe in general, wind generated electricity - under certain weather conditions lasting days if not weeks - will be available either to excess or hardly at all. However, electricity can only be stored in negligible quantities; hence a large proportion of wind-generated electricity cannot be used at all or only very inefficiently.

Strategic hydrogen reserve

For the above reason the following is the result. Since wind is careless as to when electricity is needed in the grid, wind-generated electricity becomes the first choice for the production of hydrogen as hydrogen can be stored as simply as natural gas – at a large scale and relatively inexpensively. When the former Minister of Economic Affairs Michael Glos intended to double the strategic natural gas reserve to 90 days of the annual consumption, the German foreign trade federation for mineral oil and energy complained that this would cost a private household, with an annual consumption of 20,000 kWh, about 40 €. However, 20,000 kWh of natural gas have about the same energy content as, for example, 2300 litres of gasoline, which would be sufficient, assuming a consumption of seven litres per 100 km, for approximately 33,000 km of road travel per year. The average mileage in Germany amounts to about a third of this. A strategic hydrogen reserve for electric transport would thus cost comparatively little, even if hydrogen storage would prove to be more expensive.

Text: F.A.S.
Pictorial material: F.A.Z.
Translation: R. Wurster, LBSt, Ottobrunn, and C. Ilgmann, CAWM, Universität Münster

Fuel cells for bus and rail use

A hydrogen-based fuel economy is not only suitable for the car

On the way to oil-free mobility the car is the main field of application for the fuel cell. Currently Daimler, for example, has produced 200 second generation fuel cell cars based on the Mercedes-B-Class in order to assess their acceptability by customers. At the same time fuel cell driven vans and buses for urban transport are also being tested, the fuel cell technology being nearly identical in each case. According to Günter Elste, the head of Hamburger Hochbahn, which has been using hydrogen fuelled buses on scheduled services since 2003, technological progress made on the enormous mass market for cars is directly transferable to buses. Beginning in 2011 ten buses of the newest generation will be put into service. Furthermore, a field trial with so-called serial diesel hybrid buses will be launched this year. A diesel engine which operates continuously within the highest efficiency range drives a generator producing the traction current. A relatively small battery serves as a buffer for this arrangement. It stores the current generated by the braking energy and releases it when accelerating, a phase in which the electric motor cannot convert the energy of the diesel engine into propulsion at a sufficient level.

Other concepts use buffering capacitors, so-called supercaps. They experience hardly any energy losses while either charging or discharging, they are cheap to produce and do not suffer from wear. By buffering with batteries and supercaps the diesel engine may become smaller, more economical to operate and less expensive to produce. A reduction in energy consumption of 25 per cent is expected. The reduction of pollutants in their exhaust fumes will prove to be even greater.

If the diesel engine is replaced by fuel cells the remaining power train hardly needs to be changed. Fuel cell vehicles buffered with batteries and capacitors have a similar importance in energy saving because the fuel cell also has capacity ranges with lower efficiency. Thus, with a very small load the current is drawn exclusively from the battery and the supercap. At high load, e. g. when accelerating, the current flows from the fuel cell as well as from the battery and the supercap.

The fuel cell could also be interesting for railway use. On the main tracks, overhead lines will continue to be used, but on secondary lines the need for the installation of overhead lines could be reduced by using hydrogen as the fuel with the addition of braking energy recovery, at least for trains with small payloads. In addition, disturbances to overhead lines could be overcome more easily. The German railway system could be used more efficiently, because congested junctions could be by-passed on non-electrified secondary lines.

gilg

Text: F.A.S.
Translation: R. Wurster, LBSt, Ottobrunn, and C. Ilgmann, CAWM, Univ. Münster