Journal of Power Sources, 37 (1992) 75–80

A gas utility approach to fuel cell commercialisation

J. Doelman
N. V. Nederlandse Gasunie, P.O. Box 19, 9700 MA Groningen (The Netherlands)

Abstract

The most attractive application for fuel cells seems to be in decentralised combined heat and power generation (CHP). The market for energy efficient CHP is growing, partly as a result of the wish to decrease CO_2 emissions. Gas utilities are facing this development and can react in different ways. One of these is to operate natural gas powered CHPs themselves. The attractiveness of fuel cell powered CHPs for gas utilities depends firstly on the economy and reliability of CHP in general in the markets considered and secondly on the competitiveness of fuel cells versus, for example, the gas engine and gas turbine based CHP. Important possible activities for a gas utility in relation to fuel cell commercialisation are helping develop the market for CHP, defining the requirements for fuel cells in CHP and helping the fuel cell manufacturers to build up practical experience by participating in demonstration projects. The situation in the Netherlands will be used for examples.

Introduction

We may assume that a gas utility sells natural gas to customers on the basis of what is known as the market value of gas (in real competition with other fuels), and that the gas utility wants to make a profit, over a long period of time.

A fuel cell is an installation which converts natural gas into electricity and (useable) heat. This paper discusses the methodology used to determine whether the fuel cell is a prospective gas application and, if so, the possibilities for a gas utility to support its commercialisation.

As a simplification, the Dutch situation will be used as a background. Since the most obvious use of fuel cells is for combined heat and power production, this application will be viewed as the potential fuel-cell market.

The Dutch natural gas situation

In the early sixties, when the large Groningen gas field was found and the Dutch natural gas period began, there were about 150 small, 100% gas utility or public distribution companies which supplied gas to small consumers. In connection with the discovery of the Groningen field, Gasunie was founded to handle natural gas purchasing from producers, the transport of the gas, direct sales to large industrial customers and sales to the public distribution companies. These public distribution companies have acted for a long time as essentially retail companies.

0378-7753/92/$5.00

From the beginning, natural gas prices reflected its market value. For small (household) consumers this was represented by the distillate oil price, whereas for large consumers (including, for example, large power plants) the residual fuel price was taken as the market value indicator. The gas price for volumes over 170 000 m^3/annum has always fluctuated with the residual fuel oil price. Variations in the natural gas price must be approved by the Minister of Economic Affairs. In the eighties a large number of distribution companies merged, so that at present only about 30% of the gas sold to distribution companies is handled by 100% gas distribution companies. The other 70% is dealt with by so-called integrated distribution companies, i.e. those integrated with electricity distribution companies.

The electricity industry has also changed recently. In the sixties we had twelve large electricity companies who had their own production units and transport and distribution systems. At present there are four large electricity production companies who sell electricity directly to large consumers and to distribution companies. These companies, which as already mentioned, are often integrated with gas distribution companies, can produce electricity themselves if this is more economic than the purchase of electricity from the large producers.

Development of combined heat/power generation in The Netherlands

It has been quite common for large, energy intensive industries to produce steam for heating purposes and to produce electricity in back-pressure steam turbines, which are in fact a combined heat/power system. When natural gas became available some large chemical industries decided (around 1968) to install gas turbine based combined heat/power generation. The most important reason for this was the geographical situation of the industries where it was very costly to become connected to the electricity high-power system.

In that period, Gasunie started to promote the use of small (gas engine based) combined heat/power generation. Although quite a number of cases showed that the concept was economically viable, electricity companies offered lower electricity prices and thus at that moment prevented the development of small scale combined heat/power generation. Only a few installations were built.

In the seventies the situation was that the major part of the electric energy was produced from natural gas and heavy fuel oil (Table 1), while the large Dutch industries used natural gas for steam generation. Then the fuel oil prices increased rapidly and with it the natural gas price. In the same period the amount of natural gas available for the Dutch market was considered to be so limited that a selective-gas-sales policy

TABLE 1

Average fuel package (%) for electricity production by Dutch electricity companies

Year	Coal	Oil	Natural gas	Nuclear
1964	60	40		
1974	2	6	84	8
1980	12	40	40	8
1984	28	2	62	8
1990	43		49	8

was accepted. This policy meant that no natural gas was made available for large scale steam production either for extending old contracts or for new contracts. However, natural gas was available for combined heat/power generation based on gas turbines as this was a natural-gas application with an interesting energy saving potential. The industry accepted this concept, as it proved to be economically attractive as well as technically sound. As a consequence the use of gas turbines increased. The size/ capacity of the combined heat/power system was mainly based on the electricity requirements for the industry considered. The main reason for this was that electricity companies were not offering a good price for excess electricity delivered to the electricity grid for a unit whose power was based on heat demand. It should be stated that it is of great importance for the economy of combined heat/power systems that the electricity produced should either be used or sold for a reasonable price. The waste heat of the gas turbine was and is nearly always used to produce steam. If the amount of waste heat is not sufficient to produce the required steam, the exhaust gas of the gas turbine can be heated by additional firing. In this context, Gasunie showed to potential users that natural gas was more economically used in such combined heat/ power systems than as a fuel for steam production in boilers. The industrial users have carefully selected their power capacities with the result that all industrial CHP installations proved to be economic. Gas-turbine technology also proved to be sufficiently reliable for industrial use. The energy saving potential proved to be so high that the Dutch Government quickly decided to stimulate large scale combined heat/power generation by granting investment subsidies and urging electricity companies to offer reasonable terms for electricity stand-by contracts and for the electricity delivered to the grid.

Success in industry initiated two related developments. One is that the electricity companies have retrofitted a considerable part of their power plants with additional gas turbines (so-called STEGs) and are now planning to build a number of high efficiency combined cycles (an efficiency of 52% (LHV) has already been obtained) (Table 2). The other is that small consumers (like hospitals, supermarkets, greenhouses) became interested in small scale, gas engine based combined heat and power generation (Table 3). Later, the gas and/or electricity distribution companies found it an effective way to economically boost their electricity system by selecting places where a high demand for electricity and waste heat exists (e.g. greenhouses) for production. The introduction of gas engines was accompanied by more technical problems than for

TABLE 2

Total gas turbine capacity (MW electric) in Dutch industry and power plants

Year	Industry		Power plants	
	Number	Cumulative capacity	Number	Cumulative capacity
1968	2	46	3	98
1972	12	197	8	215
1980	23	357	22	629
1984	66	677	27	832
1990	99	1044	54	2173

TABLE 3

Total 'installed gas engine capacity' (MW electric) in combined heat/power generation units in The Netherlands

Year	Cumulative capacity	No. of engines
1972	11	21
1980	34	110
1984	102	815
1990	400	~2700

TABLE 4

Gas engines, NO_x emission (g NO_x/GJ) and shaft efficiency (% of lower heating value) development

Year	Legal limits	State of the art	Efficiency
<1986	no	750–6000	<36%
1987	<800	ok	36
1990	<270	ok	38
1991	<140, subsidy limit	<100 possible	39

gas turbines. This was because engine manufacturers generally lacked sufficient experience with gas engines, which were mostly diesel derivatives. Gasunie Research has assisted in giving the gas engine its present reliability. An important aspect is also the NO_x emission from gas engines, which has been drastically reduced during recent years (see Table 4).

Fuel cells — do they have a future?

The relative value of natural gas is strongly influenced by the technology available for converting natural gas into the required product such as heat, power and products such as H_2 and CO. This technology determines, for example, investment, safety, maintenance, reliability, operating costs, (energy) efficiency and emissions. The gas industry uses gas technology to make gas a more desirable product, compared to alternatives such as oil, coal and electricity. A new gas technology can mean an improved technology (e.g. low NO_x burners versus high NO_x burners), but also a technology creating new possibilities for gas. Fuel cells represent a new technology which also offers new possibilities for natural gas. In fuel cells natural gas is not burnt directly, but first converted into hydrogen (H_2) and carbon dioxide (CO_2) whereupon the H_2 is converted into H_2O in an electrochemical process. The electrolyte through which H_2 travels to the area where it reacts with O_2 (from air) determines, amongst others, the temperature of the process and thus the temperature of the waste heat.

The literature gives the following, qualitative, fuel cell advantages:

- high electric and total fuel efficiency, even at part load
- modular construction, prefabrication
- variable heat/power ratio
- environmental benign operation
- reliable, long life, low maintenance

We will discuss these points by considering the presently known performance of a phosphoric acid fuel cell (PAFC).

High efficiency

The reported electricity production efficiency of an on-site PAFC may reach 40% (LHV). This is not really an exceptionally high efficiency, although that of a dedicated pressurized PAFC for electrical production alone is 46%. For instance electric power in The Netherlands is produced with an average LHV efficiency slightly over 40% (fuel intake about 40% coal and 60% natural gas). Gas engines have LHV efficiencies of up to 39%. If waste heat is recovered from the phosphoric acid cell (at a temperature level of 40–80 °C with some 170 °C steam) a total efficiency of about 90% (LHV) can be achieved. The same also applies for gas engine systems. Gas turbine based combined cycles can produce electricity with an efficiency of over 50%. When used for town or district heating a total efficiency of about 85% is realistic for such installations.

Modular construction; prefabrication

The advantage of modular construction/prefabrication is that production costs will be low. In Japan it is expected that the investment for a phosphoric acid fuel cell may ultimately be about 1900 $/kW. However, this is at least double that for a gas-engine driven co-generation unit. It is doubtful whether this high investment can make the phosphoric acid cell competitive.

Variable heat/power ratio

This does not seem to be an advantage over other systems.

Environmentally benign operation

Low NO_x emissions are an advantage. However, gas engines can also be operated with rather low NO_x emissions. It is questionable whether the rather small amount of NO_x produced by the new generation gas engines can be considered to be too high and how much it may cost to bring this amount down to that of a PAFC.

Reliable, long life, low maintenance

This has still to be proven. It must be realised that the PAFC uses catalysts, which always show performance decay, and catalysts always have a limited lifetime. The presumed absence of moving parts, giving low maintenance, may not be true for further developments.

So, from our point of view the phosphoric acid fuel cell does not seem to offer real (technical) advantages over, for example, a gas engine. The economic attractiveness is still much lower. Notwithstanding the fact that the economics are not encouraging, gas companies may want to test a PAFC to get acquainted with the new technology involved.

The molten carbonate fuel cell can produce electricity with efficiencies between 50 and 65%, depending on whether the conversion of methane into CO and H_2 is carried out externally or internally, respectively; waste heat is available at a temperature of about 500 °C in the former case. The temperature of the waste heat is comparable to the exhaust of gas engines. However, since it is more efficient than a gas turbine, it has less waste heat at 500 °C available.

Although the highly efficient production of electricity seems attractive, the molten cabonate fuel cell is a very difficult technology to implement and is it questionable whether carbonate cells can be produced within the next 10 years for a reasonable investment and an acceptable lifetime. As mentioned earlier, gas turbine based combined cycles can already produce electricity with an efficiency of 52% and figures up to 56% are considered attainable before the year 2000.

The evaluation of the potential attractiveness of the molten carbonate cell is about as difficult as that of the solid oxide fuel cell. Ten years may be needed before solid oxide fuel cells are offered on a commercial basis.

An interesting development will be reported during this symposium by Dr Blomen. He will describe integrated systems with a very high electric efficiency, even up to about 70%, and an investment which looks commercially attractive. The phosphoric acid fuel cell stack may be part of such an integrated system and may therefore warrant interest.

Possible support of a gas utility to the market introduction of fuel cells

Natural gas-fueled systems which produce electricity and heat have found their way in the Dutch market under very favourable conditions, however their introduction has needed considerable effort from various interested parties, including the gas industry.

Combined heat/power generation is expected to be of great importance in the future. Gas utilities may see this development as an interesting market. They can wait until fuel cells are commercially available and then develop the CHP market. However, an immediate start can be made by using gas engines/gas turbine based CHP. Many problems can then be solved which have no connection with fuel cells but are related to CHP systems.

Gas turbines have been shown to be reliable tools, which is not surprising if one realises where and for how long gas turbines have been used. For gas engines, we have provided technical assistance, as not much experience was available with this technology. Nowadays, one can buy very good, reliable, gas engines. A problem for both prime movers is NO_x emissions. Our Government is very positive about the use of combined heat/power systems, since it reduces CO_2 emissions. NO_x emissions have, however, to be brought to acceptably low levels and gas utilities are assisting in this area. Thus, the creation of a market in which, small scale, combined heat/power systems are accepted should be very helpful for fuel cells. As a second step, a gas utility can test prototypes to familiarize itself with the various characteristics of the new technology. For example, it might be essential to find out which restrictions could be posed on the natural gas composition (sulfur compounds, higher hydrocarbons, etc.). Collecting such information can be most helpful during the introductory phase. Last but not least, the gas utility can collect the required information needed for advising customers.