Ceramic fuel cells: consortium approach

Cleaner power from Australian science

CSIRO scientists working with Ceramic Fuel Cells Ltd (CFCL) have helped put Australia among the world leaders in energy with the successful demonstration of a working 5kW ceramic (or solid oxide) fuel cell.

Energy production is the fountainhead of industry. Global demand for power is increasing rapidly, especially in Asia. Environmental constraints, such as the Greenhouse Effect, are creating a significant demand for equipment, services and technology that can supply energy more cheaply, cleanly and efficiently.

Ceramic fuel cells marry the properties of modern ceramics with the long known principles of fuel cell technology, which uses the heat released in chemical reactions to generate electricity. They are highly efficient, portable and environmentally friendly. They are also compact - a 5kW fuel stack is only the size of a shoebox, yet can meet the needs of several households.

The successful operation of CFCL's 5kW fuel cell stack allows the company to proceed with fabrication and testing of larger demonstration systems which will lead to commercialisation of the technology.

Calm logic, senior level support and a willingness to share frustrations have enabled a research team to triumph over those who insisted that the ceramic fuel cells project couldn't be done in Australia. The team has brought together a group of leading Australian companies to back the project, and successful completion of the first five-year (Phase I) plan is attributed to the strong focus on specific research objectives, rigorous monitoring of progress, and clear communication of the roles of individual researchers in achieving those objectives.

Commercial application is still well into the future, but the project is now entering a second stage plan, during which the technology that has been developed will be proven in specific applications. That will be followed by a third stage plan, during which the technology will be put into commercial use. While there are many commercial hurdles still to be overcome, the project is already a triumph for research, both for its fundamental advances in knowledge and in bringing together CSIRO's strategic capability with that of Australian industry.

Dr Sukhvinder Badwal, along with Dr Karl Foger and Dr Mike Murray were the 'true believers' behind the solid oxide fuel cells work. Dr Badwal's experience in the project epitomises the reality of research and its commercialisation - it has been 99% dedication, hard work and frustration. The 1% exhilaration has made it all worthwhile.

Project origins

Over a number of years, Dr Badwal was part of CSIRO's research effort into oxygen sensing and zirconia-based ceramics. The researchers were at the leading edge of their field and had

spun off a number of commercial applications during the 70's and 80's, including oxygen sensing equipment and a new ceramic known as transformation toughened partially stabilised zirconia (TT-PSZ).

In one of those episodes that has dogged Australian science, the oxygen sensing research was almost closed down following an unfavourable review by overseas experts. However, CSIRO rejected the negative review, a move that departed from earlier responses to similar reviews. For example, Australia had pulled out of computers and rocket science research, following recommendations by overseas reviewers.

"The reviewers said our low-temperature oxygen sensing work was heading down a dead-end and recommended it be stopped," explains Dr Badwal. "But timing was on our side and before the review recommendations could be implemented, we were able to prove that it was the overseas teams who were on the wrong track. Paul Wild, the then Chairman of CSIRO, was impressed enough with our work that he ordered it to be expanded".

The decision was rewarded through the further commercialisation of oxygen sensor technology.

At around the same time, Dr Badwal realised that CSIRO's intellectual property and technical capability in oxygen sensing and ceramics could be applied to fuel cells, a technology long recognised in principle for its efficiency in electricity generation. During the 1960s and 1970s, fuel cells were investigated in major research programs, including overseas at Westinghouse, General Electric, and ABB, and in Australia by BHP and Aeronautical Research Laboratories. Dr Badwal says they didn't progress commercially because the materials and processing technology available at the time were both poor and expensive. The key component of the solid oxide fuel cell – fully stabilised zirconia – was weak and fragile. This made it difficult to fabricate cells on any scale.

A new generation of ceramics promised to change this. CSIRO had pointed the way with its TT-PSZ, but this was not a suitable material for fuel cells because its low conductivity caused high voltage losses. However, the TT-PSZ discovery led directly to the development of related ceramics. One of these, tetragonal zirconia polycrystals, which became available in the early eighties, was strong, durable and easy to fabricate into the thin structures needed in solid oxide fuel cells. It was this material that caught Dr Badwal's attention and he saw an opportunity for Australia to gain an international lead in a technology that could revolutionise power generation.

The search for commercial partners

Persuading other people, however, proved a difficult task. In 1986 he and his colleagues produced a brochure on the technology and mailed it out to a range of companies. Although at that time there was a stockmarket boom in technology stocks, Dr Badwal found that the first question people asked was: 'who else is pursuing the technology?'. The answer was: 'only Westinghouse had persisted with research into solid oxide fuel cells'. This led most people to question the value of a technology in which there was little interest overseas.

This was a difficult period. "We were all on a steep learning curve," says Dr Badwal.

"CSIRO was beginning to market the benefits of research more aggressively and there was less emphasis on curiosity-driven research. Personally I also had developed a preference for research leading to a commercial product."

Systematic marketing

So, he, Dr Foger and Dr Murray persisted. In 1989, they took a more systematic and planned approach to their marketing. First, they analysed their potential market. Initial studies were encouraging, indicating a potential future market of several hundred million dollars in Australia alone. Fuel cells have several advantages over conventional fossil fuel based power generation technologies. They offer significant increases in the efficiency of conversion of chemical energy into electricity - 60% compared with about 30-40% for normal thermal power generation. With heat recovery, fuel cell system efficiency approaches 80%.

Their modular construction and economies of scale would also allow the installation of power plants in a variety of sizes. This meant that the fuel cell plants could be dispersed around the electricity grid, instead of coming from a massive power station. This would cut transmission losses as companies could generate their own power and sell excess capacity into the grid. Other benefits of solid oxide fuel cell technology included significant reduction in pollution and emission of greenhouse gases, generation of high-quality waste heat for cogeneration, and low noise and vibration levels.

"Karl and I spent an enormous amount of time in the library going through lists of companies and descriptions of their capabilities." The team decided initially to concentrate their marketing efforts on electric utilities, manufacturers of power generating equipment and those companies that sell or produce gas. The cells can use a variety of fuels, but natural gas is best able to take advantage of the dispersed energy generation capability because it is already delivered via pipes to most industrial sites. This led them to target oil companies and gas utilities.

"We produced a new brochure that talked a little bit about the technology but put more stress on its market potential, and CSIRO's research capability," recounted Dr Badwal. "We then mailed it out to our target companies with a covering letter foreshadowing that we would be calling on them in the near future. That started us out on a roadshow. We gave over 150 talks between 1989 and the launch of the company, Ceramic Fuel Cells Limited, in December 1991."

These talks ranged from calls on individual companies, to presentations at conferences and to Parliamentary Committee hearings. The Senate Committee on Industry Science and Technology was especially interested because of the potential of the technology to reduce greenhouse gas emissions. The higher efficiency of conversion means that there's less emission per unit of electrical power generated. Several members of that Committee have retained an interest in the progress of the research and in the commercialisation of the technology.

Dealing with frustration

The team was beginning to get a return on its efforts, but the frustrations along the way were

many. "People who didn't know the technology were very skeptical. We had to put up with sarcastic comments and disbelief that Australia could take a lead in such a potentially revolutionary technology. Some told us bluntly that we would have to move offshore to get backing. We had to be tolerant and demonstrate that our case was based on logic and that we weren't chasing dreams. Our plans and timetables, at this stage, had to be constantly re-worked. We had to keep contacting people and following up on presentations. For the most part, it took several sessions to bring people to the point where they would take an active interest."

During this phase, internal CSIRO support was essential. "Karl and I were almost working on the project full time. Our Divisional Chief, Mike Murray, remained an active supporter. Our CEO, John Stocker, and our Institute Director, Colin Adam, were also right behind us. This was important because it gave us credibility, and the confidence to keep going. We couldn't have kept at it if we faced skepticism internally as well."

Industry champions emerge

A critical breakthrough came following a presentation to the Victorian Government's Strategic Research Foundation (now Strategic Industry Research Foundation - SIRF). A BHP executive, Dr John Parrott, chaired a SIRF sub-committee on Minerals and Energy, and he became very interested when he was made aware of CSIRO's efforts. Dr Parrott had previously come across the technology when working in Japan, where Mitsubishi had begun research in the field.

"John opened the door for us to BHP and became a champion for the research," said Dr Badwal. "BHP sent staff to Japan to talk to Mitsubishi Heavy Industries and other groups. Some were also sent to the USA, which had also entered the field. They came back very positive about the CSIRO capabilities and the fuel cell technology."

BHP then provided support with market assessments, and its interest encouraged other companies. "One of Pacific Power's (ELCOM at the time) executives saw a presentation we gave at a conference in December 1989," recalls Dr Badwal. "He arranged for us to give a presentation to another senior executive, John Wiedermier, and his senior staff. In only a matter of days, John came back and asked 'how much do you need?' Mr Wiedermier became a key supporter of the project and was a founding Board Member."

There was general consensus that the best route forward was to establish a consortium to spread the risk. Pacific Power's enthusiasm, plus that of BHP, fed the interest of others such as the then Victoria State Electricity Commission, the Gas and Fuel Corporation, Shell and SIRF. Dr Badwal recalls that in March 1991 he gave a talk on the technology at a Commission for the Future Round Table on Energy Efficient Technologies. This led to the active involvement of the Energy Research and Development Corporation (ERDC) in establishing the consortium, through Dr Bruce Godfrey.

From a consortium to a company

The Minerals and Energy sub-committee of SIRF recommended solid oxide fuel cell technology as a key area for strategic R & D in Australia. With ten to twelve parties now

taking an active interest, the next phase was to get a formal structure for the consortium. The commercial partners had a very firm view of what they wanted.

Dr Badwal: "We had initially thought of undertaking the research and development inside CSIRO, but the partners wanted a separate structure, so that researchers wouldn't be distracted by other activities within CSIRO. We went along with that structure."

Under CSIRO and SIRF facilitation, a consortium was subsequently formed which resulted in work commencing at CSIRO in April 1991. "From then until the launch of the Ceramic Fuel Cells Ltd in December 1991, we had to prepare research plans and costings. When the company was being established, we had good assistance from the partners and from Sirotech, CSIRO's then commercial arm. But we had to prepare research plans and costings and liaise with the partners, who were suspicious that we wanted to wander off into other areas of fundamental research rather than keep a strong focus on the commercial application."

"In retrospect, we could have done with some additional business support. The key is to get a balance – the business planning can't be all left to the scientists, but neither can the scientists be ignored because ultimately they know what has to be done. Nevertheless, it was a very useful experience for us and we learnt a lot. Our initial estimates of the research costs were low as we hadn't taken into account the costs of setting up and operating a separate corporate structure, and the costs of setting up laboratories away from CSIRO. These had to be adjusted when the full budget for a separate entity was prepared."

Ceramic Fuel Cells Ltd was launched in December 1991 by the then Commonwealth Minister for Resources, the Hon Alan Griffiths, and was attended by State Energy Ministers from Victoria and NSW. The Consortium provided cash and in-kind funding of $6 million per year for a five-year R & D program. CSIRO's infrastructure support and intellectual property were a crucial component of the success of the project. However, to demonstrate its belief in the project, CSIRO had to agree to take all its R & D payment in equity. This was a long term financial burden that the Division had to carry. The belief in the project of the Chief of the Division, Dr Murray, was again crucial at this time.

Establishing the management structure proved even more difficult. There were doubts among some consortium partners about the capability of CSIRO scientists to manage a project with a strong commercial focus. However, after some persuasion by Colin Adam and Mike Murray, eventually they gave the go ahead.

Dr Badwal was appointed Director R&D and Dr Foger, Deputy Director R& D. After the first Chief Executive resigned, Dr Parrott took over in March 1993. Mr Peter Coates CBE, who at the time was Executive Chairman of Davey John Brown, was appointed founding Chairman of the Board of Directors. He was a much needed stabilising influence throughout the first five-year phase.

The company was finally established in 1992, with CSIRO, BHP, PP, ERDC and SIRF as the founding members. CSIRO seconded a number of key staff to help transfer the technology, and also to provide much needed expertise in several critical areas. Funding to employ company R&D staff became available in March 1993.

Putting together a strong team

A number of researchers and engineers were employed and collaborations were established with research organisations and Universities in key strategic areas. According to Dr Badwal, sometimes it was difficult to attract high calibre people. "Potential employees perceived it as a high risk venture, not so much from a scientific point of view, but from a commercial point of view. They were concerned because of the short term nature of the funding," he said.

But in the end, a good team was established and the research and development proceeded in a highly focused effort. The team grew from fifteen CSIRO and three BHP R&D staff in March 1993 to over 70 (as the company attracted its own employees) by the time the first five-year phase was completed in June 1997.

Dr Badwal: "We had strict management procedures in place. At the start of the project in 1992, each technology area was reviewed through brain-storming sessions to generate ideas to solve problems, and to decide which problems were critical and which technologies would achieve a commercial outcome. These brain-storming sessions continued throughout the five-year phase. The overall company program was divided into several discipline-based projects led by a team leader. Each group had responsibility to achieve strict milestones which were tied to the overall Company Technology Development Plan.

Meticulous planning

A formal approach to planning was taken. The five-year R&D plan cascaded down to 12-month operational research plans. Every researcher's personal performance objectives were driven by the current operational plan. In order to keep track of the technology, and to provide overall coordination for the program, each project area was reviewed on a monthly basis by Dr Badwal and Dr Foger. Major reviews were held every six months and the plan and personal objectives updated accordingly. All the research results were documented in six-monthly and intellectual property reports. This process also helped record and protect any intellectual property developed along the way.

"We also set up teams to address particular issues," says Dr Badwal. "This provided cross fertilisation of ideas between researchers working on different projects, and gave them some exposure to the broader problems of the project. But we were careful to keep researchers focused in their specific areas, so we didn't have the problem where everyone was trying to work on all aspects of the project."

All the effort was focused on achieving strict project milestones. There was little effort towards exploring areas of scientific interest alone. "As you can imagine this can create a problem in a project where you have high-calibre staff, many with doctorate degrees. Some of them didn't like this at first but as the project progressed, they recognised the benefits and became absorbed in the excitement as we started to achieve the goals we had set," said Dr Badwal.

Other consortium partners (SECV, SECWA, ETSA, QTSC and ECNZ) joined later on and provided additional R&D funding. The company was expanding rapidly and it was always running short of laboratory and office spaces. The company was continuously designing, building and upgrading laboratories and new equipment. New laboratories were built at

Monash Science and Technology Park at Clayton and at Churchill in the Latrobe Valley.

For four consecutive years, technical milestones were brought forward, after having met or exceeded objectives set in the previous year. During the last two years of Phase I, when the Project had greater success in achieving its technical milestones, several new milestones were introduced. These related to the scale-up and semi-commercialisation of the technology.

The group also kept close track of the activities of overseas competitors. There was regular interaction with researchers at Siemens, Mitsubishi, Westinghouse and others, although each group carefully avoided giving away any commercial secrets.

Results exceed projections

The effort paid off. After five years, the project was not only on budget, but had achieved far more than had been originally projected. Dr Badwal: "The decision to locate outside CSIRO in a separate corporate entity proved correct in that it provided a strong focus on the research and development effort. I'm confident we're well placed in the international race to commercialise this technology."

The company has recently embarked on Phase II which is scheduled to be completed by December 2000. Phase II focuses on achieving cost targets for commercial products, and demonstrating the technology by evaluating up to 100 kW-size fuel cell units. Dr Badwal will continue to be associated with the company now as General Manager, Technology Strategy. However, with the main research phase complete, it will no longer dominate his life in the way it has for the past decade. He is now looking forward to having more time to spend with his family.

"It was a challenging and rewarding time. At times it was very frustrating, managing such a complex project when the company had little infrastructure of its own. That's the time when you most need a supportive team to share the frustration. I was lucky that I had people like Karl assisting me and we had constant support from our Mike Murray, Colin Adam and Peter Coates. There were also plenty of problems in the research itself, as could be expected. What counts is not only finding solutions to these problems, but also how you manage the entire process. We had only half the budget of Siemens, but we showed that when people really set their mind to it, Australian industrial research can succeed."