STATUS OF SOFC DEVELOPMENT IN AUSTRALIA

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ABSTRACT

CSIRO through its Division of Materials Science and Technology has been involved in research on zirconia ceramics (both electrical and mechanical properties) and oxidation catalysis for more than 20 years. Based on this experience and expertise in a number of other key areas around the country a company, Ceramic Fuel Cells has been formed by a consortium to provide focus for R & D and commercialisation of solid oxide fuel cell technology. The consortium will invest $30 million over the first five year R & D stage. The SOFC development program is relatively new in Australia. Performance of individual electrode and electrolyte materials has been optimised and planar single cells with LSM air electrode Ni/zirconia cermet electrode and zirconia doped with yttria are currently undergoing evaluation.

HISTORICAL BACKGROUND

In July 1992 a consortium was established in Australia to fund a program on the development of solid oxide fuel cell. The program is based on CSIRO's expertise established over the past twenty years in zirconia technology, electrical and electrochemical properties of ceramic systems, and catalysis. This is not the first time that an Australian team has got involved with SOFC R&D. In the mid sixties Aeronautical Research Laboratory (Melbourne) had a program on SOFC R & D and in the early 1970's BHP (the largest Australian company) carried out SOFC development, but both projects were later abandoned.

Involvement with zirconia ceramic R&D started in the CSIRO Division of Materials Science and Technology (DMST) in the early 1970's. In 1972 transformation toughening was discovered. The work was published by Garvie et al (1) in 1975 under the title "Ceramic Steel". During the following years partially stabilised
zirconia (PSZ) technology was further developed and in 1979 licensed to Nilsens Sintered Products, which later became Nilcra and is now part of ICI Advanced Ceramics. The company produces a series of products for corrosion and severe wear applications, among them extrusion dies; valve guides and seats, ball valves of substantial size for oil and slurry pumping; nozzles, plungers and bearings for food processing industry; and diesel engine components. Over the years, CSIRO developed a world class reputation in zirconia technology and established extensive facilities for microstructure characterisation, mechanical properties measurements and ceramic fabrication.

In parallel to PSZ development, a program on zirconia sensor technology was pursued. The first sensor, a high temperature, high thermal shock resistant oxygen sensor for measuring oxygen concentrations in molten copper was developed in 1971 for the mining company Mount Isa Mines (MIM). Subsequently, a high temperature gas sensor for operation in the range 700 - 1300°C was developed (2). This sensor incorporates unique joining technology between zirconia and alumina and is characterised by high thermal shock resistance. The technology was licensed to an Australian company in the late 1970's. Further development in particular in the area of electrode technology resulted in a low temperature sensor capable of operating down to 350-400°C in the early 1980's. Currently, four Australian companies offer sensors based on CSIRO technology mainly for combustion and process control. This program later on formed the foundations of the current solid oxide fuel cell project in Australia.

Extensive skills and facilities exist in CSIRO - DMST also in catalyst development. In the mid 1970's the Division was involved prominently in a program on developing catalysts for alternative fuels. When interest in this area declined in mid 1980's the effort in the Division was refocused to oxidation catalysis and natural gas conversion, including oxidation of methane in a zirconia membrane reactor, production of powders with controlled surface areas and pore structures in particular binary and multi component oxides, and catalysts for chemicals production. Extensive facilities specific to characterisation and testing of catalyst are available.

In 1986 a program was established in CSIRO-DMST to develop technologies based on solid electrolyte cells excluding oxygen sensors. State of the art facilities for evaluating fuel cell materials (air electrode, fuel electrode, electrolyte and ceramic interconnect), performance (short and long term) of single cells and stacks were established, and extensive knowledge of materials relevant to SOFC technology was accumulated.

CSIRO has been promoting SOFC and related technologies since 1984 in Australia although with only limited success. However, in 1989, after consultation with several groups, round table discussions were initiated with the aim to establish a national program on SOFC development in Australia.
There was general belief that Australia is in a good position to carry out SOFC research and development, because of its expertise base in zirconia technology and a number of other relevant key areas. Moreover, Australia has large reserves of raw materials and natural gas and an ideal introductory market consisting of power supply systems for remote locations such as remote settlements and cattle stations, mining sites, oil and gas drilling sites. Also fuel cells in general and especially solid oxide fuel cells have a number of distinct economic and operational advantages over other power generation systems. These include: low atmospheric and noise pollution, high system efficiency, high power density, fuel flexibility, modular construction to suit load, excellent load following capability, high operating temperature allows combined heat and electricity generation, all solid state device and no corrosive electrolyte. SOFC are thus ideal for dispersed power generation resulting in savings on transmission/distribution and more effective power management at user sites. All these factors put together eventually provided justification for starting a program on solid oxide fuel cells in Australia.

AUSTRALIA'S SOFC R & D PROGRAM

Vehicle

In July 1992 a company, Ceramic Fuel Cells Ltd, was established by a consortium to provide focus for research, development and commercialisation of solid oxide fuel cell technology in Australia. The consortium consists of Pacific Power, BHP, CSIRO, Strategic Research Foundation (SRF), Energy Research and Development Corporation (ERDC) and State Electricity Commission of Victoria (SEC). Negotiations are under way with other gas and electricity utilities and private sector companies to join the program. Pacific Power (NSW) and SEC (Victoria) are the two largest electric utilities in the country. SRF and ERDC are Victorian State Government and Federal Government agencies respectively contributing to the establishment of private and public sector research and development projects. BHP is Australia's largest company with major businesses in mining, petroleum and steel. CSIRO is the largest Government funded research organisation in Australia with a staff of 7000, amongst them 2500 scientists and engineers. The annual 1992/93 budget is over Aus$ 650 million. CSIRO is divided into six institutes, 32 Divisions and is located in 100 laboratories around Australia.

R & D Resources, Expertise and Facilities

For the five year R & D phase the consortium will provide a total funding of Aus$ 31 million. The funding for first three years has been approved and a major review of the project is scheduled for June 1995. A team of 35 scientists and
engineers in total (15 from CSIRO-DMST and two from BHP through separate research-sub contracts, the remaining are being employed by Ceramic Fuel Cells Ltd) will work exclusively on the project. THE CSIRO-DMST scientists form the core team in the areas of materials development/optimisation, component fabrication and cell stack evaluation. The engineers from BHP Research are working on developing mathematical models to predict performance, fluid dynamics and thermal stresses, thus providing input into cell and stack development and design. Initially, additional expertise (detailed design, systems engineering and power conditioning) will be accessed as required by collaboration with or subcontracting to engineering groups in the country (BHP, utilities, other CSIRO Divisions, power systems companies). In areas of strategic benefit, the company is collaborating with a number of universities and research organisations around Australia. This interaction is taking place by sponsoring of research projects directly by the company or through state or federal research funding agencies.

The SOFC program has access to state of the art facilities, located at CSIRO-DMST, which include:

(1) Sophisticated electrical and electrochemical property evaluation tools for components, single cells and stacks such as impedance spectroscopy (static and dynamic mode - constant current or potential, four-probe DC techniques, fully automated galvanostatic current interruption method capable of handling large currents). Special equipment has been designed and constructed for evaluation of short and long term performance of individual cell components, single cells and stacks. All techniques are of high precision and fully automated for control and data acquisition (control software has been designed, written and evaluated in-house).

(2) General materials characterisation equipment, such as SEM/EDX, ATEM/EDX, XRD, ESCA, DTA/TGA/MS, image analysis, TEC measurement and mechanical properties test equipment (low and high temperature).

(3) Equipment for catalytic electrode evaluation, consisting of tailored catalytic reactors, temperature programmed reduction/oxidation reactors, facilities for determination of surface areas and pore structures.

(4) Facility for preparation of component powders.

(5) Extensive ceramic fabrication and powder processing facilities.

(6) Sophisticated computing facilities and software packages for fuel cell modelling are located in BHP and CSIRO Divisions.
R & D PROGRAM AND STRATEGY

The program aims to develop prototype multi kW SOFC stacks within a period of five years. A planar type stack design has been selected and at this stage both ceramic and metallic interconnect options are under investigation to allow assessment of the most promising technology at a later stage. The strategy is outlined in Figure 1. The project pursues two major directions. Optimisation of currently known materials and stack construction with these materials, development of fabrication routes, solving problems associated with stack construction and operation, constitutes a major focus of the project. The second part of the project is devoted to carrying out research into new and improved materials for SOFC components (air and fuel electrodes and electrolyte) for incorporation into second generation stacks.

One of the major aims of the project is to investigate, develop and incorporate fabrication techniques for individual cell components and stacks which are economical and suitable for mass production.

Another focus of the program is the direct conversion of natural gas in the fuel cell stack. Internal reforming as practiced at this stage uses substantial quantities of steam in the feed to avoid carbon deposition at the stack entrance. The project aims to achieve direct conversion of natural gas within the fuel cell stack at the lowest possible steam to carbon ratio. An extensive screening of potentially suitable materials in a fixed bed reactor for activity in methane conversion, and effects of steam on methane conversion and carbon deposition is in progress. The most promising materials are being tested for electrocatalytic activity at fuel cell operating conditions.

Temperature and current gradients substantially affect performance and life-time of stacks, and the models are required to arrive at a design which strikes a balance between performance and life of the stack. BHP is developing mathematical models to predict performance, fluid dynamics and thermal stresses, thus providing input into cell and stack development. The final aim of this sub-project is to develop a 3-dimensional stack model as design tool, for evaluation of different fuel processing strategies, for obtaining design parameters and for optimising operating conditions.

CURRENT STATUS OF THE PROJECT

The SOFC R&D effort is divided into a series of sub-projects, dealing with different fuel cell and stack components, fabrication, modelling, stack design and construction, sealing, and cell and stack testing.

At the early phase of the program a substantial effort has gone into:
(i) design and development of hardware and control software for testing and evaluation of individual cell components, single cells and stacks;

(ii) evaluation and optimisation of currently known electrode and electrolyte materials; and

(iii) fabrication methods for electrolyte plates and electrode deposition techniques.

As a result of this work (LSM) and fuel (Ni/zirconia) cermet electrodes have been optimised with respect to coating quality, microstructure and composition. Fully and partially stabilised zirconia wafers of 50 mm X 50 mm X 250 μm size have been made. Single cells with active area up to 15-20 cm² are currently under construction and evaluation.

REFERENCES

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2. M.J. Bannister, W.G. Garrett and S.P.S. Badwal, in "Electrochemistry, Current and Potential Applications", T Tran and M. Skyllas-Kazacos editors, p. 191, Proceedings of Seventh Australian Electrochemistry Conference, February 15-19th, 1988, University of NSW, Australia. (1988).
Figure 1  R & D strategy for the Australian SOFC program