Energie-Spiegel [engl. ed.]
Facts for the energy decisions of tomorrow

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ENERGIE-SPIEGEL

FACTS FOR THE ENERGY DECISIONS OF TOMORROW

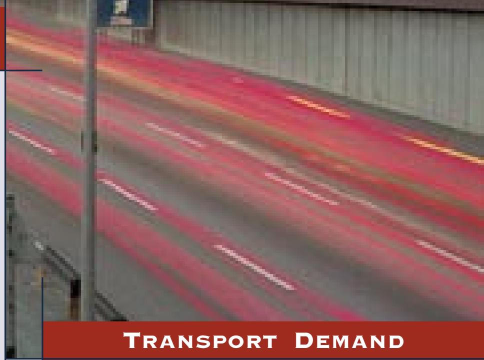
SYNOPSIS

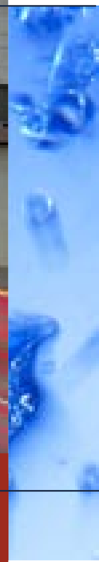
Motor traffic consumes 20% of global energy end-use, and in Switzerland the share is even higher at 33%. The transportation sector causes ever higher pollutant emissions, and is also the fastest growing energy use sector. In addition to measures for limiting traffic and promoting less-polluting public transit, the state of individual transport demands attention. The vehicle fleet of the future must become far more energy efficient if one wishes to reduce energy demand, and with it the emissions of the greenhouse gas CO_2. At the same time, the emissions that damage human health must be strongly reduced, including particulates, nitrous oxides, hydrocarbons and the resulting ozone.

The development of very clean diesel motors addresses the CO_2 reduction demanded by law. Methane fueled cars using modern gas engines can also help in the short to medium-term. These would be fueled first with natural gas, and later with methane from native biomass. This resource represents at least 15% of Switzerland's current primary energy demand.

In the long-term, fuel cells using hydrogen as fuel are the best solution. They have a significantly higher efficiency than combustion motors, and the only direct emission is water vapor. The complete dependence on petroleum is reduced, along with geopolitical risks, if the hydrogen is produced from renewable resources, including biomass and solar energy.

For a successful market introduction, the coordinated efforts of automobile and fuel companies are necessary, as well as well as improved political conditions. The costs of fuel cells must also sink significantly (by a factor of 20 to 50). For a significant market presence, a minimum of ten years research and development are therefore necessary. The production of biomass fuels and drivetrains for natural gas and fuel cell cars are researched and developed under the ETH research umbrella, particularly at PSI. PSI initiated and conducted a project to build a fuel cell car with super-capacitors, which recover the braking energy and increase acceleration. Thanks to excellent cooperation with partners from industry and the rest of the ETH research realm, and the financial





Traffic and the Atmosphere

Whether car, truck or airplane, traffic never stops growing. Human health and the natural world suffer under the growing emissions, and the carbon dioxide emitted destabilizes the global climate. Efficient, low emission vehicles are urgently necessary. Fuel cells powered by hydrogen could bring us a step closer to the vision of a sustainable economy in the area of individual transit, and also reduce the dependence on foreign fuel resources.

The energy demand and pollutant emissions from motorized individual traffic vehicles are high. Worldwide, 20% of the final energy demand, and in Switzerland even 33%, is consumed by the transportation sector. Of this amount, 60% is used in personal vehicles. An entire series of unsolved problems is associated with this demand. The combustion of fossil fuels releases large quantities of CO_2, which strengthens the greenhouse effect. The air quality limits for particulates, nitrous oxides and ozone continue to be exceeded, so that in spite of the successes that have been achieved, an urgent need for further improvement in engines exists. Finally, the complete dependence on petroleum carries with it considerable geopolitical risks.

A strategy that fashions environmentally sustainable transportation will rest on four pillars;

• **Reduction** of demand through regional planning, traffic control and economic incentives. Individual customer decisions will determine the success.

* **Shifting** individual vehicle traffic to more energy efficient public transportation (mobility management).

* **Increasing** efficiency and minimizing emissions through technical measures.

* **Substituting** fossil energy carriers by renewable energy.

Domestic leisure traffic in Switzerland is dominated by the car, and makes up 60% of the person-kilometers driven, so the last two measures are especially important. Therefore new paths must be explored in the areas of vehicle technology and fuel supply. This issue of the Energie-Spiegel emphasizes these areas.

Lightweight vehicle construction Next to air and rolling resistance, vehicle weight decisively influences the need for mechanical driving energy. Present efforts should be strengthened, with the goal of halving vehicle weight.

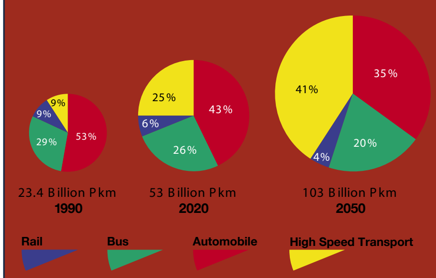
Combustion Engines In the short and medium-term, the further development of conventional combustion engines is very important. However the development of vehicles with energy efficient diesel drivetrains, combined with strict limits on particulates emissions, can achieve only part of the legally demanded reduction of CO2 emissions from vehicles.

Natural Gas Motors Combustion engines burning natural gas are an attractive alternative for CO2 reduction. The advantages are good efficiency, along with extremely low nitrous oxide emissions and no particulates, as ETH has recently been able to show.

Fuel Cells Experts agree that fuel cell automobiles with hydrogen fuel provide the best long-term solution. They show a significantly higher drivetrain efficiency than combustion motors, and their direct emissions contain only water vapor. The vehicles themselves however must become considerably cheaper. The long-term fuel supply of hydrogen from renewable energy sources must also be assured (see figure *). Mass production of fuel cell vehicles is not expected for at least 10 years.

The development of a prototype fuel cell car using Supercaps (see insert) by the Paul Scherrer Institute with VW and other partners is a step on the way to a cleaner future.

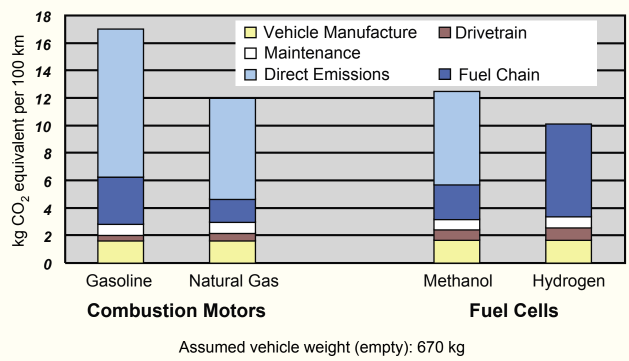
Transport Demand



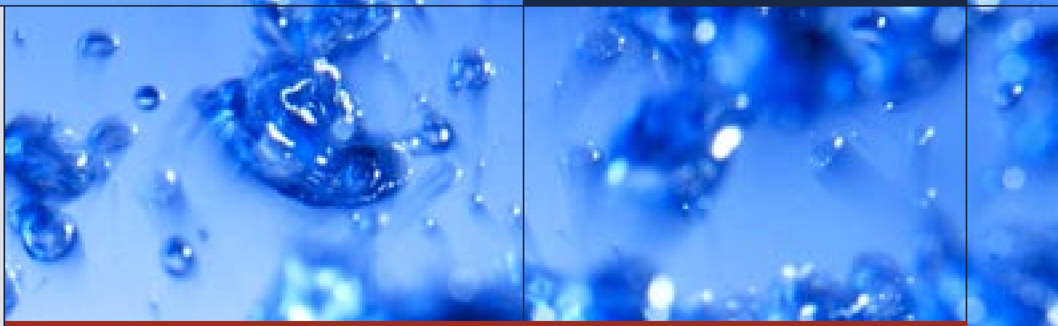
Projections of the global development of traffic demand are based on the extrapolation of present trends. Population and economic growth are expected to lead to a quadrupling of demand and a shift to faster forms of transportation.

Source: A. Schäfer, MIT

Greenhouse Gas Emissions from the Full Energy Chain



Greenhouse gas emissions from future vehicle systems (2010). The use of hydrogen from renewable energy sources removes the majority of emissions from the fuel chain (highest potential CO2 reductions).



Hydrogen can become the energy carrier of the future in a sustainable energy system. However fossil fuels may also be used more efficiently than today in optimized drivetrains, which will limit pollutants to a minimum. Synthetic fuels and methane will also play an important role in the construction of a hydrogen-infrastructure.

Fuels of the Future

Trends in the Fuel Supply

To reach the climate protection goals, we must use primary energy sources with lower carbon intensity (CO_2 emissions per energy unit). As a first step, natural gas is therefore favored. In the medium-term. It is very important to use CO_2-neutral biomass, which could provide approximately 10% of primary energy demand in the industrialized countries. The long-term potential of solar energy is high (see. Energiespiegel 5). However, nuclear energy can also provide an important contribution to current production with very low CO_2 emissions.

The customer may expect in parallel a fundamental move to new energy carriers. Today's dominant gasoline and diesel will be replaced by energy carriers delivered over wire and pipeline networks, namely electricity, methane and hydrogen.

Methane will play a key role in the transition to a future energy system based on hydrogen. Methane is the main component of natural gas, but can also be manufactured from biomass through fermentation or gasification. Hydrogen can be produced by transformation from methane from either fossil or biomass sources. Methane is also non-polluting, difficult to ignite and just as safe in vehicles as gasoline or diesel. Therefore it facilitates the gradual development of the vehicle fleet in the direction of natural gas motors and fuel cells. That the fuel supply infrastructure can be successfully established has been shown in Italy, which has more than 300,000 natural gas vehicles.

Where will the hydrogen for fuel cell cars come from? By the end of this century the majority of hydrogen should come from renewable sources of energy, with an emphasis on solar energy. The main problem comes in the storage and transportation of solar energy (see Energiespiegel 5). Hydrogen is especially appropriate for the following reasons:

- Very high energy content per kg (120 MJ/ kg)
- Transportable by pipeline or in ships when cooled to low temperatures
- Non-toxic to the environment
- Can be produced from various sources, like high temperature solar chemistry, electrolysis (i.e. from electricity), biomass, natural gas etc.

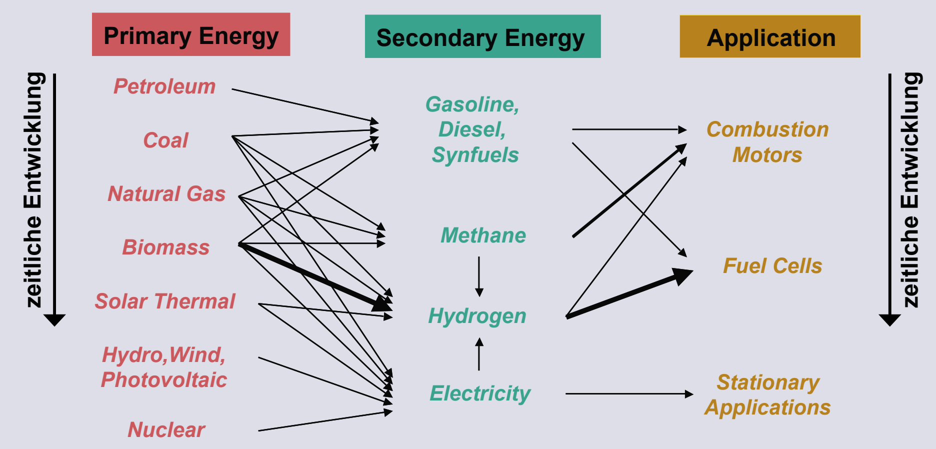
Future hydrogen production will follow different, regionally optimized methods. For Switzerland, the principal first step of interest is economical production from biomass.

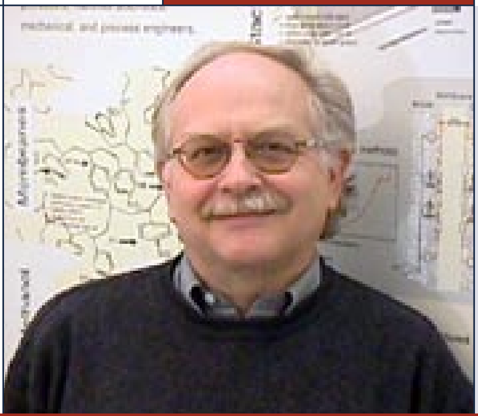
Distribution The comparative evaluation is between centralized production of hydrogen with distribution by truck or pipeline, and the decentralized production at the filling station. The construction of distribution and sales infrastructure is expensive, so only a few fuel paths can be pursued on a large scale. Automobile and fuel companies will have to determine their strategies.

Storage Hydrogen has a low energy density by volume. Therefore there is intensive work on storage options for vehicles. The goal is lightweight pressure tanks, cryogenic flasks for liquid hydrogen, or storage within solid metallic or carbon-matrix materials.

Production Costs A fuel cell car of the Hy Power type today needs about 1.5 kg of hydrogen per 100 km, which can be produced and distributed for about 3.50 CHF from natural gas and about 8.50 CHF from biomass. The corresponding cost for 8 liters of gasoline per 100 km in a conventional car is about 2.40 CHF without taxes, and 10.00 CHF at current tax levels. So it is not the cost of the fuel, but rather the cost of the vehicle which is a problem (see page 4).

From Primary Energy to the Road





Günther G. Scherer took his doctorate in chemistry in 1976 at the Technical University of Berlin. He then spent his postdoc at IBM in California and worked at the Battelle Institute in Frankfurt, at the BBC Research Center in Baden and at Ingold Messtechnik in Urdorf. In 1989 he became leader of fuel cell research at PSI and has led national and international project on the materials and structural aspects of fuel cells. Since 2002, he has led the Laboratory for Electrochemistry.

"Clear Signals are Necessary"

The principle of the fuel cell was discovered in 1839. Why did it take so long to make a breakthrough?

To understand the fuel cell, one needs knowledge of the thermodynamics and kinetics of electrochemical processes. This knowledge was first developed around the first of the 20th century, and continued until around the middle of the 20th century. The development and availability of new materials has been just as decisive for advances in fuel cell technology.

What are the largest remaining scientific problems for fuel cells?

Different combinations of electrode and electrolyte materials allow the construction of many different fuel cell types that are distinguished by operating temperatures from room temperature up to about 1000 *C. Specific, as well as general, scientific challenges remain for all types. Two examples include the kinetics of O_2 reduction and the oxidation of carbonaceous fuels. The development of new electrolytes in temperature ranges between about 100 and 500 *C pose further challenges where interdisciplinary work is necessary.

What are the technical challenges that must be solved for a breakthrough in fuel cell technology?

Fuel cell systems must become more robust, simple and inexpensive, without losing the principal advantages of the fuel cell. New materials developments are moving in this direction. The integration between auxiliary systems and fuel cells demands optimization strategies, according to each available fuel. The cold start behavior at low temperatures is unresolved.

Do you foresee the commercial use of fuel cells in other areas before they are applied for transportation?

Whether fuels cells can be used in vehicles depends upon the decision to create a new fuel supply infrastructure. The present discussions of decisionmakers (automobile companies, oil companies, political actors, etc.) turn upon the medium-term options for special hydrocarbons (gasoline) and a long-term option for hydrogen from renewable energy. The storage problem for hydrogen in automobiles must be solved. The decentralized generation of electricity in homes connected to the natural gas network appears possible in a few years, supposing a competitive price is achieved. Small portable applications (e.g. laptops, cameras, etc.) are also being developed, but here too the questions of fuel storage arise (hydrogen v. methanol, safety, etc.)

When will mass-produced fuel cell automobiles be available on the market?

It may be observed today that the market signals of the automobile industry are formulated very carefully. Combustion engines are also being further developed, so that their emissions will hopefully soon no longer be an issue. Comparable user comfort, costs and the infrastructure question will be decisive for the series introduction of fuel cell vehicles. Fuel cells costs (relative to performance) must drop by a factors of 20 to 50 to compete with the internal combustion engine. Various firms indicate today that they expect that in the year 2015 a significant part (20-30%) of their vehicle fleet will be driven by fuel cells. If a rational energy policy promotes renewable energy, then the fuel cell vehicle will receive the customer base that is necessary for a market breakthrough.

IMPRESSUM

ENERGIE-SPIEGEL, or Mirror On Energy, is the newsletter of the GaBE project at PSI. GaBE is the abbreviation for Ganzheitliche Betrachtung von Energiesysteme, which translates as Comprehensive Analysis of Energy Systems. The Energie-Spiegel appears every four months. Contributors to this edition include Drs. S. Biollaz, F. Büchi, Ph. Dietrich, F. Gassmann, R. Kötz, S. Lienin, A. Röder und G. Scherer, alle PSI.

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Energy Systems Analysis at PSI
The GaBE project performs Comprehensive Analysis of Energy Systems. It is a joint project of the Paul Scherrer Institute, Villigen, and the ETH Zürich. Its goal is to analyze present and future energy systems in a comprehensive and detailed way, considering in particular health, environmental and economic criteria. On the basis of Life Cycle Assessment (LCA), energy-economic models, risk analysis, pollution transport models, and finally multi-criteria decision analysis, it is possible to compare different energy scenarios to create a basis for political decision-making.

GaBE works closely with other institutions, including:

- ETH Zürich
- EPF Lausanne
- Massachusetts Institute of Technology, MIT
- University of Tokyo
- European Union, EU
- International Energy Agency, IEA
- Organization for Economic Cooperation and Development, OECD
- United Nations Organization, UNO