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THE MOLTEN CARBONATE FUEL CELL PROGRAMME IN THE NETHERLANDS

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Introduction

NOVEM started to manage the Dutch Fuel Cell Programme in 1986. The programme exclusively supported research on molten carbonate fuel cells (MCFC) and aimed at an international research position comparable with those in the U.S.A. and in Japan. Also the interest of an industrial partner had to be raised.

Focus points in the programme were material research in combination with fabrication techniques, the operation of a 1 kW MCFC stack in 1989 and international cooperation. ECN was the exclusive contractor with support of the Technical University of Delft. ECN agreed with IGT, Chicago, U.S.A. on a programme for support and education.

Hoogovens/ESTS joined the programme in Spring 1987. The research programme was intensified with development activities. A much tighter time schedule for upscaling the stack components was envisaged supported by system studies. Also two field experiments of 25 kW phosphorous acid fuel cell (PAFC) systems by KTI were partly financed.

In October 1987 the Ministry of Economic Affairs expressed again their interest in fuel cells on the basis that they:

- Are environmentally benign
- Require a high level of technological research in which electrochemistry and material technology play an important role
- Offer new prospects for Dutch industry
- Make use of fossil fuel, natural gas, in an efficient way

Hoogovens/ESTS unfortunately withdrew from the R&D programme in Fall 1988. Although the technical and economic prospects were acknowledged as being good, the MCFC technology did not fit into their core business and it would have required too much of their available R&D capacity.

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NOVEM consequently temporized the developing activities. At this time the following time schedule for stack development is being aimed at:

- Second half of 1989 a second 1 kW stack
- 1990 a 2.5 kW stack
- 1991 a 10 kW stack

At this moment NOVEM and ECN are putting much effort into attracting successors of Hoogovens/ESTS for participation in a joint venture to produce and commercialize MCFC systems in the Netherlands. If we succeed in establishing a joint venture in the next months then the following development phases will be executed:

- Phase 1, period 1986 - 1991, research and development, 10 kW stack in 1991
- Phase 2, period 1991 - 1995, preparation of the commercial phase with supporting R&D activities
- Phase 3, after 1995, commercialization of large units (250 kW and more) with supporting development activities

NOVEM and ECN are optimistic in establishing the joint venture.

Up to this moment NOVEM has spent about Dfl. 28 mln. financial means of the Ministry of Economic Affairs and ECN about Dfl. 8.5 mln. Now two questions can be raised:

- Is the MCFC technology still promising from economic and environmental viewpoints?
- What is the R&D status in the Netherlands?

Economic and environmental prospects of MCFC systems

Two comprehensive studies about MCFC systems are available. The first is the much quoted KTI study, titled "Fuel Cell Systems", May 1988. The second study is the ESTS report "Process Design of a Pilot Plant for MCFC", March 1989 (in Dutch only). Both engineering studies focussed on the optimal component configuration for producing electricity with high efficiencies. The important components in an external reforming fuel cell system are:

- Fuel Processing equipment, including the reformer, and piping
- Fuel cell stack
- d.c.–a.c. convertor

Besides the engineering of the system, KTI also executed detailed cost studies. Two effects on cost reduction were included in their calculations, namely:

- Learning curve experience
- Upscaling of the MCFC plant size capacity

KTI defined different levels of production capacities (see Table 1). The upscaling of the system size ranged from 25 kW up to 100 MW systems.

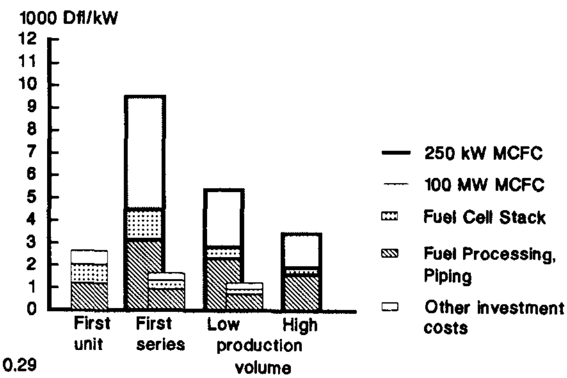
Results of the calculations on the installed plant costs per kW are presented in Fig. 1. The cost reduction for a 250 kW system of 65% was calcu-

TABLE 1

Number of units to be produced of different fuel cell system capacities[a]

Capacity fuel cell	Number of units			
	First unit FU	First series FS	Low volume production LVP	High volume production HVP
250 kW		5	20	200
3250 kW		5	20	100
100 MW	1	5	20	

[a]Source: KTI.



1 Dfl. = £ 0.29

Source: KTI

Fig. 1. Investment costs for MCFC systems (Dfl/kW) for different capacities and production levels.

lated when the 200th unit would be installed in comparison with the 5th unit of the first series. The dominant cost factor is still the fuel processing equipment including the piping. The cost percentage of the fuel cell stack ranges between 10 and 15%.

Even larger cost reductions are feasible by increasing the plant capacity from 250 kW up to 100 MW. Cost percentage of the fuel cell stack ranges in this case between 20 and 30%.

The system efficiencies must be estimated in order to calculate the price/performance ratios or in other words the cost of electricity production.

ESTS calculated the operating area of a MCFC stack of 25 MW. The system should preferably operate between 3 and 9.5 bar with an optimum of 7.5 bar with an electrical efficiency of 59% (LHV of natural gas). The results agree with KTI results although these results were calculated for different plant capacities (see Fig. 2).

The same effects of the cost reducing factors are clearly visible in the costs of electricity production at different production capacities and plant

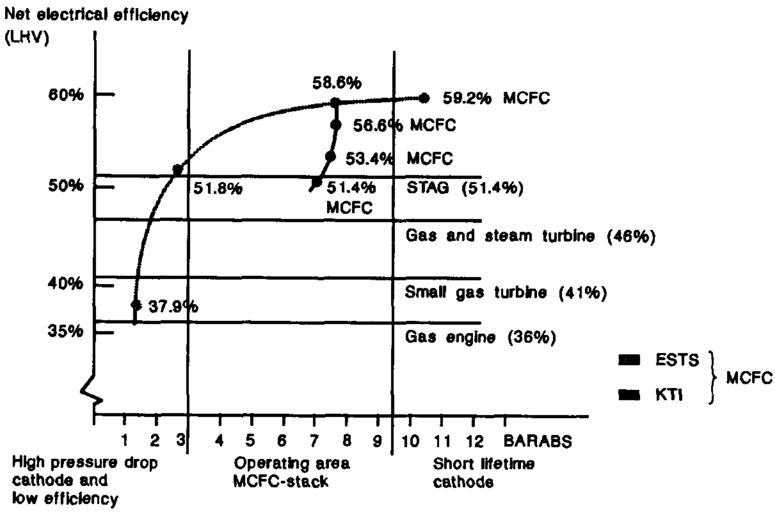


Fig. 2. Operating area MCFC stacks and net electrical efficiencies.

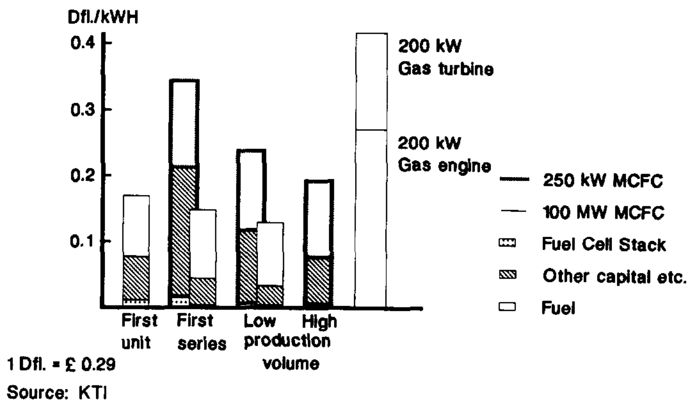


Fig. 3. Cost of electricity production for MCFC systems for different capacities and production levels.

sizes (see Fig. 3). At low production volume, the 20th 250 kW MCFC plant in a series of 20 could compete with small gas engines and gas turbines. The much larger 100 MW units could produce electricity at a cost price which is comparable with the cost price of a steam and gas turbine.

The characteristics of, for example, a 250 kW plant producing heat and electricity are good. The total system efficiency from the lower heating value of natural gas to useful energy is 80% of which 52% is the electricity generating part. The heat/power ratio is 0.55 (see Fig. 4).

The load following characteristics are good. A 40 kW PAFC unit supplying an electricity resistance heater for a sauna in a hotel in Tokyo follows for example immediately the variations in the demand between 17 and 34 kW.

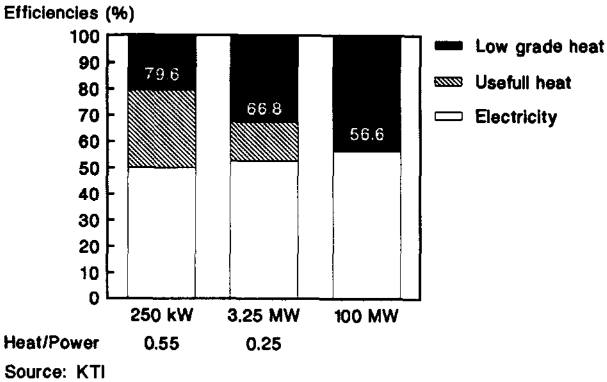


Fig. 4. MCFC system characteristics for coupled production of heat and electricity.

The NOx emissions are negligible when low NOx burners, or more preferably ceramic fiber burners in the reformer converting natural gas into hydrogen, are being used. The CO_2 emissions are relatively low because of the high efficiency of the technology and the possibility to recycle CO_2 from the anode off-gas to the cathode supply gas. SO_2 emissions are not present. The noise level is relatively low about 60 dB(A).

The conclusion is that the MCFC technology still offers the opportunity of a highly efficient, profitable and extremely benign fossil fuel conversion technology suitable for a broad range of (heat and) power applications. For the R&D programme it is necessary to research:

- The lifetime of the electrodes when stacks will be operated at 7.5 bar
- The effects of operating under pressure on internal reforming

Status of the research and development programme

About 50 people of several disciplines are working in the R&D field for MCFC systems using all kinds of test facilities and fabrication techniques for porous components and separator plates.

In the research part of the National Programme emphasis has been put on:

- Electrochemical research
- Improvement of state-of-the-art materials and new materials for the electrodes (conductive ceramics) and matrices
- Design and fabrication of separator plates
- Corrosion test with state-of-the-art materials for separator plates
- Improvement of the steps in the fabrication techniques such as powder processing, tape casting and sintering of improved state-of-the-art and new materials
- Testing of porous components under laboratory conditions (3 cm^2 and 3% use of hydrogen) and practical conditions (100 cm^2 respectively 1000 cm^2 and 75% use of hydrogen)

- Modelling of the ion migration through the electrolyte
- International cooperation

In the development part of the National Programme the attention is focussed on:

- Batch fabrication of the 1000 cm^2 porous components and separator plates and the design and engineering of scaling up the facilities to 4000 cm^2 (semi series production)
- Testing of the 1000 cm^2 components in the stackable cell test facility
- Testing the 1 kW stack (10 cell with an active area of 1000 cm^2 each) under atmospheric conditions
- Engineering of the 10 kW stack test facility up to 4000 cm^2 and 7 to 8 bar
- System studies
- International cooperation

The progress in the R&D programme can be illustrated by the results obtained in the test facilities:

- Laboratory cells of 3 cm^2 with improved state-of-the-art materials show performances in the range of 900 to 940 mV at a current density of 480 mA
- Bench scale cells of 100 cm^2 show voltages of 800 mV at 15 A
- The test with the subscale cell of 1000 cm^2 resulted in 775 mV at 150 A
- Subscale ministack test (two cells of 1000 cm^2 each in between three separator plates) resulted in 1450 mV at 150 A
- The best performance of the 1 kW stack was 5.81 V at 130 A

On the basis of these results the following conclusions could be drawn:

- The scaling up of the porous components from three to one thousand square centimeters has been successfully executed
- The operating parameters such as start-up procedures, holding force equipment, continuous calibrations etc. of the laboratory, bench scale and stackable cell test facilities are quite good
- The design of the bipolar separator plate has to be improved in order to boost the performance of the second 1 kW stack at the end of this year.

Some other highlights from the programme are:

- Promising candidates for alternative anode materials have been selected
- NiAl anode will probably be the standard anode in the future ECN programme
- Fabrication procedures and routes are improved
- The further need of a bubble barrier for preventing cracking of the matrix materials, is questionable
- The concept of the bipolar separator plate with integrated manifolds for the reactant gasses has proved to function
- The modelling activity is at this moment already a powerful instrument for supporting stack engineering activities

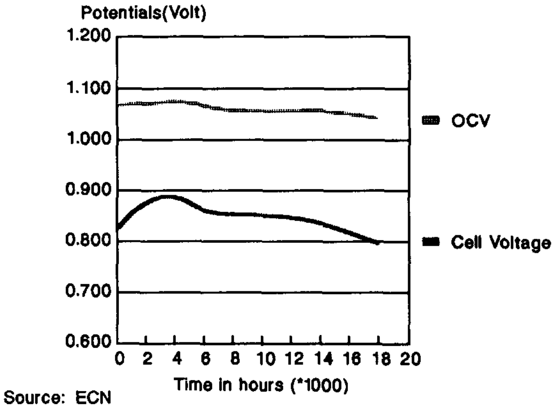


Fig. 5. Laboratory cell (3 cm^2) performance OCV and cell voltage.

One laboratory cell of 3 cm^2 has now been in operation for nearly 2000 hours. It still produces 814 mV at 480 A (see Fig. 5).

At this moment the accent in the R&D programme changes from aiming at high power densities to improvement of the lifetime behaviour of improved and alternative electrodes and matrices. This will be studied in close combination with effects of raising the pressure in a stack.

The Commission of the European Communities approved a joint proposal of ECN and British Gas to develop a 1 kW internal reforming MCFC stack.

The combination of applied research from several disciplines in combination with developing and testing stacks in one institute has proved to be successful. The old aim to attain an internationally accepted position on MCFC research has been reached. We are hopeful that we can maintain this position by establishing a joint venture which has to define the research and development goals for the near future.