Proton exchange membrane fuel cell systems engineering at Vickers Shipbuilding and Engineering Limited (VSEL)

C. M. Seymour
Vickers Shipbuilding & Engineering Limited, Barrow-in-Furness, Cumbria LA14 1AF (UK)

Abstract

A project, jointly funded by VSEL and CJB Developments Limited, is aimed at the development of complete power generation systems based on PEM fuel cell technology. Potential markets for such systems are seen as being very broadly based, ranging from military land and marine systems through to commercial on-site power generation and transport. From the outset the project was applications driven, the intent being to identify market requirements, in terms of system specifications and to use these to produce development targets. The two companies have based their work on the Ballard PEM stack and have focused their efforts on the development of supporting systems. This benefits all three companies as it allows Ballard to obtain applications information on which to base future research and VSEL/CJBD are able to capitalise on the advanced development of the Ballard stack. Current work is focused on the production of a 20 kW, methanol fuelled, power generation system demonstrator, although work is also in hand to address a wider range of fuels including natural gas. The demonstrator, when complete, will be used to indicate the potential benefits of such systems and to act as a design aid for the applications phase of the project. Preliminary work on this next phase is already in hand, with studies to assess both systems and fuel cell stack design requirements for specific applications and to generate concept designs. Work to date has concentrated on the development of a methanol reformer, suitable for integration into a fuel cell system and on extensive testing and evaluation of the Ballard fuel cell stacks. This testing has covered a wide range of operating parameters, including different fuel and oxidant combinations. The effect of contaminants on the performance and life of the fuel cells is also under evaluation. PEM fuel cells still require a great deal of further development if they are to gain widespread commercial acceptance. A recent study conducted by VSEL in conjunction with the UK Department of Energy has addressed the fuel cell cost and performance requirements in order to both focus future research and to aid understanding of the time-scale to reach full commercialisation.

The present work, being conducted jointly by CJB Developments and VSEL, forms the second phase of a long term plan to develop packaged power generation systems based on solid polymer fuel cell technology. The first phase of the work concentrated on an assessment of the market and commercial case for investing in this technology. Having identified the range of possible markets and applications and with a knowledge of the likely time-scales to commercialisation, the decision was taken, early in 1990, to embark upon the current phase of the project which is aimed at the development of a generic systems demonstrator. This is intended to fulfil the following objectives:

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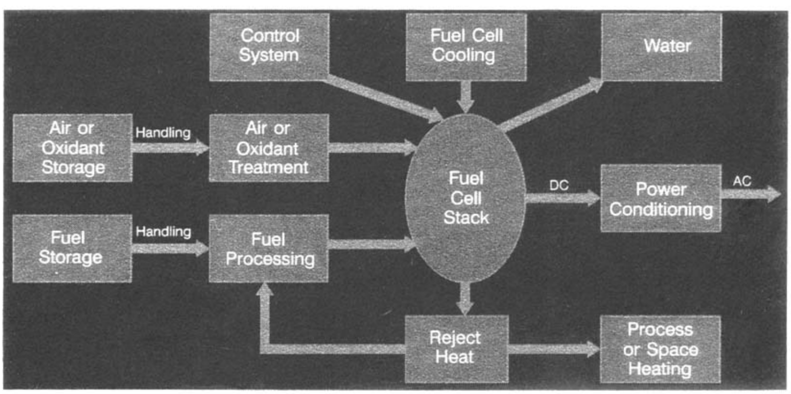
- to demonstrate the viability and performance of a complete system using a commercially acceptable fuel
- to promote market awareness of the potential
- to obtain a better understanding of the detail design aspects for the subsequent phases
- to demonstrate both companies' commitment to this technology

From the outset, it was decided that neither company would invest in the development of the basic stack design since this was already well advanced and was approaching commercial viability. Both companies saw their strengths in systems design and engineering being used to develop the necessary supporting systems as indicated in Fig. 1. Agreements were therefore concluded with the Canadian company, Ballard Power Systems, for the supply of solid polymer fuel cell stacks and the associated technology and development support. The relationship between the three companies is shown in Fig. 2.

In order to produce a power generation package to meet the market requirements it is necessary to address the total system design. If attention is focused solely on fuel cell stack development to the detriment of supporting systems for instance the result will inevitably be an unbalanced design which fails to satisfy the needs of the application.



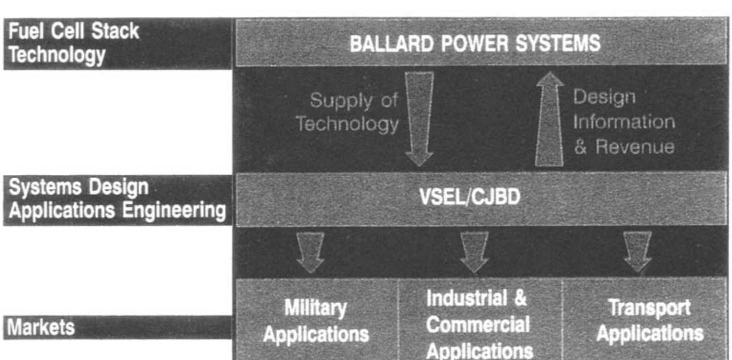


Fig. 2. Company relationships.

It is important therefore that the design process begins at the interface of the total power generation system with its surrounding environment. This is preceded by a specification for the total system and is based upon the particular application. Inevitably some of the requirements will produce conflict for the designer in attempting to fully meet them, this is typified by the need to provide the best possible performance with the least cost. In order to rationalise these requirements and produce a clearer focus for the designer the approach shown in Fig. 3 has been adopted whereby the required attributes are weighted and ranked in order of importance so that priorities can be set.

As an aid to the optimisation of the complete system a mathematical model has been generated covering the parameters shown in Fig. 4. This model is, for the most

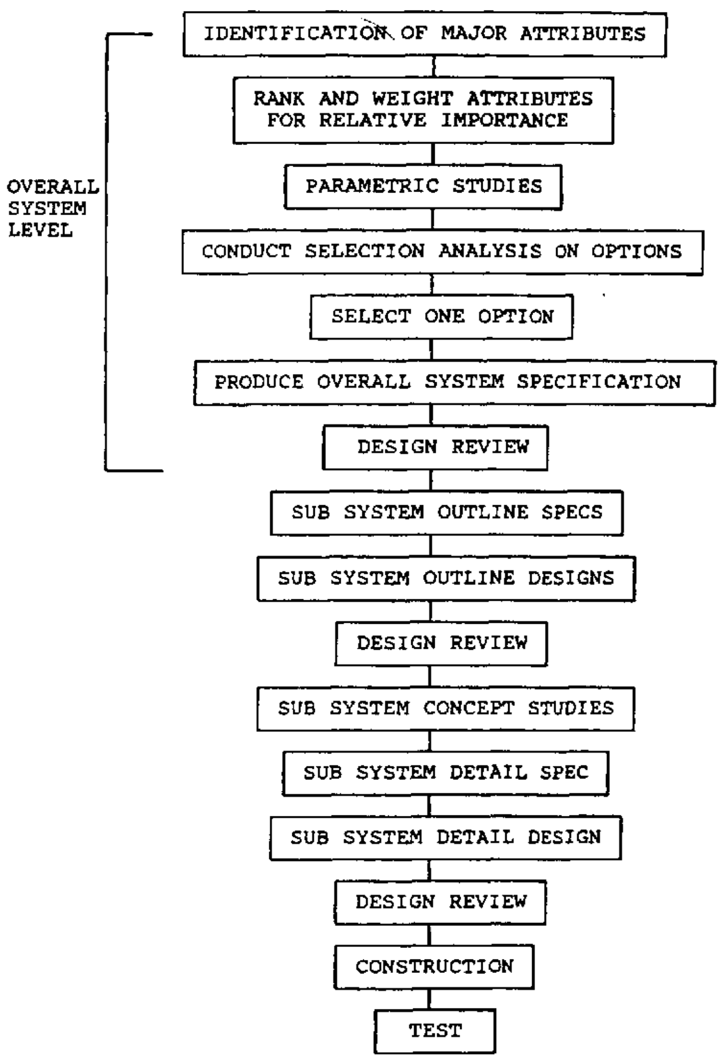


Fig. 3. Fuel cell system design flow chart.

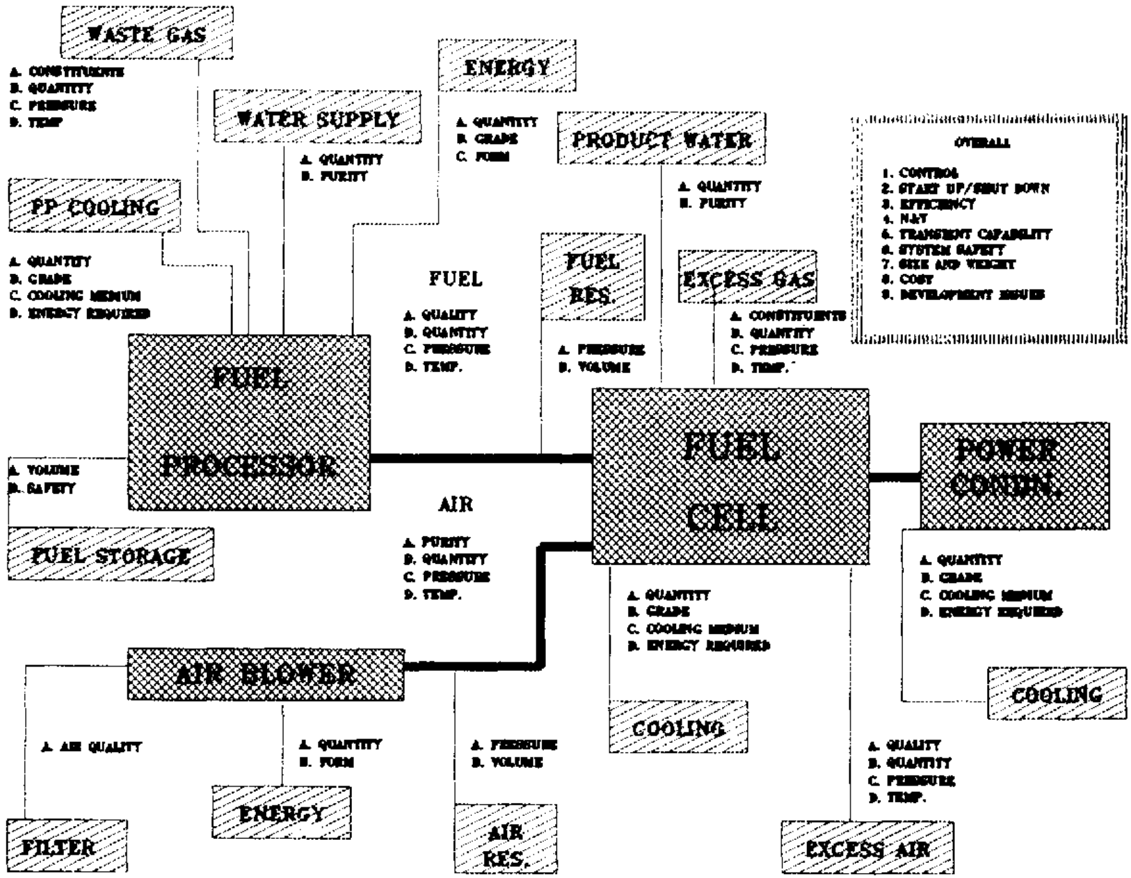


Fig. 4. Schematic of mathematical model.

part, based upon data generated during this current phase of the project. In order to produce this information therefore, fuel cell stacks have been extensively tested under a variety of operating pressures, temperatures and fuel and oxidant flow rates. In addition, different gas distribution systems within the stack have been evaluated and a range of gases including various synthetic reformates consisting of varying proportions of CO_2 and H_2 have been used. Other cell stacks have been run on synthetic reformates containing various contaminants such as carbon monoxide, methanol, formaldehyde and formic acid to evaluate their effect on performance and life. A typical trace showing the effect of CO on performance is shown at Fig. 5.

Reformer development has continued in parallel with fuel cell stack evaluation and a variety of catalysts and bed configurations have been tried. This experimental work has been used for the database and for the empirical equations used in the mathematical model. A typical set of results is shown in Table 1. The experimental reformer has now been directly coupled to a fuel cell and combined system performance is under evaluation.

Although current work has focused on the development of methanol fuelled systems, natural gas is also under investigation. These two fuels will allow a wide base of applications to be addressed, with the methanol based systems being suited to military and commercial transport applications and the natural gas systems providing on-site power, possibly also supplying low grade heat for CHP systems.

A number of application studies have been conducted concurrently with the systems development. These have addressed systems performance requirements and configurations for such applications as:

- fuel cell/battery hybrids for commercial transport
- auxiliary power generators for armoured fighting vehicles and military field generators.

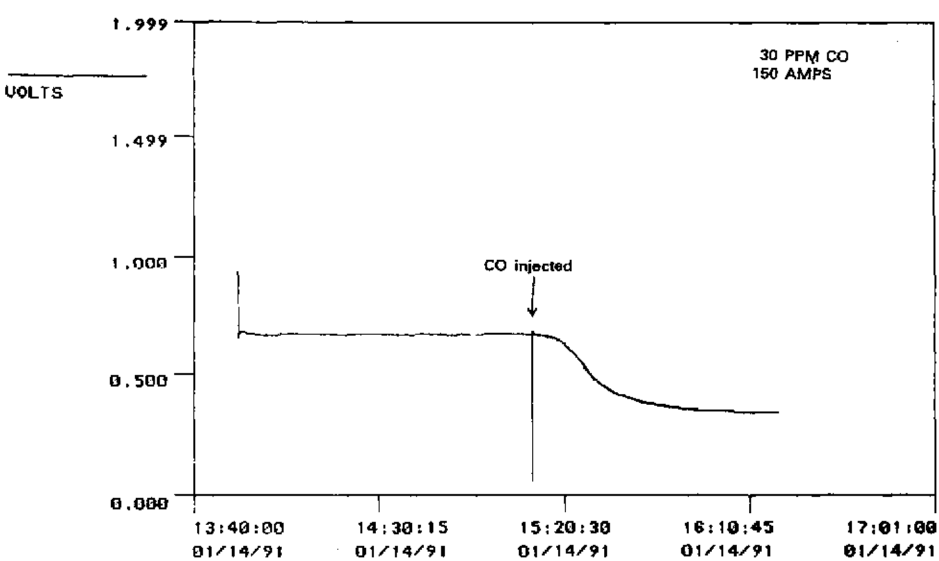


Fig. 5. Effect of CO on fuel cell stack performance.

TABLE 1

Carbon monoxide levels and bed temperatures[a]

Methanol reacted (%)	Carbon monoxide (%)	Catalyst cat wall c	Wall & bed cat top c	Temperatures		Condensate rate (cc/min)	Methanol (%)
				cat mid (°C)	cat bot (°C)		
94.29741	0.08	230	192	183	195	9.7	4
95.06167	0.09	235	189	183	197	9.6	3.5
95.06167	0.08	235	183	181	193	9.6	3.5
95.89942	0.1	240	185	182	198	9.3	3
96.72983	0.13	250	186	186	207	8.9	2.5
98.69193	0.14	260	186	189	213	8.9	1
98.70663	0.19	260	193	191	218	8.8	1
99.36066	0.23	270	194	193	226	8.7	0.5
99.35331	0.29	280	194	196	235	8.8	0.5
99.35331	0.36	290	193	198	244	8.8	0.5
99.36066	0.4	300	195	201	253	8.7	0.5

[a]When running with a feed of 1 kg MeOH to 2 kg H_2O, catalyst bed 1 litre, feedrate 21.6 cc/min of 33.3%, by weight, methanol in water, reformate flowrate 20 l/min.

TABLE 2

Target stack specifications

	Stationary	Transport (cars)
Power density (kW/l)	0.5	1.0
Specific power (kW/kg)	0.375	0.750
Life	around 5 years between overhauls/major operations	up to 2500 h accumulated time
	up to 20 years	over 8–10 years total
Capital cost (price)	around £1150/kW	<£100/kW

- energy systems for autonomous underwater vehicles (AUVs) where high energy densities are required that are beyond the scope of the majority of advanced battery technologies.
- air independent power systems (AIPS) which would allow non-nuclear submarines to remain submerged for around 10 times their current capability.
  As the name suggests, atmospheric air is not available to support conventional power generation systems so oxidant storage and conversion systems have also been developed. Although heat engines have been adapted for this form of operation, the fuel cell is potentially more attractive due to its near silent operation and greater efficiency in the use of both fuel and oxidant. Work at VSEL has addressed both hybrid systems, operating in addition to the standard submarine diesel generators and mono systems where all of the energy needs of the submarine are met by a large fuel cell system used in conjunction with advanced battery technology.

Although solid polymer fuel cells already exhibit many attractions for certain applications, a great deal of development effort is still required if they are to be widely exploited commercially. A study recently undertaken by VSEL in collaboration with the UK Department of Energy has looked at the potential for solid polymer fuel cell technology and derived a target specification to allow fuel cell stacks to enter commercial stationary and transport markets. Part of that specification is shown in Table 2. In addition to the above, standards for air and fuel quality have been recommended as well as such factors as the environmental temperature that the stack would be required to tolerate, shock tolerance and safety features.

A great deal of work is being undertaken in various establishments around the world to develop high performance low cost catalysts and membranes and this, together with a focus on stack engineering to achieve improved gas distribution, better thermal management and reduced production costs, could lead to these targets being achieved within the next two to three years.

Although the achievement of the above stack specifications may appear onerous, the development required for the necessary supporting systems and particularly the fuel processor provide an equal challenge. If the targets can be met, solid polymer fuel cell systems will find wide acceptance in the power generation and transport markets within the next 4 to 5 years.