FUEL CELL TECHNOLOGY - READY FOR TAKE-OFF?

Technologie de la pile à combustible - Prête a' décoller ?

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1 Introduction

Introduction

Beside some other basic needs, the supply with electrical and thermal energy is of high priority worldwide. Ecology policy on the one hand and the global liberalisation of the energy markets on the other hand follow different aims.

With regard to the impending climate change highly efficient energy production and environment-friendly fuels may contribute to solving this problem. Apart from the pressure to reduce the carbon dioxide emissions, the limitations for classical pollutants, such as carbon monoxide and nitrogen oxide, are strict and will be even stricter in the future.

In contrast to this target, a liberalised energy market demands minimal energy price. Only a tightly planned cost management guarantees success for a company. Therefore only a minimum of legal requirements will be met.

Nevertheless one tries to follow both directions. The technical and economic limits of the so called standard technologies are well known. But some alternative technologies are already in the course of development. One of these "new" developments is the fuel cell technology.

Intensive research and development programs are carried out to realize the potential of this technology worldwide. It is planned to use the fuel cell technology for a lot of different purposes.

AUSTRIA FERNGAS is a small company trying to promote this new clean technology. Up to now the company has been actively involved in two R&D projects where pre-commercial fuel cell power plants were tested and their performance was analysed. A further project is in preparation.

2 Overview on the fuel cell technology

Résumé de la technologie en matière de /a pile à combustible

In 1839 the Welsh lawyer and physicist Sir William Grove identified the principle of the fuel cell. He constructed the first laboratory cell that worked. It was realized by the reversal of the water electrolysis. At this time hardly anyone knew how to utilize this technique. After the invention of the dynamo (Werner von Siemens), the fuel cell technology fell into oblivion for nearly a whole century.

The successful development of fuel cell systems for space missions in the sixties and the upcoming discussion about pollutants and a possible climate change led to increased research and development efforts in this field.

The theory of a fuel cell is relatively simple. Only combine hydrogen, oxygen and the result is electricity, heat and -very important - no pollutants (except carbon dioxide).

Conventional power plants have certain limits as to their electrical efficiency in production (Carnot cycle limitation). Fuel cells offer the potential to produce electricity at a much higher rate of efficiency.

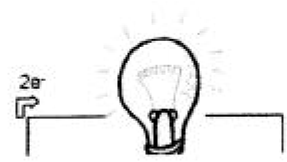

Figure 1: Principle of a fuel cell
Principes de fonctionnement de à combustible

In Figure 1 the principle of a fuel cell is shown. For a steady process it is necessary to continuously feed some fuel (e.g. hydrogen or hydrogen rich gas) and some oxidant (e.g. oxygen or air).

One single element consists of an anode, a cathode, an electrolyte, a bipolar plate and a cooling element (Figure II). Some of these single cells are connected in series to obtain a useable voltage. Such a package of cells is called a cell stack. Different kinds of concepts are being developed: planar, tubular and a mixture of these two technologies.

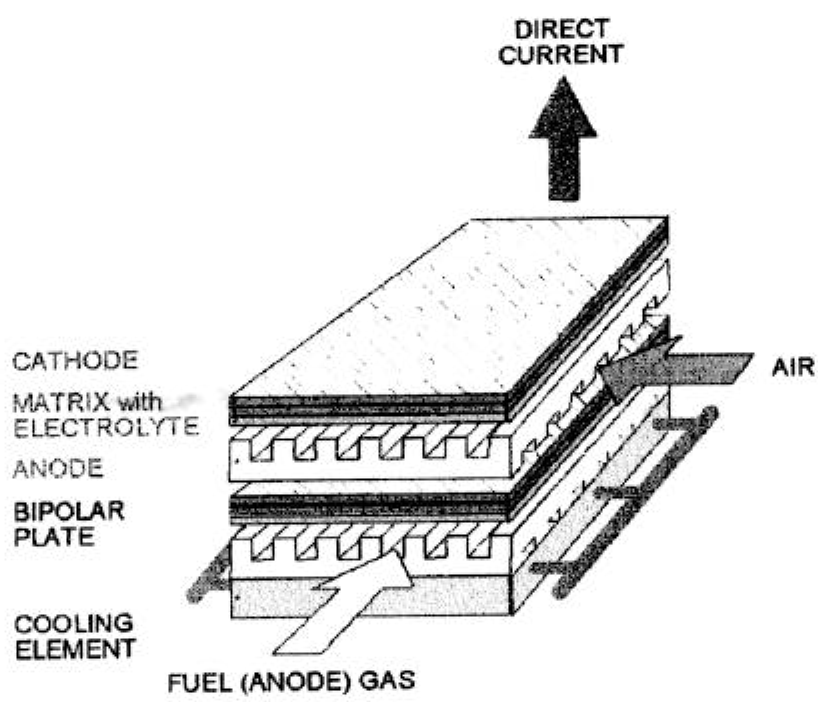

Figure II: Example for a planar cell stack
Exemple d'une batterie planar

There are some possibilities to distinguish between the different fuel cell technologies. The most common method is to classify the technologies by the operation temperatures used (Table I).

	PEFC	AFC	PAFC	MCFC	SOFC
Electrolyte	Ion exchange membrane	Caustic potash solution	Immobilized liquid phosphoric acid	Immobilized liquid molten carbonate	Ceramic
Operating temperature	80°C	120-250°C	200°C	650°C	(600) 800-1000°C
Charge carrier	H^+	OH^-	H^+	$CO_3^=$	$O^=$
Reforming (methane)	External	External	External	Internal	Internal
Material	Carbon based	Asbestos	Graphite based	Stainless steel	Ceramic
Catalyst	Platinum	Various	Platinum	Nickel	Perovskites
Cooling	Independent cooling medium and process gas	Independent cooling medium and process gas	Independent cooling medium and process gas	Internal Reforming and process gas	Internal Reforming and process gas

Table I: Summary of fuel cell types
Sommaire des différents types de pile à combustible

The maturity of these different types varies a lot. Below a very short description about the status of the technologies is given.

- **PEFC - Polymer Electrolyte Fuel Cell:** This technology has been used in space missions for a long time. It is the preferred type for usage in vehicles. The car manufacturing industry is developing fuel cell driven automobiles. The very optimistic target is to present a commercially viable product in 2004. Recently a lot of companies have been working on small co-generation units for households. First field demonstration units have been tested. Moreover, a multihundred-kW co-generation plant is under development.

  Some advantages and disadvantages:
  - No corrosion problems (+)
  - High current densities (+)
  - Short start-up time (+)
  - Low temperature level of the heat (-)
  - Carbon monoxide sensitivity (-)

- **AFC - Alkaline Fuel Cell:** This kind of fuel cell was used in the Apollo missions. Because of its complex technical construction this technology is not of very high interest at the moment.

  Some advantages and disadvantages:
  - Very high stack efficiency (+)
  - Use of cheap materials is possible (+)
  - High carbon dioxide sensitivity (-)
  - Complex management with mobile electrolytes (-)

- **PAFC - Phosphoric Acid Fuel Cell:** The PAFC is the most mature cell-type. Several hundred pre-commercial units in the capacity range from 50 kW to 11 MW have been in field tests since the late nineteen-eighties. Some units had a life-time of more than 40,000 hours (at reduced power). Recently the PEFC and the high-temperature fuel cells have aroused more interest than the phosphoric acid technology.

  Some advantages and disadvantages:
  - Proven technology (+)
  - Lower carbon monoxide sensitivity than the PEFC (+)
  - Precious metals are needed as catalysts (-)
  - Maximum potential has already been reached (-)

- **MCFC - Molten Carbonate Fuel Cell:** After a development phase in the laboratories in the nineteen-nineties a few demonstration units in the capacity range from 250 kW to 2 MW were put into operation. In the opinion of some experts the scaling-up was too early for the technology. The MCFC is about 5 to 10 years behind the PAFC-technology. At the moment the life time of the cell stack is not satisfactory.

Some advantages and disadvantages:

- Internal reforming is possible (+)
- Precious metals are not obligatory (+)
- Carbon monoxide can be used as a fuel (+)
- Material (corrosion) problems (-)
- Carbon dioxide re-circulation is needed (-)

- **SOFC - Solid Oxide Fuel Cell:** Research and development programs have existed for more than forty years. Nevertheless, this technology lags behind the other types. In contrast to its competitors different stack concepts (planar, tubular) have been developed. At the moment the first units in the range of 100 kW are in the test phase. The first combined-cycle-plant (fuel cell + gas turbine) is in an early test phase too.

  Some advantages and disadvantages:

  - Internal reforming is possible (+)
  - Precious metals are not obligatory (+)
  - Carbon monoxide can be used as a fuel (+)
  - Material (sealing) problems (-)

3 Operating experiences
Expériences acquises au cours du fonctionnement

The Austrian PC25-A
La PC25-A autrichienne

Since 1992 AUSTRIA FERNGAS (AFG) has been actively involved in the fuel cell technology. AFG purchased a 200 kW PAFC power plant from ONSI, a subsidiary of the UTC-conglomerate. This unit has been tested at the Vienna Public Utilities for 1½ years. In 1994 the unit was transferred to a District Heating Plant of EVN in Lower Austria (Figure III). The plant was operated until 1997.

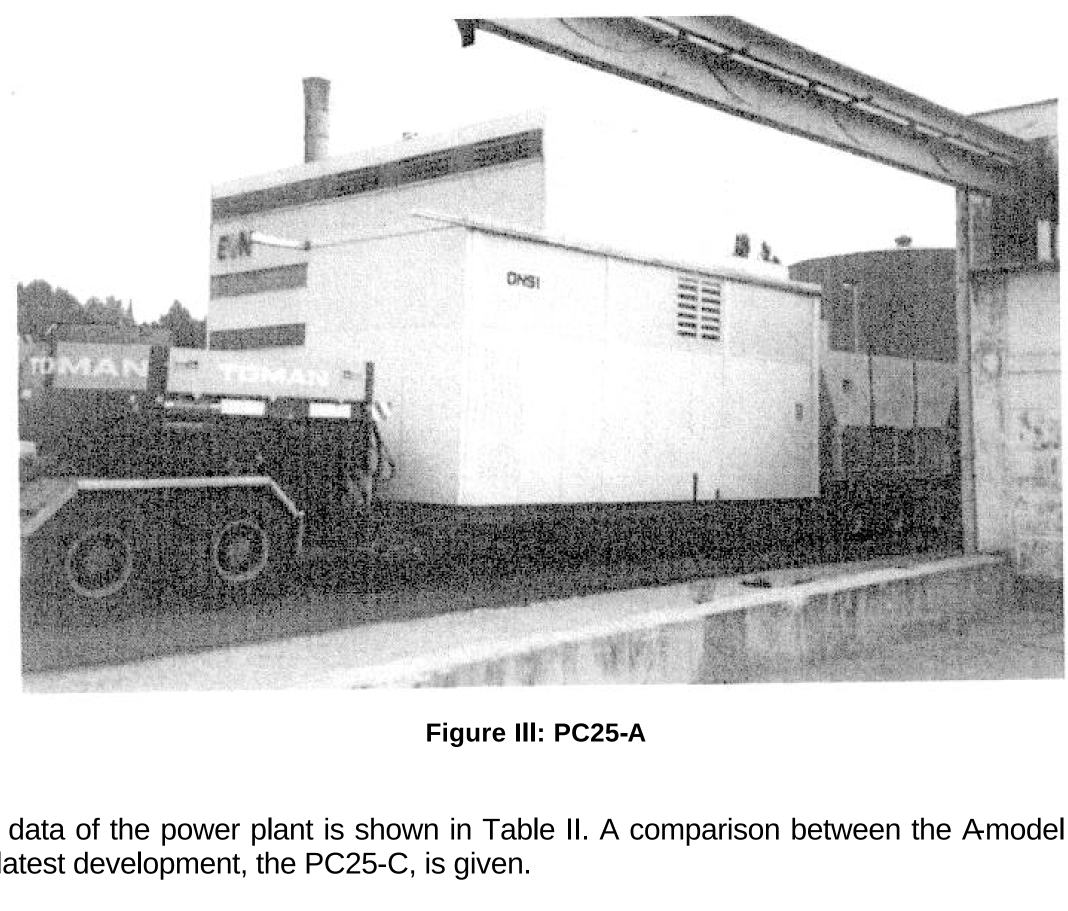

Figure III: PC25-A

The data of the power plant is shown in Table II. A comparison between the A-model and the latest development, the PC25-C, is given.

Manufacturer's information	PC25-C	PC25-A
Power	200kW	200kW
Voltage - frequency	400V - 50 Hz	400V - 50 Hz
Operation mode	Grid connected, grid independent optional	Grid connected and independent
El.efficiency (LHV)	40%	40%
Heat	215-220kW @ 60°/40°C	215-220kW @ 60°/40°C
Therm. efficiency (LHV)	43-44%	43-44%
Single cells	256	319
Stack voltage	167V	210V
Stack current	1360A	1070A
Dimensions (l x w x h)	5,5 x 3 x 3m	7,3 x 3,1 x 3,5m
Mass	18t	27t
Dimensions cooling module (l x w x h)	4,2 x 1,2 x 1,2 m	3,9 x 1,5 x 2,1 m
Mass cooling module	0,7t	2,2t
Sound level (without measure)	60dBA in 10m	60dBA in 10m

Table II: Comparison PC25-A and PC25-C
Comparaison entre la PC 25-A et la PC25-C

The ONSI PC25 is not only a power plant, it is also a small chemical facility. It includes a complex gas-treatment-system for desulphurization, besides a reformer to convert the methane into hydrogen and CO which, in a second step, is converted to H_2 and CO_2. The main components are the reformer, the fuel cell stack, the inverter and the control system.

After about 22,000 operating hours the cell stack showed a good reliability. None of the shut-downs was caused by a failure of the cell stack.

In principle the fuel-cell-plant is a fully automatically controlled unit. But in case of problems highly qualified personnel is required because it is a new technology and the distance to the manufacturer and its expertise is long.

The MTBF (mean time between failures) is about 1,450 hours. This qualifies the PC25 as a reliable plant. On the other hand the fault detection is a very time-consuming process that causes long shutdown periods.

The plant produces the promised output data. The quality of the produced electricity is within the prescribed values. Operation in grid-connected and grid-independent mode has been tested and both work without any problems.

The problems observed have mainly been caused by faults of auxiliary units, such as pumps, and by corrosion and erosion in some pipes.

The start-up procedure should be a fully automatic process. After two years of operation the reformer start-up became a very tricky matter and several start-up sequences were necessary to start the power plant successfully.

Under normal conditions the start-up time is approximately 4 to 5 hours, which means that the PC25 is suitable for base load operation only. Besides, continuous operation is required to keep the aging process within limits. The average decrease of the cell stack voltage was measured at approximately 0,8%/1,000h. During the same period the electric efficiency dropped from 41% to less than 35% at nominal power.

The great advantage of the fuel cell technology is its low output-level of the classical pollutants CO and NO_x. A comparison with gas engines of the same capacity range shows that the CO and NO_x-emissions of the environment-friendly fuel cell are about 1 to 2% of the emissions of the gas engine. Even compared to large power stations the fuel cell emissions are 10 to 20 times lower.

The Nuremberg PC25-C

La PC25-C Nuremberg

The project was initiated by the Studiengesellschaft Brennstoffzellen e.V. Members of this organization are mainly energy suppliers in the south of Germany. AUSTRIA FERNGAS took the opportunity to take part in this project. The current version of the PC25 technology, the model C, is combined with an absorption heat pump to improve the thermal efficiency. The electricity and heat produced is used for the partial supply of some hundred flats and commercial enterprises.

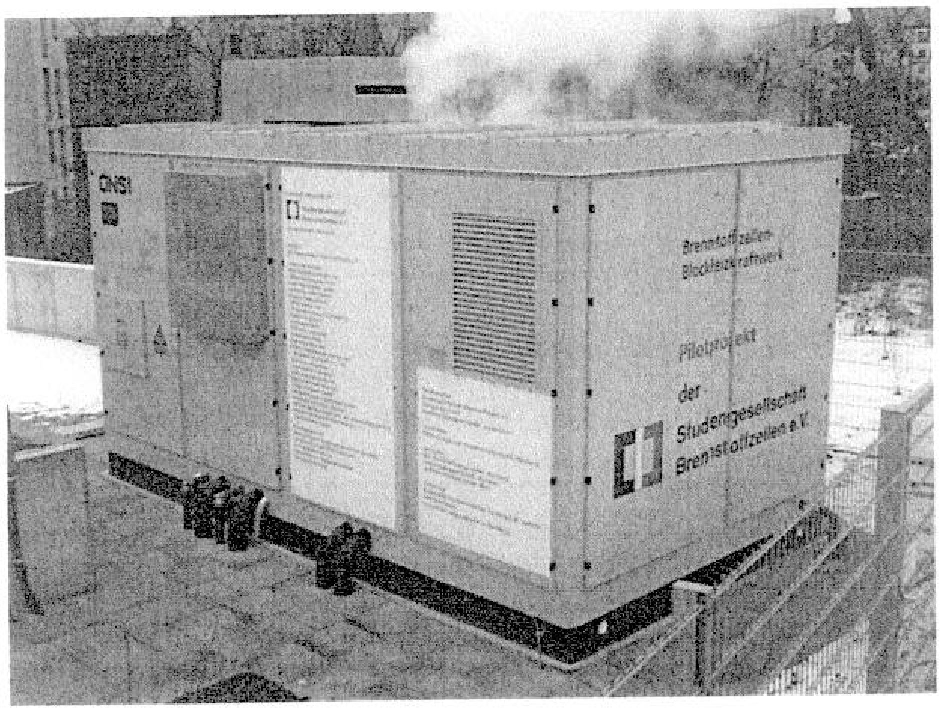

Figure IV: PC25-C in Nuremberg
La PC 25-C à Nuremberg

The amount of utilizable heat depends strongly on the existing temperature in the heating grid. In the selected district heating grid the temperatures are 70/55°C. In case of a standard installation of the fuel cell plant only 100 kW of the available heat can be used. The remaining 115 kW are blown into the air by means of the cooling module.

In Nuremberg the PC25-C is combined with a heat pump. Therefore about 180 kW of the heat can be used for the district heating grid. The installed PC25-C offers the possibility to extract the thermal energy at two different temperature levels. The "high temperature heat" at 120°C/100°C is the driving force for the heat pump. The heat pump lifts the "low temperature heat (60°C/40°C) to the temperature of the heating grid and improves the thermal efficiency.

The operation phase began very successfully in late 1997. In the first year of operation the plant reached an availability of more than 90%. The average electrical efficiency of the fuel cell plant was more than 39% in 1998. The total efficiency of the system was about 70% in this period. After 3 years of operation the average availability dropped down to about 75%. The decreased availability was mainly caused by problems with thermo-couples needed for the temperature measurement in the reformer. This and other minor technical problems led to extended periods without operation. Checking the faults took up a lot of time and reduced the availability dramatically.

The total investment costs were approximately 1 Mio. € including the costs for the alteration of a building and an extensive measurement program. Power production with a fuel cell is very expensive. Even if the investment costs are neglected, it is most unlikely to operate a fuel cell plant economically at the moment.

4 Benefits and obstacles
Avantages et obstacles rencontrés

The technical benefits of the fuel cell technology are easy to describe:

- Potential to reach a high electrical efficiency - no limitation by the camot factor.

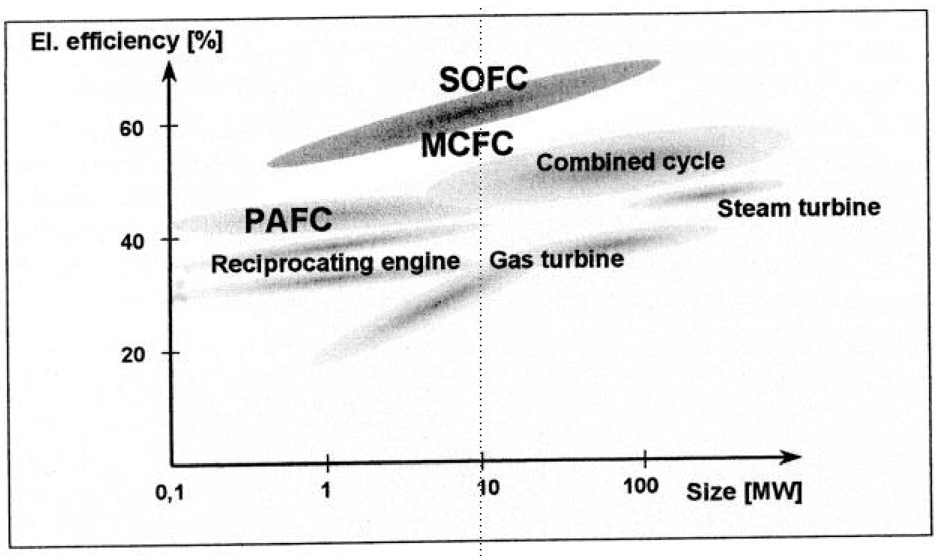

Figure V: Electrical efficiency of different technologies
Rendement électrique des différentes technologies

- Modularity: The efficiency is nearly independent of the power-size of the plant.
- Flexibility: Constant efficiency in partial load operation (of a wide range).
- Minimal Emissions (Figure VI)

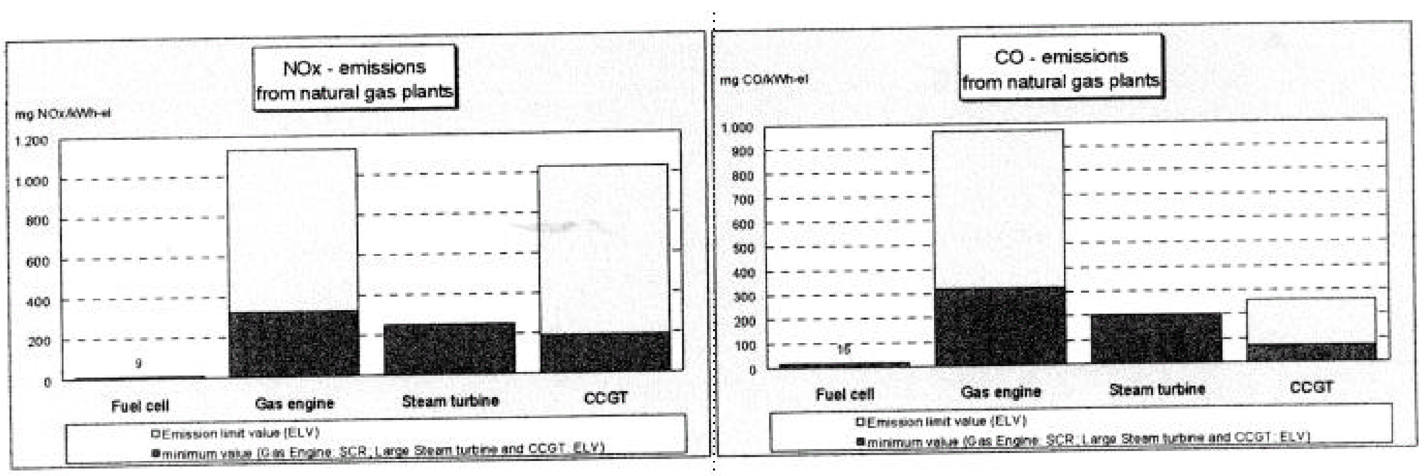

Figure VI: Emissions from natural gas plants vs. fuel cells
Emissions des stations de gaz naturel comparées à celles des piles à combustible

Apart from these very attractive advantages there are some technical reasons and particular economical arguments against the fuel cell technology:

- High investment costs
  - Low-volume production
  - Expensive high-tech materials (e.g. precious metals)

    - Very complex equipment (in particular for the fuel-treatment system)
- Long-term reliability and stability of the electrochemical components
    - Corrosion and sealing problems in some high-temperature types
    - Decreasing efficiency due to irreversible ageing-processes
- System-inherent disadvantages for some applications
    - Start-up time of a few hours (mainly a problem of the necessary reformer)
    - Temperature-level of the heat from the low-temperature fuel cells

It seems that there are no principal obstacles which prevent a successful entry of the fuel cell technology into the market. On the other hand, it has not been possible to commercialise this technology in the past decades. Despite public subsidies and long-range demonstration projects the economic targets have not been reached. But the progress shown gives confidence that the fuel cell technology will be part of the energy supply of the future.

5 The European energy market vs. new technologies
Le marché énergétique européen et les nouvelles technologies

The completion of the internal European market is one of the objectives of the European Commission. In the sector of the energy production the responsibilities are clearly distributed between national and European Union policy. Already in 1985 the European Commission was convinced that the rules for the internal European market are an important issue also for main-bound energies.

1998 the European Commission published a report containing essentials about different fuels and electricity. The European Commission recommended directives as the appropriate way to accelerate an integrated market. Directives have to be integrated in the national legislation. If there are particular national needs, legal exceptions may be granted.

The first step were three directives regarding price transparency and transit of electricity and gas in 1990 and 1991. After some years of negotiations the Electricity Directive was adopted in 1996 and had to be implemented in national laws in early 1999. The Gas Directive was adopted in 1998 and had to be integrated in the national legislation in 2000.

The influence on decentralized power-production and especially on the fuel-cell technology in the first phase was far from encouraging. At the moment the industry concentrates on restructuring and adapting to the new rules. The small R&D budget limits investment in new technologies. The willingness to invest in immature technologies is reduced.

On the other hand the liberalised energy market presents some new chances. Energy companies will move towards lower risk investments. This means that projects with a short time of preparation have a better position to be realized. Furthermore it is less risky to build a CCGT (combined cycle gas turbine) plant than a nuclear power plant. If there is an efficient, economical new technology on the market, it will be easier to invest in such a small decentralised unit than in a centralised power plant.

Apart from liberalisation the European energy market is further influenced by agreements like the Kyoto protocol, the policy to double the renewable energy from 6 to 12% by 2010 and the target to reduce the level of the European Unions dependence on external energy sources.

Finally, the market is of course strongly influenced by the energy prices. In 2000, for instance, the price of natural gas was very high whereas electricity was very cheap. Economical power generation with e.g. a gas fired cogeneration plant was not possible. In this case environmentally friendly technologies need additional subsidies.

6 Markets for fuel cells
Marchés potentiels des piles à combustible

In this paper only the stationary application of the fuel-cell technology has been considered. At the first glance it seems that there are some synergies between stationary and mobile applications. Particularly the possible huge production volume in the car industry and the potential for cost reduction are the most-often used arguments. On the other hand the requirements of the products are very different. For instance the needed lifetime, the start-up-time and the time of response in a car deviate very much from a power plant. Therefore critics cannot find a link between these two kinds of application.

Potential markets for fuel cells in the stationary area are:

- The classical block type thermal power plant for residential use up to industrial power production: This very efficient way to use power and heat has been losing market share since the beginning of the liberalisation of the European energy market. Due to the very low cost of electricity the decentralised power production is unattractive at the moment. In some countries the national bodies subsidize combined power and heat production for ecological reasons.

- Central power stations: Especially high-temperature fuel cells with their potential for high efficiency and a high life-time are of interest. The available heat can be used only in a few applications. This sector is a long-term market.

- Decentralised units for grid-stabilization and power management. In Europe this is not a subject for discussion at the moment. It might be of interest in the future if the redundancy of the grid is decreased and the reliability is at risk.

- Uninterruptible power units: Highly available fuel cells could be used for installations where even short power failures may lead to production-failures and heavy losses. At the moment this is not of high importance in Europe either because of the high reliability of the grid.

Therefore the feasible short- and medium-term uses for fuel cells, especially in Europe, are as follows:

- Small co-generation (a few kW_{el} for residential and commercial use: This is a very promising sector. A lot of companies are developing systems - mostly the PEFC technology is used. The technical challenges are the complex fuel-treatment system and the resulting high costs of a unit.

- Co-generation units from 50 kW_{el} to 5 MW_{el}: They are applicable in the industrial and municipal sector (e.g. hospitals, breweries, housing areas). Experience exists from several hundred demonstration units. With a breakthrough in the investment costs the technology might become successful.

- Decentralised power production for industrial use from 5 MW_{el} to 60 MW_{el}: A few demonstration plants up to 11 MW_{el} provide sufficient evidence for feasibility. Especially the high-temperature technology is predestined for this application.

7 Conclusion

Conclusion

A couple of different technologies are in the race for becoming "the" future technology for power production. The pressure to deliver clean energy at very low costs is a challenge. The proved technologies are very competitive and show an increasing performance. Some "new" technologies, such as the fuel cell technology, are very clean and have the potential for high efficiency.

In product-development the fuel cell technology has shown good progress in the past decades. From the technical point of view some types are about to reach a breakthrough. But on the economic side there are still a lot of efforts necessary to commercialise the technology.

The liberalisation of the energy markets restricts the positive development of new technologies. The most important point is competitiveness with low energy prices. The political authorities are urgently requested to set the framework and to grant benefits for clean technologies.

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Summary

The principle of the fuel cell has been well known for more than 150 years. In simple words, it only means putting hydrogen and oxygen together and getting electricity, heat, pure water and - very important - no pollutants. In reality, it is of course not as simple as described - otherwise fuel cells would be a very common technology for energy production.

Up to now space technology has been the only commercially viable application of the fuel cell technology. In stationary energy production some units from a few kW to several MW have been in a testing phase. Several hundred units have been in operation worldwide. Most of them are demonstration units at gas companies. The reason for this is that it is relatively easy to produce hydrogen from natural gas. Therefore the mentioned technology is of high interest for the energy industry - as it produces clean, highly-efficient energy.

The worldwide field tests demonstrate the potential of the fuel cell technology. Some types of fuel cells show good progress and are technically nearly mature for being used in practice. Nowadays cost reduction is the first target to establish a commercial product at an economic basis.

The opening up of the electricity and gas markets in Europe moves on. Beside the fact that politics has to prevent unfair competition, the political authorities should be urged to grant advantages to environmental friendly technologies in order to help them become economic.

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Résumé

C'est depuis plus de 150 ans que nous connaissons le principe de fonctionnement de la pile à combustible. Expliqué de facon simplifiée, il s'agit de mélanger de 1'hydrogène à de 1'oxygoène afin de produire de l'électrité, de la chaleur, de l'eau pure et - ce qui est très important - pas de polluants. En réalité, bien entendu, les choses ne sont pas aussi simples que décrites ci-dessus, s'il en était ainsi la pile à combustible serait établie depuis longtemps comme méthode courante de production d'énergie.

Jusqu'à nos jours la technologie spatiale est l'unique secteur à utiliser la pile à combustible de facon commerciale. En ce qui concerne la production d'électricité, cette technologie a été mise en service d'essai pour des unités de quelque kW à quelque MW seulement. A l'échelle mondiale nous comptons une centaine d'installations ayant été en fonction. La plupart d'entre elles ont été installées chez des compagnies gaziers à titre démonstratif, parce qu'il est relativement facile à produire, de l'hydrogène à partir de gaz naturel. C'est pourquoi l'industrie énergétique attache un intérêt tout particulier au développement de cette technologie produisant de l'énergie à rendement élevé sans pour autant polluer l'air.

Des essais effectués à l'échelle mondiale ont prouvé l'efficacité de la technologie de pile à combustible. Il y a donc des types de piles à combustible dont la technique bien mûrie permettrait une mise en pratique prochaine. Aujourd'hui la réduction des coûts est l'objectif le plus important à réaliser quand on veut lancer un produit sur le marché dans des conditions économiques favorables.

De même nous assistons à la libéralisation continue des marchés électrique et gazier en Europe. Et si les hommes politiques sont appelés â empêcher une concurrence déloyale, les responsables économiques, eux, doivent encourager le développement des technologies non polluantes et en même temps les rendre plus intéressantes du point de vue économique.