

Stationary Fuel Cells

Fuel cells for distributed power: benefits, barriers and perspectives

Fuel cells are often portrayed as the answer to the world's pressing need for clean, efficient power. They are also seen as a key component in a future »hydrogen economy« that will substantially reduce or eliminate pollutant and greenhouse gas emissions associated with current power generation and transport. However, questions about the technology still remain: to what degree are the expectations surrounding fuel cells realistic and can they deliver what they promise?



- ▶ **The following report summary**, which focuses on stationary fuel cells, addresses these questions. Stationary fuel cells are the type of fuel cells used in buildings or power generation parks. They will most likely enter the market before automotive fuel cells for technical and cost reasons.

What are fuel cells?

A fuel cell combines hydrogen with oxygen (from air) in a chemical reaction, producing water, electricity and heat. Fuel cells do not “burn” the fuel, the conversion takes place electrochemically without combustion. Fuelled with pure hydrogen, they produce zero emissions of pollutant and greenhouse gases at the location of the power plant. Where hydrocarbon fuels such as natural gas are used a “fuel reformer” (or “fuel processor”) is required to extract the hydrogen. In this case the production of hydrogen is connected to greenhouse gas emissions and - very low - emissions of pollutants. However, the production and supply of the fuel also causes emissions. Therefore the future role of fuel cells and their environmental benefits have to be assessed through life-cycle and energy systems analyses.

Where does the fuel come from?

Hydrogen, the most common chemical element, is not naturally available in useful quantities in its

pure form. The process of separating hydrogen from chemical compounds like water, natural gas and other carriers always requires energy. The method used to produce this energy determines the environmental impact and economic prospects of power generation in fuel cells.

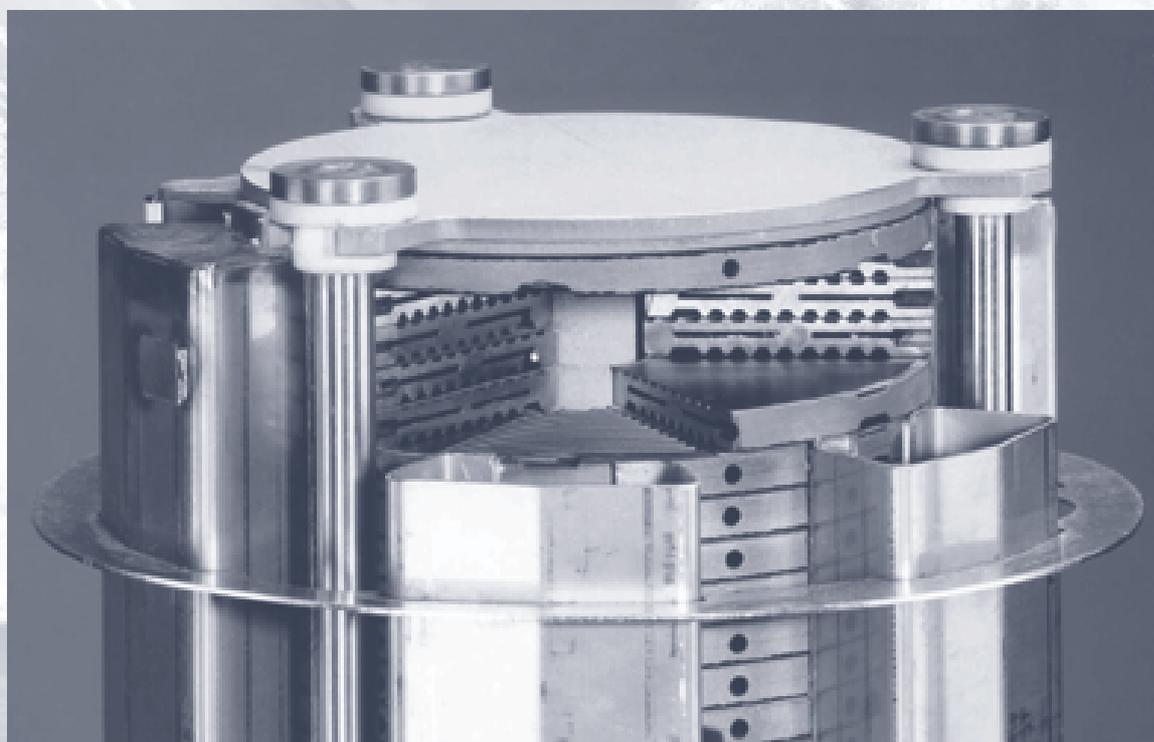
The cleanest and most environmentally friendly way to produce hydrogen is through renewable energy. Electricity from wind and solar power can be used to produce hydrogen by electrolysis as one component of the ultimate long-term vision of a fully renewable based energy system. Unfortunately the conversion of renewable electricity into hydrogen and then back into electricity is associated with significant energy losses and additional costs.

For stationary fuel cell applications, this solar hydrogen path makes sense only with a high share of renewables in the electricity generation system, because in these systems, a storage medium for electricity generated from intermittent renewable sources such as wind or solar power is required. In large electricity grids, stationary fuel cells run with solar hydrogen are thus a longterm option whereas island and remote applications could offer an early niche market.

Fuel cells can also operate on biomass-derived fuels. In bio fuel applications, all combined heat and power (CHP) technologies have very low

A fuel cell stack converts chemical energy into electricity and heat - without an open flame.

Photo: Sulzer Hexis





The Solid Oxide Fuel Cell consists of many of these ceramic tubes. Each of these tubes will deliver 200 Watt.

Photo: Siemens Westinghouse

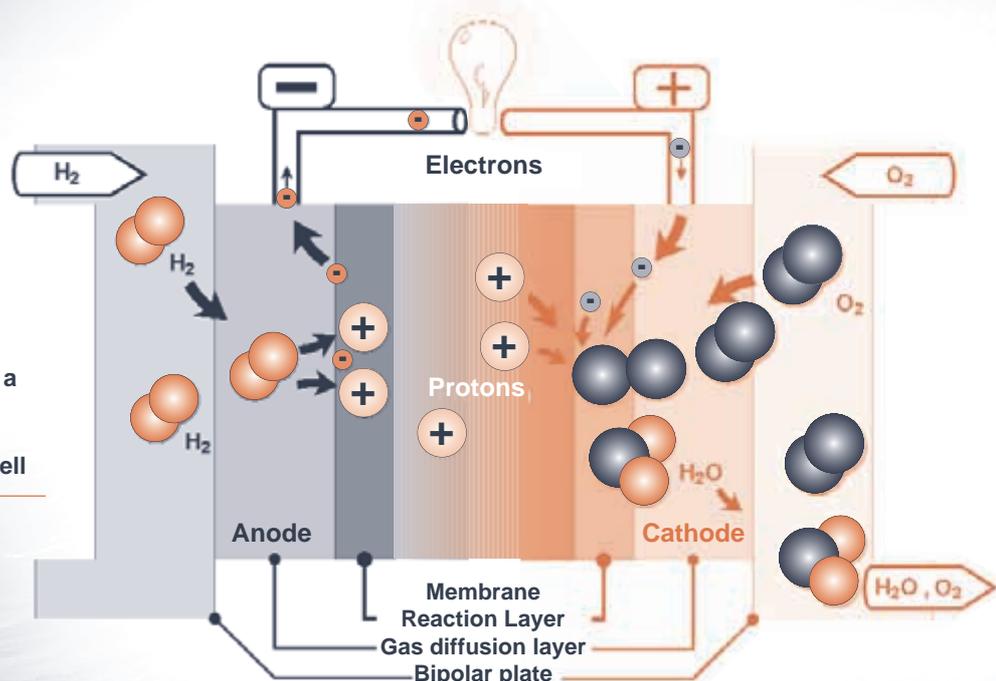
greenhouse gas (GHG) emissions. The advantage that fuel cells deliver in this application is the more efficient use of limited – and often costly – biomass resources. Due to the high capital cost and the technically challenging integration of still premature components like gasification, gas processing and fuel cells, bio-based fuel cells are a long-term option for 2020 and beyond. Biogas produced from manure or sewage gas could, however, provide an attractive early market.

Fossil fuels and nuclear power can also be used to produce hydrogen. However, fossil fuels generate greenhouse gas emissions and nuclear power causes many problems such as waste disposal and safety risks. Due to extremely high capital cost, low electrical efficiencies and prevailing technical problems, the use of coal gas in fuel cells with subsequent CO₂ storage is not seen as a successful climate strategy for the next decades. In addition,

carbon disposal remains an open issue, as the safe storage of CO₂ cannot be guaranteed presently.

The cleanest conventional hydrocarbon fuel to be used in fuel cells is natural gas. It has the lowest greenhouse gas emissions per energy unit of all fossil fuels. While natural gas based CHP is not considered a sustainable energy source as such, it does represent an efficient way of economising the inevitable fossil energy input during a transition period to a renewable energy supply system. Moreover, natural gas can bridge the gap between our fossil system and a future system because it offers the possibility to gradually switch to renewably produced hydrogen (or biogas/synthesis gas). This can then be fed into the pipeline distribution system and ultimately replace natural gas as a fuel. Therefore this report focuses on the environmental benefits of natural gas powered fuel cells in comparison with conventional technologies. ▶

Basic principle of a fuel cell: example of a Polymer Electrolyte Fuel Cell



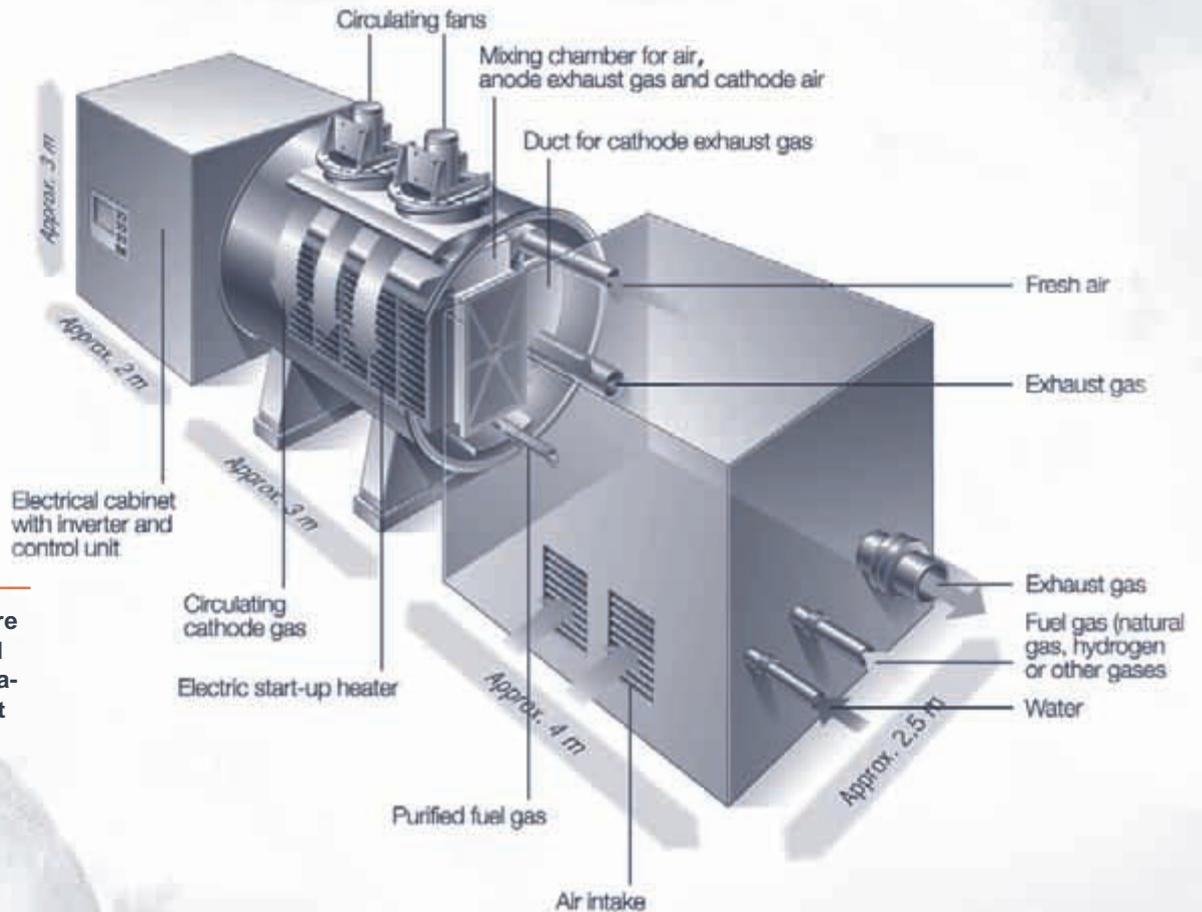


► **Can fuel cells help to reduce CO₂ and pollutant emissions?**

Fuel cells will enter the market too late to make a significant contribution to the Kyoto commitments for 2008/2012. In the mid-to-long-term, however, stationary fuel cells have a high potential for environmentally friendly energy conversion: they offer high electrical efficiencies and extremely low (fuel: hydrocarbon) or even zero (fuel: hydrogen) pollutant emissions. The potentially high electrical efficiency of fuel cell power plants is one of the major advantages of these systems. For each power range, fuel cells will offer higher efficiencies than the conventional competitors.

For instance, compared to separate electricity production in central power stations with a coal biased electricity mix (such as the German electricity mix) or even compared to a lignite power plant, GHG reductions above 50% can be achieved with fuel cells powered by natural gas. In a life cycle assessment, each kWh of electricity produced by a

fuel cell will reduce the related CO₂ emissions by at least 40% compared to the existing fossil power generation in the current 15 countries of the European Union (EU-15) and 20 to 30% compared to modern separate production (modern gas plants and boilers). However, compared to competing CHP technologies such as Stirling and reciprocating engines or gas turbines, only low GHG reductions, if any, can be achieved. This is mainly due to lower thermal efficiencies of fuel cells and it underlines the necessity to optimise their total/thermal efficiency. Fuel cells powered by renewable hydrogen will reduce emissions almost 100% compared to fossil options.



This is how a future power plant based on Molten Carbonate Fuel Cells might look like.

Source: mtu Friedrichshafen



The transition from fossil to renewable energy carriers is urgent. What role will the fuel cell play?

In order to estimate the total potential emission reductions achievable in the EU-15 until 2020 this report adopts a market introduction scenario of the United Nations Environment Programme (UNEP). The UNEP projections envisage some 27 GW of installed fuel cell capacity in OECD Europe for the year 2020, which represents an optimistic starting point for the analysis.

Under the assumption that fuel cells displace the average EU electricity and heat mix (excluding nuclear and hydropower), the estimated GHG reduction amounts to 55.4 Mt/a CO₂ equivalents, which equals 1.3 % of the European GHG emissions in 1990, or 22.3 Mt/a CO₂ eq., if the electricity mix includes nuclear and hydropower.

These reductions are the result of four separate mechanisms: the reduction due to a fuel shift (oil and coal to gas), an efficiency increase from average to advanced power plants and heating systems, an efficiency increase from separate to combined production, and an efficiency increase from modern CHP to fuel cells. The first three would also be realised based on conventional CHP so that only the last effect can be fully attributed to fuel cell technology. If one considers the coming need to replace power generation capacity in Europe, a comparison of fuel cells to modern separate production (i.e. a natural gas combined cycle plant and a gas condensing boiler) is required. In this comparison a GHG reduction of 14 Mt/a CO₂ eq. would be achieved.

Under the assumption that CHP is developing quickly we must also compare fuel cells with competing CHP technologies, e.g. the reciprocating engine in district heating CHP or the gas turbine in industrial CHP applications. In this instance, and using the UNEP scenario assumption, a GHG reduction in the order of 5 Mt/a CO₂ eq. would be achieved.

In addition to climate change mitigation, fuel cells offer great advantages with respect to environmental impacts that are caused by criteria pollutants, such as acidification (mainly caused by NO_x and SO₂), eutrophication, summer smog or carcinogenic substances. Compared to these impacts, fuel cell power plants yield reductions of pollutants ranging from 40% (summer smog) to almost 90% (eutrophication) depending on the baseline technologies. The EU 15's emissions situation differs from the EU accession countries. Because pollutant emission levels are much higher in central and eastern Europe, the introduction of fuel cells would lower emission levels significantly.

What are other benefits?

Fuel cells offer several technical advantages, such as modularity, good partial load characteristics, dynamic response or high heat levels which are favourable for industrial and cooling applications. In addition, advantages that are common to all cogeneration technologies, such as reduced transmission losses, reduction of required grid capacity, etc. can be made accessible. Moreover, fuel cells might open up a completely new market segment: that of domestic CHP (MicroCHP) with small-scale systems below 10 kW, which would provide heat and power for single and multi-family houses. Considering the large replacement market for gas heating boilers, a mass market for MicroCHP can be expected. In fact, most major European heating systems manufacturers are currently active in developing domestic combined heat and power systems.

The key to the market success of fuel cell heating systems as seen as providing a "one-stop solution" complete energy service package to the customer. In line with this emerging market for new

- ▶ energy services (micro-contracting), fuel cells offer new business opportunities, e.g. for utilities that aim to provide a broad range of supply services (multi-utility approach). In this context, fuel cells provide gas utilities with an opportunity to increase sales and compensate for a decreasing need for space heating – and thus domestic gas demand.

New applications might arise from grid-related operation of fuel cells that build on the dynamic performance of electricity generation. Sophisticated concepts such as the “virtual power plant” aim at the interconnection of a large number of fuel cells via communication technologies. This would enable central control and management of the decentralised generating units, e.g. for the purpose of load levelling of intermittent power production. However, considerable technological obstacles need to be overcome.

What are the barriers to a broad market introduction of fuel cells?

As fuel cells have to succeed in an already competitive market, cost is seen as the major market

entry barrier. Stationary fuel cells are still between 2.5 to 20 times more expensive than competing technologies, with the balance of plant (periphery) being responsible for a large share of total capital cost. The challenge for fuel cell development is to reconcile the often conflicting requirements of cost reduction and performance improvement. For this reason, there is still considerable uncertainty with respect to the size and time scale of the market entry of stationary fuel cells. Today’s investments in CHP should not be postponed, however, in order to wait for fuel cells. Conventional technologies should instead be used to establish CHP infrastructures that can be updated later with second generation fuel cell systems.

Traditional players in the heat market such as installation contractors play a decisive role in the dissemination of new heating technologies. They will need to be fully prepared in time through information dissemination and professional training in order for them to play an active role in the promotion of fuel cells CHP systems.

Certain barriers that may hinder a wide spread utilisation of stationary fuel cells apply to all CHP

From large cogeneration systems to domestic power plants: stationary fuel cells can be designed for various applications.

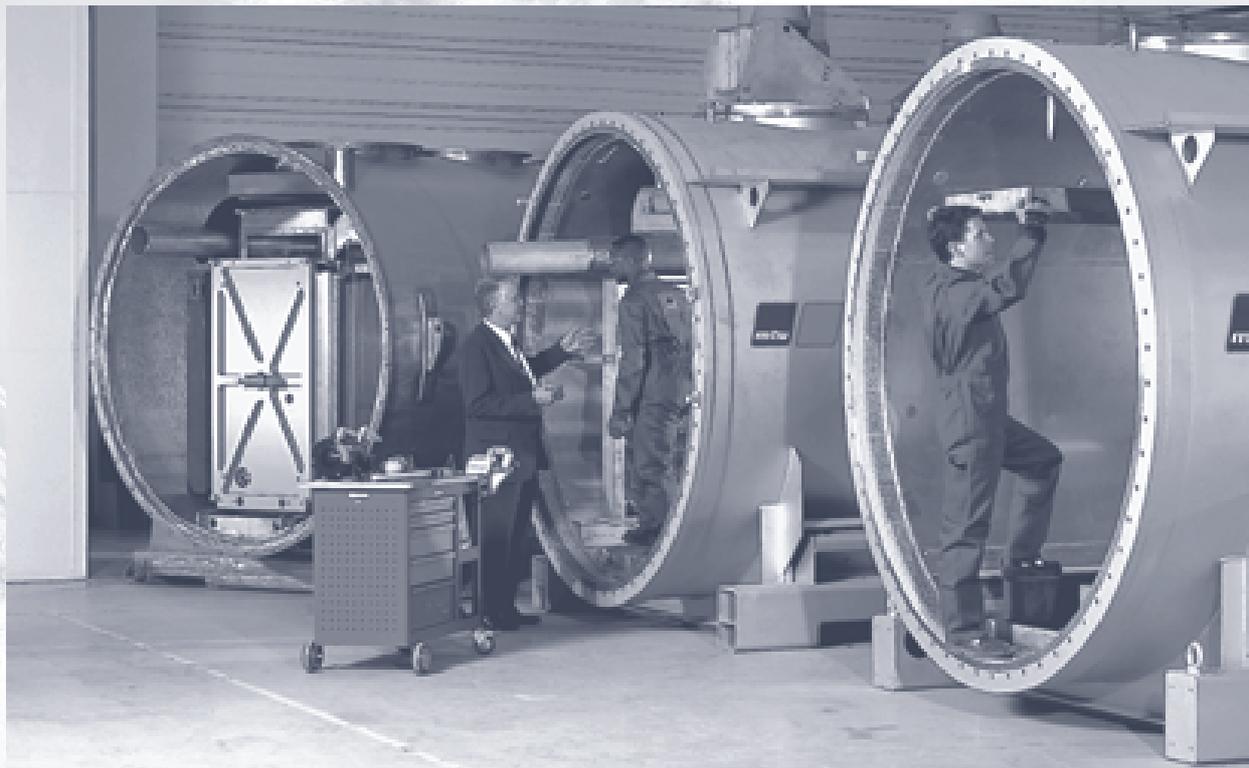


Photo: mtu Friedrichshafen

applications and are not specific to fuel cells. Among these, easy grid connection is a key to market success of fuel cells. Today, however, current distribution grids are not designed for large-scale integration of distributed power generators. All of the envisaged problems can be solved from a technical point of view but institutional arrangements for a fair and discrimination-free allocation of costs for upgrading, investment and management of grids are still lacking.

In this context, the interconnection of mid to small scale CHP plants to the grid is often hindered by restrictive conditions and complicated procedures. Problems arise with regard to connection charges, determination of the point of connection, safety and liability issues. Most importantly, a standardised technical interface needs to be established as do non-discriminatory rules for the allocation of connection costs that take into account possible positive effects of distributed generation on grid investments and transmission and distribution losses.

Regulatory regimes, however, still do not provide sufficient incentives for grid operators to connect

distributed generation plants, and conditions differ between member states, regions and utilities. Often, connection charges lack transparency and appear to exceed factual costs of the grid operator. Moreover, the administrative handling of CHP projects is delayed due to low priority for the utility.

For this reason, the introduction of distributed generation is strongly linked with the controversial debate on the unbundling of power generation and network operation and the regulation of systems operators in order to assure a neutral stance towards independent CHP plants.

Closely related to the aspect of interconnection, new traders for renewable and CHP electricity can suffer from non-transparent and excessively high connection fees and costs for stand-by and back-up power. Whereas grid use fees are of less relevance for a single project under a priority dispatch scheme, the marketing of "green power" is strongly affected. This limits the possibility to sell CHP electricity at premium prices to specific market segments.

How to overcome the barriers?

There is still uncertainty surrounding the long-term development of the energy policy framework. This hinders strategic investments into distributed generation. For this reason, long-term target setting by the EU and member states in terms of distributed generation integration would increase the reliability of market projections and investor confidence.

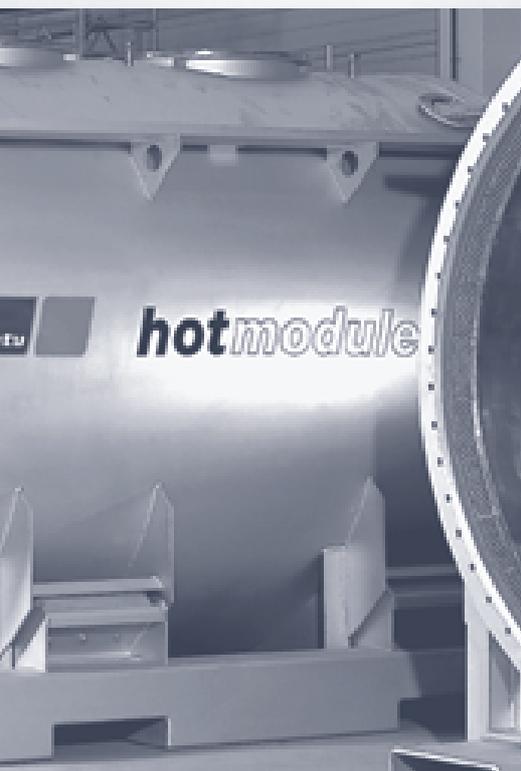
In parallel to the technical progress, therefore, a co-evolution of socio-economic and institutional prerequisites has to take place to pave the way for a smooth market introduction.

Especially during the first phases of market introduction, additional incentives will be needed to close the cost gap with competing technology. Energy policy can provide direct incentives for early adopters, e.g. as investment subsidies, grants, tax deduction, etc.; stabilise market prospects for distributed power generation by enhancing market entries and competition together with a removal of barriers; and create general incentives for efficient and environmentally benign use of energy, e.g. energy and/or GHG taxes, emissions trading, air quality standards, noise pollution regulation, etc. ▶



Photo: Vaillant

Small domestic fuel cell systems could turn residential homes into a power plant - but only if the right market conditions support cogeneration.



► **Conclusion**

Fuel cells are a potentially important option among others that may contribute to increased economic efficiency and environmental performance of Europe's energy system. It is therefore critical that fuel cell policies be integrated into an overall guiding strategy for the sustainable development of European energy systems which aims for efficient use of energy and the expansion of renewable energy sources.

The transition from a fossil based system and its fully developed infrastructure to a "renewable hydrogen system" as an ultimate goal will take a long time. During the transition, research and development as well as deployment in niche markets and lead applications can pave the road.

It is important to make clear that these demonstration projects do not substitute, but supplement the development of rational use of energy and renewable energy carriers. The political and economic decisions for tomorrow's power generation must support the full range of climate friendly and sustainable technologies in order to surmount the "fossil fuel age". With natural gas as a bridging fuel, fuel cells will help to realise the renewable energy economy and a carbon free power sector. ■

► **Full Report can be downloaded at:
www.panda.org/epo**

Fuel cells for distributed power: benefits, barriers and perspectives. By Dr. Martin Pehnt (ifeu, Heidelberg) and Dr. Stefan Ramesohl (Wuppertal Institute), June 2003, commissioned by WWF in co-operation with Fuel Cell Europe.



Energy for industry: fuel cells can also provide industrial customers with electricity and heat.

Photo: mtu Friedrichshafen



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