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Competing power-generating technologies for the 21st century

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Abstract

Several new and advanced power-generating systems are presently being developed, e.g., fuel cells, advanced heat pumps, high-performance gas turbines. An analysis of these systems is presented and is based on projections of comparative studies and relevant trends. For advanced systems, a trade-off between efficiency gain and projected development cost is crucial. Projections for market conditions in the 21st century and, in particular, environmental issues are made in order to assess market-entry opportunities. Results from various case studies indicate challenging opportunities in process and metallurgical industries; several process-integrated configurations are being studied.

Introduction

The prospect of the fuel cell in Europe depends on the future of power generation on this continent. It is therefore necessary to summarize the past and present developments in this area. In addition, several market niches can be identified where integrated use of fuel cells appears to be attractive economically.

The industrialized nations, with only 25% of the world population, consume 75% of the global energy production. Europe is a significant player.

Presently, the Europe Community (EC) with its 12 countries can be characterized by an estimated population of 330 million, a total peak electricity production demand of 318 000 MW and a Gross National Product (GNP) of US$ 6000 billion [1].

Unfortunately, the considerable differences in the EC between local economic prospects, the type of power-generation capacity and environmental concerns (real or perceived) preclude any simple reasoning or calculations from the above-mentioned figures that could yield an average profile or single pattern. For example: France has little (~10%) thermal power generation and, together with Belgium, relies heavily on nuclear power; The Netherlands has nearly zero hydro-electricity and depends heavily on natural gas and CHP; Italy is a relatively large user of geothermal energy.

Between 1985 and 1990 in the EC, manufacturing output increased by an average of 4.8% while electricity consumption increased from 1 300 000 to 1 670 000 GWh with a similar increase. In the last few years, one has seen a political and economic stagnation in Europe with a small recession.

Various surveys, however, indicate a strong worldwide growth in all categories of small power-generation equipment. A doubling of both diesel/gas engines and gas turbines in a five-year period illustrates this trend and offers a growing replacement opportunity for fuel-cell systems.

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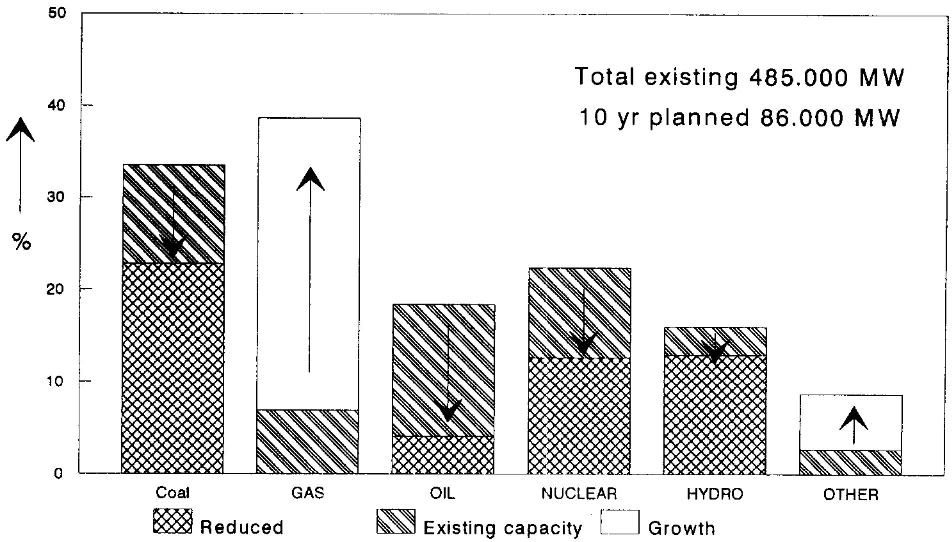

Fig. 1. Overall EC capacity trend. Source: Diesel + gasturbine worldwide.

An inspection of the data that describes the future of the installed electric generating capacity, reveals a dramatic change. A large proportion of the new capacity will be gas-fuelled, i.e., coal, nuclear and oil fuelled units will lose some of their respective market shares (see Fig. 1).

Energy use and CO_2 policy

The impact of any global or European CO_2 policy has to be assessed with the cost-effectiveness of 'local' measures in mind.

A 1992 study from the London Business School showed vast differences between the marginal costs of a (single) ton of avoided CO_2 emission in the various EC countries.

A sensible contribution to worldwide environmental problems can apparently be made by investment in the upgrading of old equipment and/or installations, e.g., in the Eastern European countries. Environmental measures in other countries can be encouraged by credit arrangements by means of a clearing-house concept.

In The Netherlands, the following long-term options for large-scale conversion of electricity production facilities have been evaluated [2] for the years 2000 to 2015:

- nuclear versus coal
- CO_2 capture and storage
- increased use of renewables and fuel-cell systems

Evaluation of the results give no encouraging or conclusive results yet. A further assessment of safety issues, cost and economic aspects and environmental benefits is necessary and is being planned. In all scenarios, the use of natural gas, and combined heat and power generation play a dominant and important role in the 'local' Dutch economy.

Cost of drastic CO_2 reduction

The effect of 40 technologies for generating electricity, that have a potential for contributing to a drastic (up to 80%) CO_2 reduction, has been assessed in an extensive

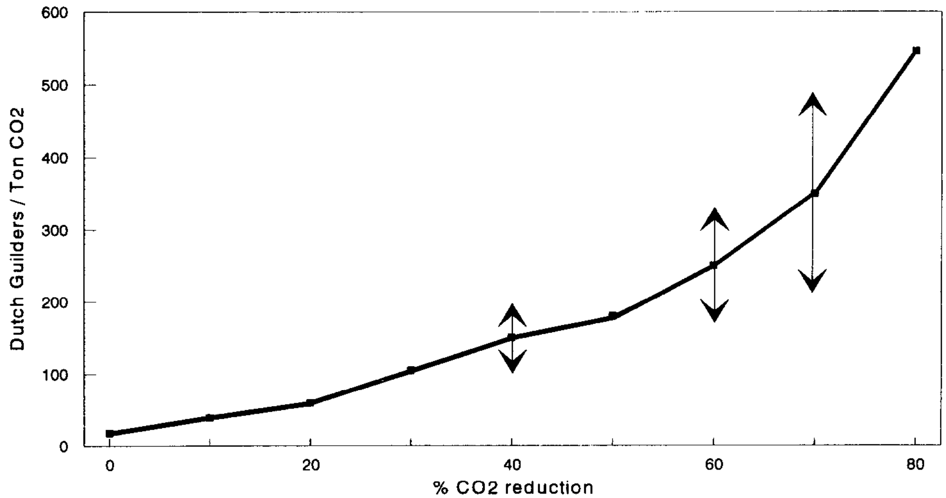

Fig. 2. Marginal cost CO_2 reduction — year 2030 [3].

study [3]. An energy system model (MARKAL), which is operational in 12 IEA (International Energy Agency) countries, has been applied. This model establishes an operational mix of energy technologies in order to satisfy the national energy demands. A consistent increase in CO_2 reduction cost is observed in all cases.

Starting from approximately NLG 100/ton, a doubling in cost is predicted for each further 20% of additional CO_2 reduction (Fig. 2). Nevertheless, an 80% overall reduction in 2040 would require only a relatively small (0.7 to 1.4%) fraction of the GNP!

Environmental policy in The Netherlands

The relation between energy use and supply on the one hand, and the associated environmental emissions on the other have been examined extensively [4]. The Dutch studies are aimed at 'no regrets policies' that could be applied effectively in any national economic scenario. In some scenarios, it is expected that Dutch primary energy consumption over the 1990 to 2000 period will increase by 9 to 16% at high rate of economic growth and between 3 and 9% at a low rate of economic growth. A further annual rise of approximately 1% is expected after the year 2000.

The local emission of CO_2 will continue to increase in the period up to the year 2000, and also into the next century, see Fig. 3. A better picture exists for acid emissions. NO_x emissions will be 40% lower than in 1980 (Table 1) and, in particular, SO_2 emissions will decrease to only 15% of the 1980 level.

Fuel cells (Table 2) therefore, appear to have an extremely good potential in the CHP and transport sectors where gas engines and the otto engine pose fundamental barriers for further NO_x reduction and/or efficiency (and thus CO_2 emission reduction) improvements.

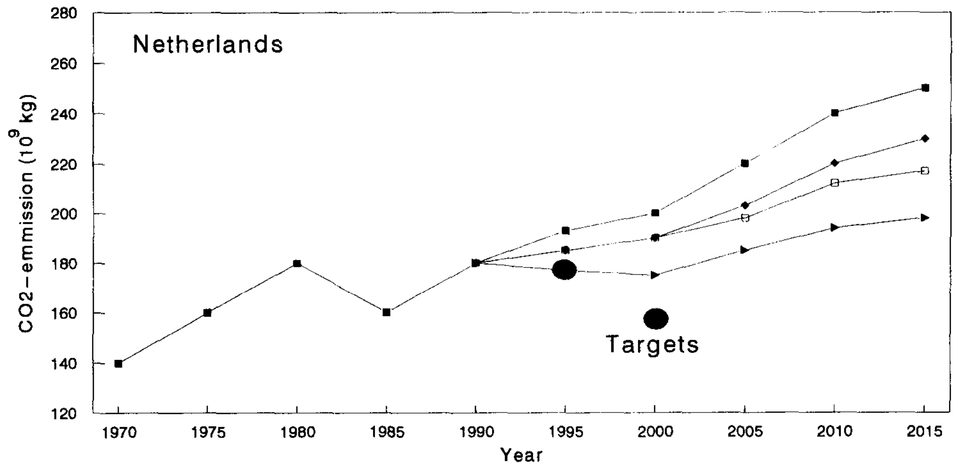

Fig. 3. CO_2 emission in the period 1970–2015: (-■-) ER–LP; (-▶-) GS–HP; (-◆-) GS–LP, and (-□-) ER–HP. GS = Global shift, ER = European renaissance, LP = Low-energy price, HP = High-energy price.

TABLE 1

NO_x emissions of competing technologies [5]

Technology	Emissions (ppm)		Control technologies
	Uncontrolled	Controlled	
IC engine	750–1500	75–150	Lean burn/torch ignition
		75–150	SCR system
Gas turbines	100–200	30–60	Steam injection
		20–40	Lean premix
		10–20	SCR system
Fuel cells	5	5	None

Opportunities for fuel cells in vehicle applications

By far the largest amount of installed power equipment is in cars and other automotive vehicles, albeit at a very low annual usage.

Rought estimates indicate a market volume that is 30 times that of centralized power stations. In addition, transport is a large and persistent producer of NO_x, dust and noise.

Fuel cells offer an opportunity for near-zero emission and the preservation of resources. The most suited configuration, the PEM cell, still has problems [6] in the areas of corrosion, specific cost and system integration, but is state-of-the-art at the 30-kW level and more.

If a comparison is made with the all-electric vehicle, the advantages with respect to overall efficiency also justify increased efforts for the application of fuel cells. The latter are capable of fulfilling the typical operational specifications of the transport

TABLE 2

Fuel cell competition [5]

Segment	Present competing technologies
Central plant	Coal-based steam cycles and IGCC, gas turbine combined cycle
Distributed generation and district CHP	Gas turbine combined cycles
Industrial CHP	Gas turbine cogeneration, steam turbine cogeneration
Commercial CHP	Reciprocating engines, gas turbine cogeneration
Self generation	Reciprocating engines
Transport and other applications	Otto-motor

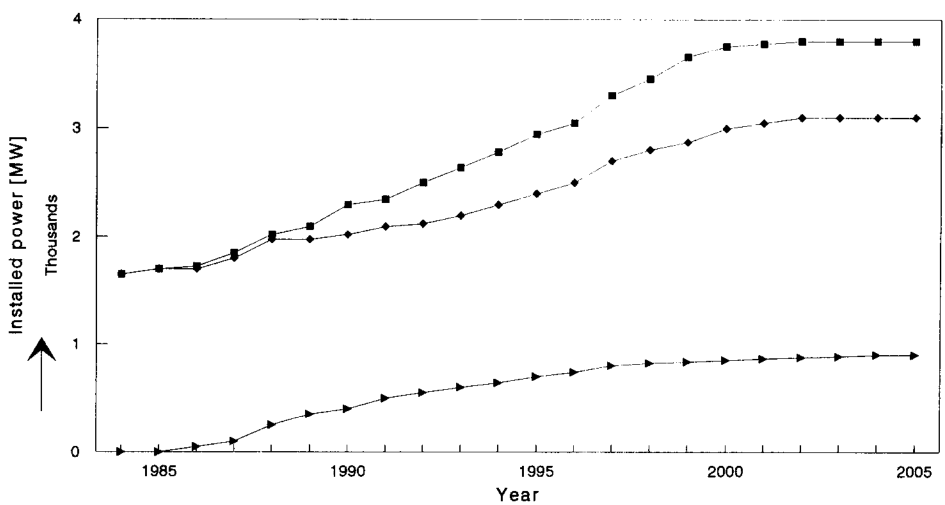

Fig. 4. Estimated CHP potential in The Netherlands [7]: (–■–) total; (–◆–) gasturbines, and (–▶–) gas engines.

sector. Both methanol and compressed natural gas are attractive fuels that can be easily made available.

The sheer size, diversity and the associated environmental problems make the transport sector more than a niche market!

Decentralized heat and power (CHP)

In The Netherlands, the amount of CHP was approximately 1500 MW in 1987. At present it is 2500 MW and is expected to rise to 4000 MW by the year 2000, see Fig. 4. The relative installed capacity of CHP (>16%) is by far the largest of any country in the EC.

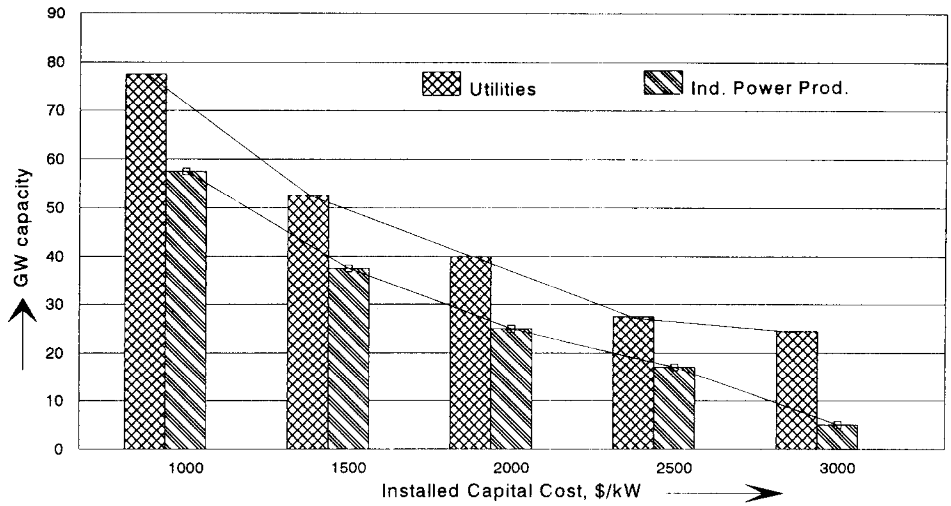

Fig. 5. US market size — capital cost impact. Source: Mc-Power.

Fine-tuning of heat and power demand and calculation of rates are still issues for discussion, but market growth is still significant. Added cost for higher efficiency can be absorbed if economics improve, see Fig. 5 for US market outlook.

The electricity distribution companies and the government are favouring this technology in order to reduce CO_2 emissions, reduce fuel use and enlarge the electric power-generating capacity. Also, the reduced electric transport losses and the potential for improvement in electricity quality are advantages to be noted.

After the year 2000, stabilization of the application of CHP is expected unless new issues arise, or more efficient systems can be offered.

Process-integrated applications

Various process flow sheets can be designed in which a fuel cell is effectively integrated in an industrial manufacturing scheme, and its typical electrochemical characteristics are exploited.

The use of a molten carbonate fuel cell (MCFC) has been evaluated in a municipal waste-treatment plant with biogas from fermented organic matter as feedstock. Although the LHV of this biogas is 15% lower than that of natural gas (see Tables 2 and 3), the high CO_2 fraction and the low N_2 content lead to an estimate of electrical efficiency of 46% for a MCFC-based system, as compared with 32% for a gas engine, see Tables 3 and 4.

The annual variations in 'fuel' quality and gas clean up require operational and engineering attention, but such attention is also important for gas-engine and turbine applications.

Systems in which heat-driven absorption cooling is integrated with a phosphoric acid fuel cell (PAFC) or MCFC system can be of particular interest if cooling or air-conditioning requirements are of importance.

TABLE 3

Biogas vs. natural gas [8]

Component	Biogas	Natural gas
CH_4	0.7	0.813
C_2H_4	0.01	0.027
C_3H_8	0.0	0.004
N_2	0.02	0.145
CO_2	0.3	0.011
Total	1.0	1.000
LHV (kJ/mol)	562.0	699.5

TABLE 4

CHP vs. biogas [8]

Efficiencies (LHV basis)	MCFC/biogas	MCFC/natural gas	Gasengine/biogas
Electric	0.46	0.44	0.32
Thermal	0.33	0.45	0.53
Total	0.80	0.90	0.85
P/H ratio	1.40	1.0	0.6

Large-scale electrochemical production of aluminium, zinc and chlorine (in the order of 100 000 tons annually) offer many opportunities if a reliable and cost-effective fuel cell can be made available. For example, in some novel zinc processes, the cathode gases and the direct current can be used directly in a unit operation of an integrated system concept. For aluminium, an improvement of 10 to 50% on primary energy use is quite feasible [9]. These and other processes will need further study and evaluation, but the opportunities appear to exist and could create attractive niche markets.

Evaluation

In order to assess potential market areas for fuel cells, it is important to validate economic and system characteristics, and to perform cycle-life analyses.

At present [10], no real competitive edge, other than the environmental issue, for fuel cells seems to exist. A need for further improvement still exists, as the market is still technology-driven.

Looking back on the more quantitive market estimate (for the year 2000), as presented by Arthur D. Little in 1991, of 4000 MW/year still seems valid, but presents a challenge.

Moreover, installation, qualification, unavoidable trouble shooting of the necessary production equipment and establishing relationships with suppliers and co-developers will take about four to six years.

A prudent estimate of the Dutch annual market for fuel cells is between 400 and 800 MW [11]. This is of particular interest due to the availability of natural gas and a reliable, dense distribution grid.

The best opportunity for fuel cells will be found in innovative applications in which more than marginal improvement over the environmental and thermodynamic characteristics of present-day gas engines and gas turbines can be achieved.

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