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# International overview of hydrogen and fuel cell research ☆

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ABSTRACT

Increasing environmental problems, limited fossil resources and the geopolitical dependence on crude oil are enormous challenges for our societies. According to energy experts from all over the world, fuel cell and hydrogen energy technologies will play an important role in the portfolio for a future energy economy. This is particularly true for the transport sector which is marked today by an extreme dependency on oil. Hydrogen needs to be produced cost-effectively and with zero or near-zero $CO_2$ emissions. Fuel cells, with their high electrical efficiencies and clean exhaust energy conversion, have the potential to produce excellent solutions to the ecological and economic problems provided that their development is pursued in a determined way and that their market launch is prepared.

Based on experiences and results from intensive R&D and demonstration programmes in the last decades, regional, national, European and international efforts are underway to overcome existing bottlenecks through efforts reaching from fundamental research to market introduction instruments. The problems still to be solved are manifold: cost reduction for all components and systems of a hydrogen economy, performance improvements, manufacturing technologies, infrastructure development, international agreements on codes, standards and regulations, and many more.



## 1. Why new energy technologies and why hydrogen and fuel cell technologies?

The battle for oil is in full swing. No country in the world imports and consumes as much oil as the United States. Western Europe's dependency on oil imports is increasing. The booming economies of China and India demand more and more new energy sources and import more and more oil. Japan, with its shortage of raw materials, competes in the race for resources. Russia fears for its reputation as a reliable gas and oil supplier. The Middle East is the world's fuelling station and powder keg at the same time.

The world is scared of climate change. Fighting it has become a top priority of the rich countries and the less developed countries have recognised the problem to be a threat, while the poor countries have different priorities. But nobody has developed a comprehensive approach to addressing the difficulties of climate change.

Since the 1970s, the industrial countries have been developing new energy technologies in both national and international programmes to meet these challenges. They have been taking on a whole portfolio of topics, ranging from nuclear fusion to the energy saving lamp (Fig. 1). This broad basis of energy technologies is needed and a balanced energy mix to ensure that energy supply is secure and compatible with the protection of the environment. A lot of new energy technologies have found their way into the energy market on their own or with government support or regulation. One of the technologies that still need to prove its capability to contribute to the energy market is related to hydrogen and fuel cells. The point here is to develop marketable products.

Finding a place in the energy market also involves competitive advantages, chances for growth and export potentials for the respective country or region. This corresponds to key political goals, a more robust economy, new jobs and more R&D where the markets are particularly favourable for innovations.

Why should hydrogen and fuel cells be part of the portfolio of energy technologies? How can they contribute to a balanced energy mix?

Can hydrogen contribute to balance the energy mix and to ease the dependency on energy imports? Like electricity and heat, hydrogen can be produced from a variety of primary energies. Consequently, if it would be possible to develop a cost effective and environmentally friendly way to produce hydrogen from fossil, renewable and nuclear energy carriers, this would already be one important step forward. If hydrogen could then even be used in the transport sector, this would be a further step in the

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**Fig. 1.** Sustainable development.

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|---|---|---|---|---|---|
| | **DMFC** | **PEMFC** | **PAFC** | **MCFC** | **SOFC** |
| **Electrolyte** | Proton conducting membrane | Proton conducting membrane | Phosphoric acid | Molten carbonate | Ceramic |
| **Temperature Range** (°C) | < 100 | < 100 | ca. 200 | ca. 650 | 800-1000 |
| **Fuel** | methanol | hydrogen | hydrogen | Natural gas, coal gas, biogas | Natural gas, coal gas, biogas |
| **Power Range** | W / kW | W / kW | kW | kW / MW | kW / MW |
| **Application (examples)** | Vehicles, portables | Vehicles, house energy, CHP | CHP | Power plants | House energy, Power plants |

**DMFC**
Direct Methanol FC
**PEMFC**
Proton Exchange Membrane FC
**PAFC**
Phosphor Acid FC
**MCFC**
Molten Carbonate FC
**SOFC**
Solid Oxide FC

**Fig. 2.** Fuel cell types under development.

right direction and the dependency on oil would decrease. The precondition is, however, the availability of marketable technologies for the production, distribution and use of hydrogen.

There are several technologies to use hydrogen: the combustion engine, turbines and some fuel cell types (Fig. 2). What advantages does the fuel cell have compared to competing technologies in the application fields of transport, residential energy and industrial use for electricity and heat production? Regarding road transport, vehicles with a fuel cell, an electric drive train and a hydrogen tank are being developed today. The benefit over vehicles run by diesel or petrol for combustion engines consists of higher efficiencies and zero-emissions. With the exception of $NO_x$, this is also true for combustion engines running on hydrogen.

Fuel cells in the stationary sector, i.e. for residential energy and for industrial application, will use different fuels and convert them into hydrogen in situ as long as there is no hydrogen infrastructure in place. In the case of low temperature fuel cells a reformer is used that converts natural gas into hydrogen and $CO_2$, for example. High temperature fuel cells can convert the fuel, e.g. biogas, internally. Once again, the advantages of such stationary fuel cell systems compared to the competing condensing boilers or conventional heat and power plants consist of higher efficiencies and reduced emissions, but also of a contribution to decentralised electricity production and to stability of the electric grid. If the hydrogen used in stationary applications is produced without $CO_2$ emissions, this is another contribution to environmental compatibility. What is needed therefore are reliable, cost-effective and environmentally friendly products! These products can indeed include fuel cells, but the consumer is not expected to purchase them just because of the fuel cell, but because the product utterly satisfies his needs.

In order to help the hydrogen economy as well as other "clean" technologies to penetrate the market, political actions need to be taken and, if possible, agreed upon at the international level, for the reduction of $CO_2$ emissions and decreasing oil imports is a societal and political task. Potential policy measures include $CO_2$ emission thresholds, incentives for energy savings and a global $CO_2$ emission trading scheme. In Europe, the trade with $CO_2$ emission credits is growing rapidly. The countries involved submitted their allocation plans for the 2008–2012 period to the European Commission in June 2006 already. Germany has assumed a leading role and is the country that has pressed ahead the most with planning for the second trading period.

As long as the advantages of hydrogen as a secondary energy carrier and of related technologies consist of benefits to the