TECHNOLOGY AND PRODUCT DEVELOPMENT AT CERAMIC FUEL CELLS LTD

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ABSTRACT

Ceramic Fuel Cells Ltd (CFCL) has constructed and tested a complete 25 kW experimental systems test bed in May 2000. With the lessons learnt from this experiment, CFCL has embarked on a development program for its first product. CFCL uses the principles of concurrent engineering with requirements management for the development project. Intensive marketing studies have identified as the market entry product a 40 kW SOFC fuelled by natural gas that is cogeneration-capable (e.g. combined with an absorption chiller). The planning phase for the product development was closed in August 2000, and the concept generation phase for cell and stack design and materials selections and systems components is in progress. An extensive field validation program is planned prior to product launch.

In parallel, CFCL is developing second generation cell technology for introduction into new and/or Mark 2 product, and processing options for alternative fuels such as LPG, diesel and renewable fuels.

INTRODUCTION:

Ceramic Fuel Cells Limited (CFCL) was incorporated in 1992 by a consortium consisting of public sector organisations and private companies with the objective to further develop and commercialise SOFC technology from CSIRO, Australia’s premier public R&D organisation. The company was restructured to a private shareholding company in 1999. CFCL is currently owned by seven energy/resource companies, a private equity group and three government agencies.

From 1992 to 1997, CFCL’s R&D Phase, the company focussed on building a competitive R&D team and developing technology packages in planar SOFC cells and stacks:
- electrolyte and anode substrate-supported cell technology;
- various stack designs with different interconnect options (externally/externally manifolded, single column and array stacks);
- stack size up to 5 kW.
Since then the company has added expertise in systems integration and control and in fabrication up-scale:
- 25 kW test-bed system construction and operation;
- up-scale of cell fabrication (electrolyte supported cells) to 1000 cells per week consistently.

During the past 12 months CFCL has acquired skills in product development and has introduced a structured approach to product development supported by appropriate documentation.

CFCL’s development and commercialisation team consists of over 100 staff and is growing. CFCL has established facilities for development, pilot fabrication and cell, stack and systems testing totalling 5000 m².

**SUMMARY OF 25 kW TEST-BED SYSTEMS OPERATION:**

The major objective of constructing this test-bed system were:
- to gain experience in the design, construction and operation of a complete system fuelled with Natural Gas;
- the size of 25 kW was chosen as it represented a substantial but manageable up-scale step, and it would be representative of a commercial product’s output;
- to drive up-scale of cell fabrication to consistently achieve 1000 cells per week.

The system was specified to operate at 850°C and ambient pressure on Natural Gas at 80-85% fuel utilisation, and to deliver 25kW AC (grid connected). The stack was designed as 4x4 cell planar array stack of a 240 layers (cell size 110x90mm). The stack’s design output was 39kW DC. Each interconnect plate consisted of four 1mm thick sheets of self-aluminising stainless steel (760 x 590mm in size).

The project stretched the company resources extensively during all stages of the project: design of BoP components and stack, construction of components and system integration, fabrication of cells and stack, final system assembly and operation. The 25 kW test-bed system was started-up in late May and operated for 400 hours before it was shutdown. The wealth of data gained from the test formed the basis for planning the way forward.

A number of BoP components specifications (air and fuel supply systems, heat management system, inverter and to a limited extend the control system performed as expected from their design. The following control strategies were proven: start-up of plant, stand-by operation, and various alarm-conditions and plant shut down.

Demonstration of the complete system was not possible due to stack failure caused by excessive leaks at the fuel inlet manifold and within the stack. The problems were caused by design deficiencies, the scale of the 4x4 array stack, thermal expansion differences between stack and gas manifold, as well as production generated problems. However, the learning experience from constructing such a large stack was substantial and as a result key technical risks have been reduced.

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After a very careful “post mortem” analysis of the 25 kW test results and experience, a detailed risk analysis and assessment of the resources required to rectify the problems, the company decided not to pursue the experiment further but to concentrate its resources on the development of CFCL’s first product.

PRODUCT DEVELOPMENT

Product definition:

After extensive market research, CFCL decided to target with its first product the small to medium commercial sector. The main attractions included the large market size and the uniform load requirements. The market segments includes customers such as supermarkets, petrol stations, fast food outlets, call centres, apartment and office blocks.

CFCL’s first product is defined as co-generation unit delivering 40 kW net AC output and hot or chilled water (air conditioning). Customers with larger electric load requirements will be served by multiple units. The units will be fuelled by pipeline natural gas, and will be designed with load-following capability and a target efficiency of 50% LHV. The target volume for the 40 kW_e fuel cell module (without heat recovery unit) is 2.5m³. Market entry is planned for 2003.

Product development process:

During the past 12 months CFCL has restructured to a project-based organisation. A well-proven product development methodology, based off product requirements determined through market and customer analysis, is being used to guide each project. Extensive risk analysis is a key element of the decision making process.

The product development process for CFCL’s first product involves 4 stages:

- Concept generation: This phase will be completed by end 2000, and is expected to deliver concepts for system components and sub-systems which potentially satisfy product requirements.
- Proof of concept phase: Concepts will be ranked and verified.
- System integration phase: This development phase will demonstrate the integration of the components, sub-systems and systems that constitute the SOFC power generating system. The outcome of this phase are system integration prototypes (SIP) for extensive in-house testing. The System Integration Prototype (SIP) will be an integrated system showing the overall characteristics of a standard production version.
- Field verification phase: This development phase will demonstrate complete functionality as defined in Product Requirements Document. A number of field test units will be constructed for testing at customers premises. The Field Validation Prototype (FVP) will be a fully integrated system identical to a standard production unit.
Seven multidisciplinary core teams for the segments marketing, cell technology, stack technology, BoP and systems, control systems and electrical, regulatory & QA, production have been established.

**Technology incorporated in the product:**

Since the Project is just completing the concept generation phase, only technology decisions involving cell components have been made. After an extensive risk analysis and consideration of the product development time frame, CFCL has decided to use electrolyte-supported cells for its first product. The cells will be made of 10 mol% yttria-zirconia sheets with a thickness of 150μm. The cells are designed to achieve their performance target in the range 800-850°C. The cells also will use CFCL's proprietary internal reforming anodes, to operate on natural gas with minimum pre-reforming.

**OTHER PROGRAMS**

**Development of future cell technology:**

Although CFCL has chosen for good reason its electrolyte supported cell technology for its first product, CFCL recognises that for long term stability and cost reasons it will require improved cell technology for lower temperature (700-800°C) operation. CFCL has developed anode substrate cells between 1995 and 1999. The concept demonstrated promising results, and power densities in excess of 0.5W/cm² were achieved at 750°C with wet hydrogen fuel. CFCL also built a 1 kW test stack with these cells (110x90mm), to demonstrate that substrate cells can be stacked, and operated the stack for approximately 600 hours very successfully. However, CFCL judged the technology as too immature to incorporate into its first product. The Cell Development Project will address the issues related to long term (>2500 h) stability, reduction in thickness of the cell (from 700μm to 300-350μm) and scalable fabrication methods. In addition, stack designs for second generation cell will be developed as soon as stack design resources become available when stack designs for CFCL's first product are frozen.

**LPG Reformer:**

As part of a longer-term strategy to cater for a range of fuels for our products, CFCL is developing fuel processing technology for higher hydrocarbon fuels. During the past 12 months, CFCL has been developing a reformer for liquefied petroleum gas (LPG), an important fuel for remote applications. The reformer aims to produce a methane-rich fuel capable of conversion in CFCL's internal reforming stack.

The program screened a number of commercial pre-reforming catalysts from different catalyst manufacturers. The CFCL researchers identified two promising catalysts and optimised the conditions to achieve complete conversion of the LPG with high methane selectivity, and then designed and constructed a reformer.
capable of fuelling a 5 kW SOFC stack. A major unknown during the reforming of LPG was the formation of carbonaceous deposits that gradually deactivate the catalyst or fill reactor spaces and catalyst pores with soot particles. A 600h test demonstrated the technology over an extended period of time. A constant composition of a methane-rich mixture (55% methane, 25% hydrogen and 20% carbon dioxide) was generated from the LPG reformer for the duration of the test. There was no observed degradation in the activity of the catalyst, and no deposited carbon was found.

A single cell was operated with the exit gas of the reformer and delivered a cell voltage within a few mV of that obtained from the same cell operating on Natural Gas. The next step will be to operate a multi kW stack connected to the LPG reformer.

Fabrication Prototyping Facility:

During the next 18 months CFCL will be establishing a fabrication/production prototyping facility. The main objectives of this facility will be:
- Definition, trialling and optimisation of fabrication/production processes;
- Trialling of continuous processes;
- Provide capacity for production of field validation prototypes.

The facility is planned for a capacity of 10 000 cells and equivalent stacks per week. The preliminary engineering and design work has been carried out, and detailed facility design will be carried out during the first half of 2001. At the same time critical and long lead time equipment will be ordered. The commissioning stage for the facility is planned for approximately mid-2002.