CERAMIC FUEL CELLS LIMITED

Creating the energy to succeed™

Solid oxide fuel cells – a step towards the "hydrogen economy"

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1 The hydrogen economy

"Jump forward in time – perhaps 100 years, but maybe much less. Scientific research and innovation has successfully developed efficient and cost competitive hydrogen production, storage and transportation mechanisms. Consumer products using fuel cells are the norm. Portable appliances use fuel cells exclusively and batteries have gone the way of vinyl records. Hydrogen has become accepted as a clean, safe and sustainable form of energy. Indeed, it is the consumer's fuel of choice. Emissions are a fraction of what they are today notwithstanding continuing population and economic growth. The world, including Australia, has made the transition to a hydrogen economy."

National Hydrogen Study, Australian Government, October 2003[1]

Hydrogen is a contentious commodity. Although many millions of tonnes are produced each year for use in diverse applications in the chemical, fertilizer, pharmaceutical and food industries public attention has been focussed on its use in transportation. The recent surge in oil prices and growing environmental concerns over greenhouse gases has stimulated renewed interest in the "hydrogen economy" in which hydrogen replaces fossil fuels such as petrol and diesel for road, rail and marine transport. Even hydrogen powered aircraft are under development. However, the focus of this paper is on the use of hydrogen for distributed electric power generation.

Hydrogen is lovely stuff. At the elemental level it is present in tremendous abundance, unlike our dwindling reserves of most fossil fuels. We are all made of it and it can be extracted from ordinary water. It has the highest energy content (per weight) of any stable chemical compound – nearly three times that of petrol, and it can be converted to electricity in a fuel cell at very high efficiency and with only water as a bi-product. So what is the catch?

Hydrogen is not an energy source. It is a carrier of energy, in much the same way as electricity. It is not found in its free state and has to be made by splitting it away from its parent compounds (water, hydrocarbons) to which it is strongly chemically bound. This splitting process consumes a lot of energy, and further energy is needed to package, transport and store hydrogen - its low molecular weight creating all sorts of problems in each of these facets of the delivery cycle. For instance, it leaks in situations where natural gas does not and it has to be stored at very high pressure or cryogenically to achieve a reasonable energy density. Hydrogen critics say that it is an energy intensive solution and given that most of it is produced from steam reformation of natural gas we are merely shifting greenhouse emissions from the point of use to the point of production, which makes no difference to the earth's atmosphere.

Nevertheless, billions of dollars are being spent around the world to develop the technologies to economically produce, store and use hydrogen in anticipation of its pervasive use as a major energy carrier of the future. The "holy grail" is cheap, clean hydrogen from renewable sources. For example, electrolysis of water using wind or solar energy is technically feasible as shown in Fig.1, but economically impractical on a large scale at the present state of technology. On the other hand hydro and nuclear power may well provide the large amount of energy required to produce hydrogen economically and without greenhouse emissions.

The question is not "if" but "when" and at what cost to develop.

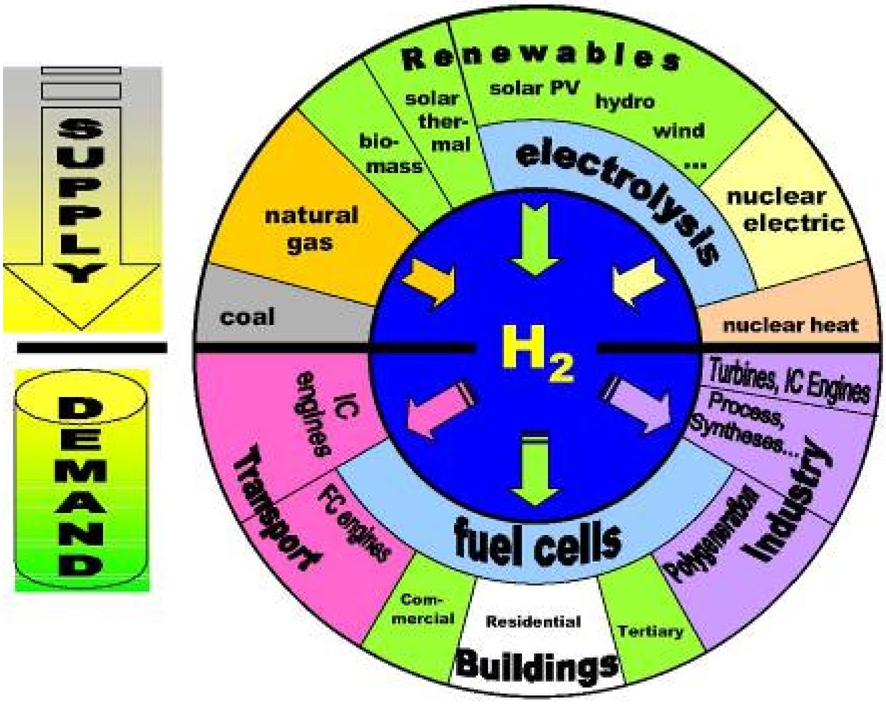

Fig.1: Hydrogen: primary energy sources, energy converters and applications
Source: *Hydrogen Energy and Fuel Cells*, European Commission

1.1 Vision for the power industry

"In this future hydrogen economy, Australia would still have central electricity generating stations utilising coal and natural gas. However, these will ultimately emit only water vapour. Australia's vast coal reserves would remain a long term, secure and cost-effective source of energy, but power plants would gasify that coal and capture and sequester the CO_2 in geological formations or convert it to useful and environmentally safe solid products. Some of the hydrogen produced would be burnt in high efficiency gas turbines to provide electricity, and some would be piped to customers for use in vehicles and distributed generation plants."[2]

What does the future hold for electricity generation in Australia and New Zealand?

How can we guarantee power when and where we need it?….Remote locations relying on diesel shipments to power inefficient generators for electricity in a greenhouse gas constrained world?…..Solar, wind, gas, coal, nuclear, hydro, wave, bio-mass, fuel cells?

The reality will be a combination of all of these, with an increased number of generators distributed amongst user communities where electricity is produced and consumed on site as show in Fig. 2. This has the further advantage that heat by-product can be utilised as well (CHP) resulting in significant system efficiency boost. A number of government agencies are already looking broadly, assessing the risk and cost of relying on centralised power stations, particularly coal fired power stations that are major contributors to greenhouse gas pollution.

It is increasingly recognised overseas that fuel cells may hold the key to providing a major proportion of new base load energy supply in the future. While renewable energy, such as wind and solar are free of greenhouse gas, they do not provide constant, reliable electricity.

Most of the development of fuel cells is taking place in Europe, Japan and USA, with highest profile surrounding portable fuel cells for appliances such as laptops, mobile phones and for vehicles. Australia's only fuel cell manufacturer, Ceramic Fuel Cells Limited (CFCL), is producing Solid Oxide Fuel Cells (SOFCs) for the stationery power market, starting with 1 kW units and building upward to larger systems.

Fuel cells operate by converting gas into electricity and heat on a continuous basis, without combustion or noise and with no moving parts. While comparatively new in Australia, NASA has been using fuel cells to power their space missions since the 1950s.

These low temperature fuel cells, including the Proton Exchange Membrane (PEM) type being developed for automotive applications, use ultra pure hydrogen and oxygen or air to produce electricity, with water as a by-product. However, high purity hydrogen gas is not readily available as a fuel source or low cost in production.

SOFCs (high temperature fuel cells), by comparison, operate on readily available, low cost natural gas that is widely distributed around the world. Other methane rich fuels can also be used including LPG, coal-bed methane, methanol and diesel, as well as bio-fuels such as ethanol, or methane from sewerage and other forms of bio-digestion. Fuel cells have wide ranging applications for generating electricity in homes, commercial, industrial and agricultural premises and in remote locations. Benefits of fuel cells include high fuel efficiency, reduced greenhouse gas emissions, secure power generation for communications and essential services, and in the case of SOFC, flexibility in types of fuel used.

In Australia and the USA there is a growing interest in the gasification of coal and sequestration of carbon dioxide, with the potential for the resultant syngas to be reticulated and converted to electricity at the point of use.

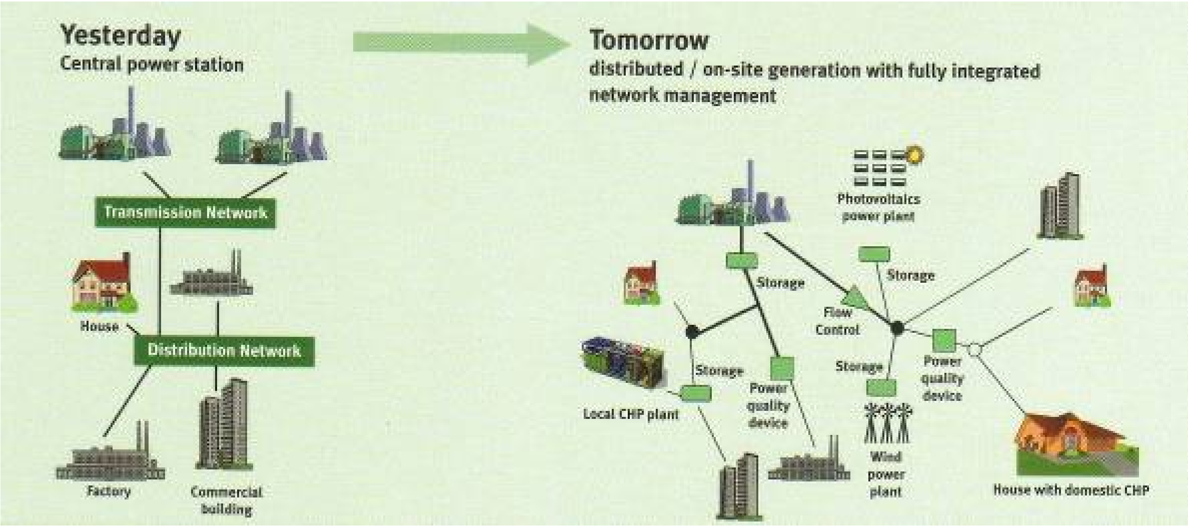

Fig.2: Distributed Energy Resources
Source: *Hydrogen and Electricity,* European Commission

1.2 Potential for widespread distributed generation

"In this future world – which may be much closer than many expect – home owners have the choice of buying electricity from the grid or supplying their own energy needs with a dedicated fuel cell that provides electricity and thermal energy for heating or cooling. That fuel cell will utilise either hydrogen or natural gas reticulated by pipeline. The latter would be reformed to hydrogen on site." [3]

With major vehicle manufacturers predicting that commercially available, mass produced, hydrogen/fuel cell cars are anything from 20 to 30 years away it is natural to think that fuel cells are a technology of the future and even the stuff of science fiction rather than fact. However, there is a growing consensus that we will see commercial fuel cells emerge first in portable appliances such as laptop computers fuelled by methanol and that widespread introduction of stationary power systems will precede transport applications by many years.

Although there are many potential applications for fuel cells CFCL has initially chosen to incorporate its cells into a small scale combined heat and power system (micro-CHP) in which a natural gas fuel cell electricity generator is combined with a domestic-sized hot water heater. In this system useful heat is recovered to heat water for use as hot water and for the hydronic heating system as shown in Fig. 3.

Distributed power generation using micro-CHP units provides significant benefits over conventional centralised power generation through high fuel efficiency and low emissions. CFCL believes its micro-CHP units have the potential to achieve up to 50% electrical conversion efficiency, compared to around 30% for current coal fired power stations, up to 85% overall energy conversion efficiency through heat recovery, and reduce carbon emissions by up to 60% compared to older coal fired power stations.

Europe is embracing this concept, especially in Germany and the UK, where governments are actively encouraging the development and adoption of micro-CHP technology. Japan is also strongly engaged in fuel cell development aimed at the domestic heat and power market.

Key drivers identified by the British Government and others for this emerging market are the high overall energy conversion efficiency, increased power security and lower carbon energy supply which can be gained by locating power generation at or close to the consumer so that waste heat can be usefully captured – this is referred to as *distributed co-generation*.[4] The natural gas powered high-temperature fuel cell, including SOFC, is recognised by the European Commission as being among the most efficient and environmentally friendly means of achieving this[5].

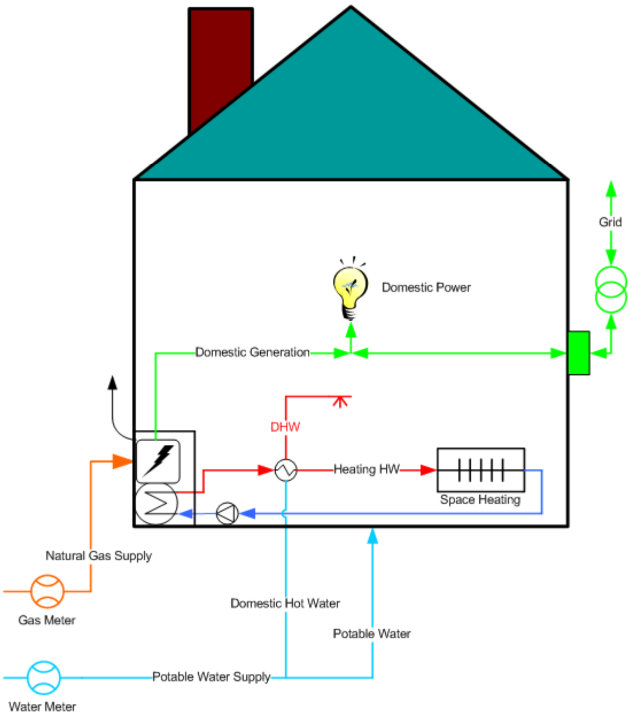

Fig.3: Micro-CHP in a domestic installation

2 Industry Challenges

The hydrogen and fuel cell industry faces many challenges. Clean, economical and safe production, storage and transport of hydrogen were referred to earlier but are outside the scope of this paper. The remaining key issues are cost and reliability of fuel cells and public acceptance.

2.1 Fuel cell cost/reliability

Fuel cells are still very expensive. Low production volumes, labour intensive processes and exotic materials all combine to load the price of what, in essence, is a simple device with the potential to be mass produced very economically. There are many parallels to the silicon chip.

Low temperature PEM cells are the most readily available at a reasonable cost to date. They have the advantage of fast start if fuelled by hydrogen, but lack the longevity to be really useful for base load power, with targeted life of around 5000 hours – all right for a car but not sufficient for a power station. To date they are achieving less than this and the technology uses high cost materials such as platinum, which limit the scope for cost reduction. They also require pure hydrogen as a fuel, which creates other application limitations or problems.

High temperature cells including SOFC are less commercially available and higher in cost at present but have much longer life. 40,000 hours is the target and systems have already been shown capable of this. They use a wider range of fuels and because they can internally reform methane to hydrogen require much less complex external fuel processors if natural gas is the energy source. Planar (flat plate) cell designs such as that developed by CFCL lend themselves to mass production and automated materials handling. As volumes increase costs will come down – to this end CFCL has developed its own ceramic powder technology and sees potential cost reduction from vertical integration back into the materials supply chain.

2.2 Public acceptance

The word hydrogen is emotive for many people. It conjures up pictures of fireballs and the concept of high pressure storage at 350 to 700 bar (5000 to 10000 psi) certainly worries many engineers. In fact it can be very safe when appropriate measures are taken and generally represents less of a hazard than petrol with which we are all quite comfortable. Because hydrogen is generated internally and almost immediately consumed at relatively high temperatures in a SOFC system there are no storage issues and leakage would be oxidised on contact with air, initiating safety shut down systems.

The concept of generating power in your own home is one that will take time to sink in. However, we are all very much aware of the inconvenience of losing mains power so the idea of having at least some capacity to make your own should prove attractive. Power companies on the other hand may view widespread uptake of micro-CHP as a threat – but in all threats there are opportunities and the transition from buying centrally generated electricity to selling more gas as well as the deferral of network augmentation investment is certainly attracting the interest of many energy service companies.

3 Government support

Without substantial government support the hydrogen economy will be a non-event. The scale of investment and long development cycle represents too high a risk for most commercial investors without the assurance of appropriate government policies and financial support. Fortunately governments around the world recognise this and are pouring billions into making it a reality. The following outlines just some of the initiatives in place to support stationary power generation.

3.1 USA

In the USA the Department of Energy (DoE) has recently initiated a working group to review opportunities for the development and introduction of micro-CHP technologies[6]. The DoE is already providing strong support for small scale SOFC development in the 3 to 10kW range via its Solid Energy Conversion Alliance (SECA) with aggressive goals over a nine year period to 2010 including a factory cost target of US$400 per kW[7]. Larger scale fuel cells, including SOFC, are supported under the US$ 1 billion Future Gen program, which is an integrated hydrogen, electric power production and carbon sequestration initiative aimed at coal gasification. Overall the US is spending around US$ 300 million on hydrogen and fuel cell programs.[8]

3.2 Europe

The UK Government recognised the potential importance of micro-CHP in their 2003 Energy White Paper, which also proposes mandatory installation of high efficiency (condensing) boilers from 2005.[9] High efficiency water heating benefits the end-user through lower energy bills but comes at a price premium so the UK Energy Savings Trust has recommended that micro-CHP systems should be subject to VAT at only 5% to assist their introduction, which they estimate could be up to 1 million units by 2010.[10] This proposal was provisionally accepted in the 2004 budget.

In order to rapidly promote market adoption of high efficiency distributed generators, the German Government has introduced a CHP law, which regulates the purchase and remuneration of electricity exported to the grid. The law provides the largest subsidy of €0.0511/kWh for electricity generated by small CHP plants of 50 kW (electrical output) or smaller.[11] If bio-fuels are used the subsidy is substantially higher.

3.3 Australia

In its 2004 Energy Policy White Paper the Australian Government recognised CFCL's solid oxide fuel cells as being "world-leading" and offering "...significant potential for moving to more distributed electricity generation"[12]. CFCL has been a major recipient of funding under AusIndustry's R&D Start program and has also benefited from Victorian State funding as well as support from Queensland via the large commercial investment through State owned energy company, Energex.

The Australian Government also instigated the National Hydrogen Study in 2003 and has joined the International Partnership for the Hydrogen Economy. In spite of this recognition the Government rejected the 2004 application from Australia's hydrogen research community, which includes CSIRO, several universities and CFCL, for the formation of a Cooperative Research Centre (CRC). This is probably more a reflection of the general change in approach to CRCs (more short term commercial focus) than a lack of interest in hydrogen technologies.

Energy efficiency legislation such as the NSW BASIX scheme may accelerate the uptake of micro-CHP[13].

4 Fuel cell technology developments

Although there are many different types of fuel cell under development this section will be limited to Solid Oxide Fuel Cells. SOFCs are based on a ceramic electrolyte that conducts oxygen ions at high temperature (700 to 1000°C). The principle of operation is shown in Fig. 4 below.

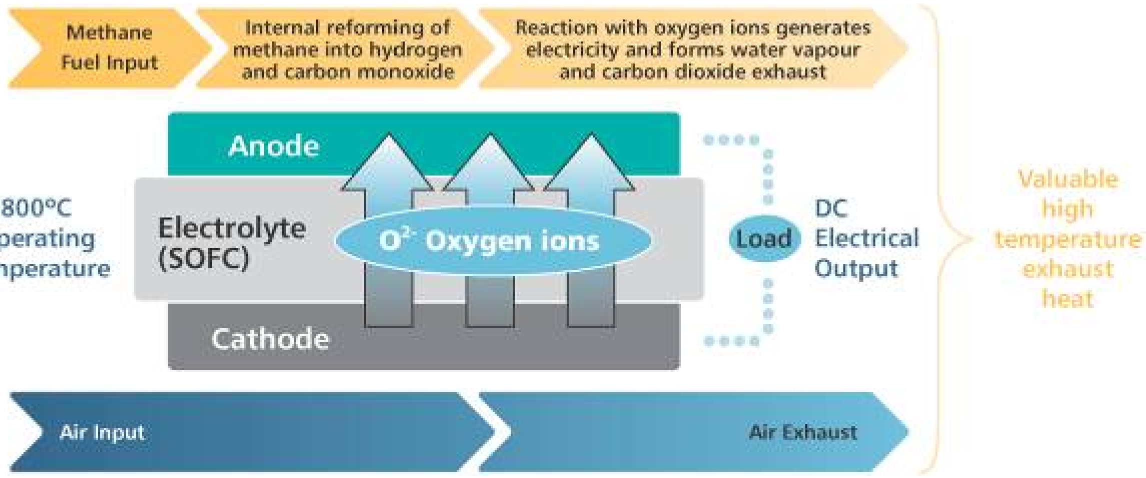

Fig.4: Operation of Solid Oxide Fuel Cell

Various materials are used for the electrolyte, the most common being based on Zirconia which is an oxide of a common mineral sand, Zircon. This is combined with other elements to stabilise and strengthen the material. The electrolyte surfaces are coated with catalysts forming the anode and cathode which promote the electrochemical reactions for internal reforming and oxygen ion formation. Internal reformation of methane to hydrogen and carbon monoxide is one of the key benefits of CFCL's SOFC compared with low temperature cells which require complex external reformers if they are to run on natural gas.

Different methods of construction are used including tubular and planar forms with either the electrolyte acting as the main mechanical support or one of the other materials such as the anode. Some forms of construction use metal plates to support the cell structure.

CFCL's 4th generation planar arrangement is illustrated below.

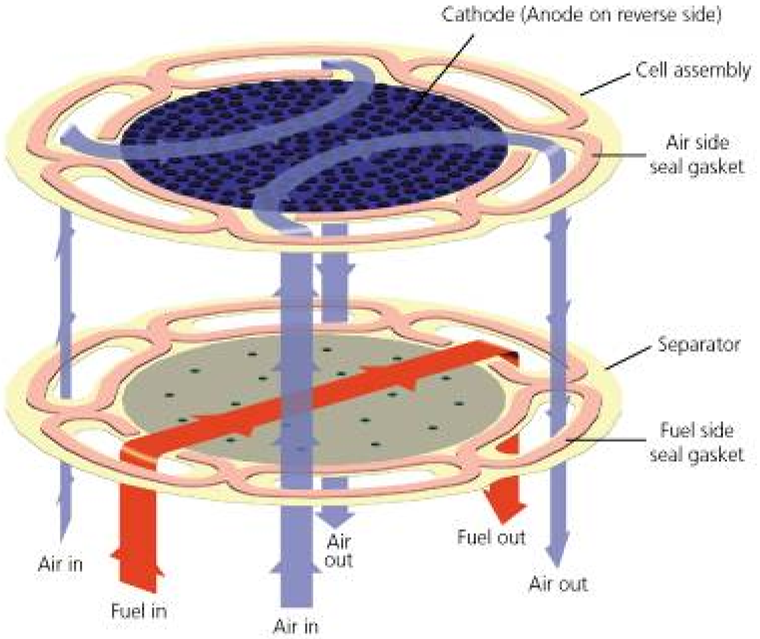

Fig.5: CFCL planar solid oxide fuel cell construction and gas flow

CFCL's fuel cell comprises four major components: an electrically conductive separator plate; glass/ceramic fuel seal; active cell with electrolytic plate, anode and cathode; and an air seal. This "layer set" is repeated 28 times to produce a 150 Watt sub-stack which is the building block for larger stacks up to 2 kW. Stacks can be paralleled to produce higher outputs. Fuel, air and exhaust gases are ported in and out of the stack via manifolds formed by the alignment of slots and seal gaps.

A key feature of CFCL's present design is the "all ceramic" construction of each sub-stack ensuring a close match between the thermal expansion of each component which facilitates cycling of the system from cold to operating temperature and back again without damage.

The application of SOFC systems range from portable generators of less than 100 watts to large stationary power plants of several hundred kilowatts. CFCL has developed designs for systems in modules of up to 50kW but is concentrating its current development effort on commercialising the technology in the range of 1 to 10kW because of the large market potential for distributed generation at the domestic or "micro" level.

To demonstrate the practical application of its fuel cell technology CFCL is building a series of pre-commercial micro-CHP units as shown in Fig. 6.

CFCL is also working to adapt its fuel cell system to create electricity from bio-fuels such as methane and ethanol. Bio-methane is becoming recognised as a gas resource that should be used, rather than treated as a waste or allowed to escape to the atmosphere, where it has significant impact. Methane occurs naturally at sewage treatment plants, waste tips, dairy farms, and coal mining operations. CFCL has also identified techniques for extracting methane from ethanol, which is produced from sugar cane, wheat, corn, wood pulp and other plant materials.

Fig.6: CFCL's micro-CHP unit in which a 1 kW fuel cell generator is combined with a domestic sized hot water heater

5 Marketplace commercialisation

Fuel cell based CHP systems are being field trialled by several European energy companies such as RWE, EoN and EnBW in Germany, who see significant added value from small scale fuel cell based distributed generation with high efficiency, low noise and vibration and minimal emissions.[14]

Apart from fuel cells, other micro-CHP technologies under trial include engine type technologies (eg internal combustion, external combustion Stirling engines, Rankine cycle steam engines) although these can only operate for a limited number of hours a year because they are essentially heat generators with very low electrical efficiency which must be turned off when hydronic heating is not required during the summer.[15]

By comparison, the solid oxide fuel cell based micro-CHP with a power-to-heat ratio of about 1 to 1 allows efficient all year round operation as it is primarily an electricity generator with useful waste heat. Additional water heating energy is supplied by an auxiliary heater.

On 18 November 2004 CFCL signed a contract for its first commercial field trial in New Zealand with Powerco, and plans further field trials in Australia and Europe for 2005.

One purpose of the trials is to attract partners with whom to develop commercial end use application products as CFCL does not intend to become an appliance manufacturer. Typically partners for the micro-CHP product will come from the water heater or gas appliance industry and discussions are taking place with several such companies.

CFCL is also planning joint venture manufacture for the fuel cells themselves with prospective partners coming from the high volume precision ceramics industry.

6 Bridging the gap

Fuel cells promise to be one of the most important energy conversion technologies of the 21st century. Because of their high fuel efficiency they can make a significant contribution to reducing greenhouse gas when running on readily available fuels such as natural gas. Overall fuel efficiency is further boosted by capturing waste heat and using it to create hot water in domestic and commercial environments.
CFCL believes there is a significant future market opportunity for residential Combined Heat and Power (micro-CHP) units in which a fuel cell based electricity generator of between 1 and 5 kW is integrated into a gas fired domestic water heating system.

When hydrogen eventually becomes economically available on a reticulated basis the design of SOFC micro-CHP units will be modified to allow its direct use. Until then natural gas and other methane rich fuels will bridge the gap.

Ceramic Fuel Cells Limited (CFCL)

CFCL is a developer of fuel cell systems based on solid oxide fuel cell (SOFC) technology that deliver reliable, energy efficient, high-quality, low-emission electricity from natural gas, LPG, methane and other alternative and renewable fuels. The company is acknowledged globally as a leading developer of flat-plate, all-ceramic, SOFC and stack technology. CFCL is publicly listed on the Australian Stock Exchange (ASX code: CFU)

CFCL has built a proof-of-concept micro-CHP system and is currently building prototypes of a pre-commercial version for field trials in Australia, New Zealand and Europe during 2005.

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[1] National Hydrogen Study, Australian Government, October 2003
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[3] ibid
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