Fuel Cells – Commercial Innovation Built on High Electrical Efficiency

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ABSTRACT

Since inception, electricity generation has virtually remained unchanged for decades. Today, electricity is generated at low efficiencies through rotational generators, driven by centralized thermal power plants and, more recently; wind turbines, solar-photovoltaic arrays and solar thermal plants. Ceramic Fuel Cells Limited (CFCL) has changed the paradigm of how electricity is generated – using Solid Oxide Fuel Cell (SOFC) technology to generate electrical energy at up to 60 per cent electrical efficiency. This technical breakthrough enables energy supply through innovative business models.

Keywords: fuel cells, solid oxide, co-generation, electrical efficiency, distributed generation

1 BACKGROUND

CFCL is an Australian based global company engaged in the development of SOFC products. Formed in 1992 from the Australian Government scientific & industrial research organization and consortium partners, the Company has invested over US$260 million in the commercialization of fuel cell technology. The goal of the Company's technology is generating highly efficient electricity from fuel cell co-generation appliances for residential and light-commercial applications. Supporting these commercialization efforts, CFCL has invested over €9.5 million (US$ 13.5 million) in establishing a high-volume SOFC assembly factory in Germany.

1.1 Energy vs. Emissions Squeeze

The prices for energy, particularly electricity, are rising throughout the world. In Australia, power bills are forecast to double in the next five years, with guaranteed price increases every year for the next decade[1]. These rises are being driven by the need for huge investments in the electricity grid. In the Australian state of New South Wales the Government is spending more than A$9 million (US$9.3 million) *per day* on maintaining and upgrading the power supply[2]. In Europe, the European Union Energy Commissioner said that over the next decade, an investment of one trillion Euros is needed in energy infrastructure[3].

In July 2010, international consulting firm Boston Consulting Group described the emergence of distributed generation as the biggest transformation to the power sector since Thomas Edison's invention of the light bulb.
The Boston Consulting Group report[4] highlighted:

"Smaller CHP plants (serving commercial and residential customers) show particular promise and are already starting to be commercialised. We believe that if they apply the right business models and tap all revenue sources, utilities will be well positioned to generate power with small-CHP units at costs that can complete with large-scale power plants over the next few years."

The USA faces its own challenges, even within environmentally aware markets such as California. Traditional installation of Renewables poses challenges for new infrastructure connecting large scale remote Renewables to the grid. The 2011 Integrated Energy Policy Report (IEPR) from the California Energy Commission highlights key requirements that affect many other US states, like **reducing peak energy demand**, making new homes and commercial buildings in California "zero net energy," specifically using more efficient technologies such as **combined heat and power projects** to generate electricity. It also includes the Governor's goals to increase renewable electricity in California by adding 12,000 megawatts of **localized electricity generation**.

The message is clear. More electricity with fewer emissions – delivered efficiently and consumed efficiently – whilst having highly flexible generation capability.

2 TECHNOLOGY

A fuel cell is an electricity generator that converts gas into electricity and heat through an electrochemical reaction, without combustion or noise. Fuel cells can provide significant economic and environmental benefits through high efficiency and low emissions.

CFCL is the only company in the world to achieve 60 per cent electrical efficiency from a fuel cell system, let alone any small-scale generation technology. CFCL has developed a modular high electrical efficiency co-generation product called BlueGen™. BlueGen™ is currently being commercialized world-wide. The company has over 55 demonstration projects with customers in Germany and other parts of Europe, Japan, Australia and the USA.

These leading customers are demonstrating the CFCL's technology, built on more than 350,000 hours of operation.

BlueGen™ is changing the paradigm of how electricity is produced and consumed as part of distributed generation networks:

- Uses existing natural gas infrastructure;
- Electrical efficiency of over 60 % at the point of use;
- Controllable, constant operation;
- High electrical efficiency at part load;
- Capability for remote control; within
- A very small package – about the size of a dishwasher.

2.1 Benefits of Modular Co-generation

BlueGen™ is designed for installation as a 'modular' or add-on unit. This enables quick and easy installation – similar to a domestic heat-pump or air conditioner appliance. Modular co-generation also allows flexible installation where the BlueGen™ unit can be installed in a number of different locations and configurations:

- Indoors (cold climate) to outdoors (mild climates)
- Heat recovery (hot water) or no heat recovery

The primary benefit of high electrical efficiency is low thermal outputs. Table 1 compares the electrical efficiency and heat to power ratio for common co-generation technologies.

Technology	Electrical Efficiency	Heat to Power Ratio
Solid Oxide Fuel Cell	Up to 60 %	< 0.5:1
PEM Fuel Cell	30-35 %	2:1
Internal combustion engine	20-27 %	3-4:1
Stirling engine	15 %	6-10:1
Rankine engine	7-15 %	7-10:1

Table 1 Typical electrical efficiency of common co-generation technologies

2.2 Low Heat Output = Longer Operation

The high electrical efficiency and modular approach provide environmental and economic benefits. In warmer climates requiring air-conditioning, high electrical efficiency and low heat outputs provide additional benefits during warmer months. CFCL's fuel cell technology operates continuously during the year. Figure 2 highlights the limitations of traditional co-generation systems, where low electrical efficiency results in either; a) wasted thermal energy during summer months, or b) idle capacity during periods of low thermal demand.

Traditionally co-generation and been viewed as an energy solution for larger installations that have a clear demand for heat – *e.g. heavy industry, hospitals, community swimming pools.* A low heat output from small-scale co-generation now allows scope for new markets.

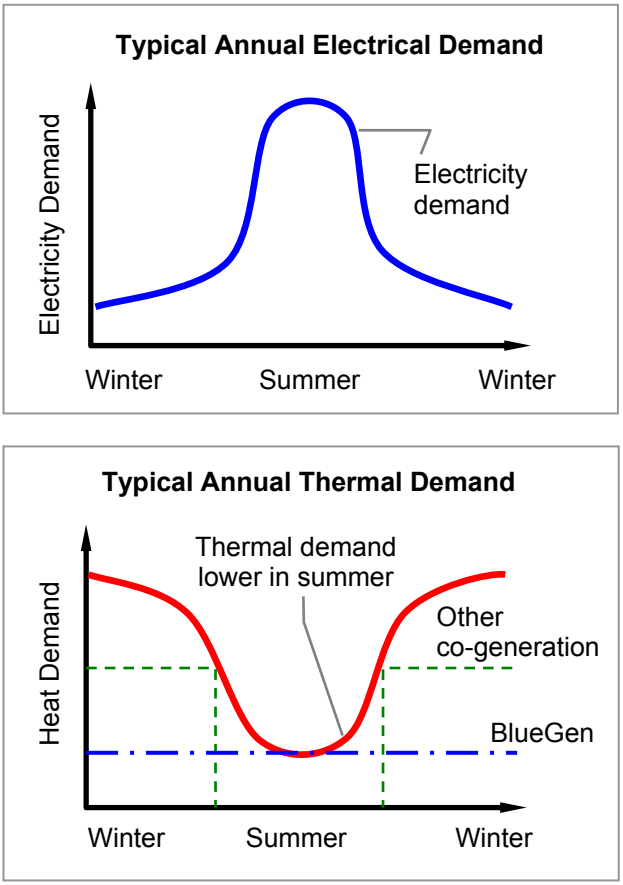

Figure 1 Mismatch of thermal & electrical demand

3 RELEVANCE AND BENEFITS FOR THE US MARKET

Small-scale co-generation with high electrical efficiency provides added benefits which are shared across sectors:

3.1 Benefits for Gas Utilities

Depending on which part of the value chain the utility operates, high electrical efficiency co-generation provides a number of benefits to gas utilities:

- Predictable base consumption of gas across the distribution network over the year - *particularly over warmer periods with lower thermal demand*
- Increased gas sales of two or three times to residential customers - *with lower carbon emissions compared traditional energy supply*
- Allows stronger and longer-term consumer relationships - *especially in 'contestable' markets, whereby gas companies can also supply electricity*

Most companies testing and deploying BlueGen™ with CFCL are gas utilities or gas-electricity utilities.

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3.2 Benefits for Electricity Utilities

For electricity utilities, the biggest benefits are also attached with the biggest challenges. Often, electricity utilities have a deep-seated centralized culture – i.e. generate centrally, distribute remotely. Electricity utilities with a strategy around Distributed Generation, Smart Grids and embedded Renewables are well positioned to capitalize benefits from modular co-generation:

- Highest level of electrical generation efficiency than any other technology - *electrical efficiencies of 60 % at the point of use*
- Integral part of Smart Grids and the virtual power plant contracting model - *distributed deployment controlled centrally*
- Can counter the intermittent nature of renewable energies - *also avoids issues & challenges with interconnection of Renewables*
- Defers up-front investment in reinforcing T&D infrastructure and helps relieve critical congestion areas - *units can be remote controlled & modulated for peak shaving operation*
- Allows stronger and longer-term consumer relationships - *especially in 'contestable' markets using small-scale energy contracting models*

With the impending electrification of transport and the subsequent increase in demand, high electrical efficiency co-generation is a complimentary technology to the mix of centralized and renewable electricity generation.

3.3 Benefits for the Environment

The key environmental benefit from high-efficiency fuel cells is low emissions. The BlueGen™ unit produces virtually no NOx or SOx and low levels of CO_2. Without heat recovery CO_2 emissions are typically less than ¾ lb (340 g) CO_2 per kWh. This figure can be further improved when waste heat is utilized from the unit (displacing additional energy that normally heats water). Annual CO_2 savings depend largely on carbon intensity of the localized electricity grid. Table 2 provides an overview of annualized CO_2 savings by country based on the carbon intensity of various electricity grids from www.carma.org.

Region	No Heat Recovery	Displacing Electric Hot Water
Australia	~ 11.6 tonnes	~ 14.8 tonnes
Germany	~ 6.7 tonnes	~ 9.8 tonnes
UK	~ 5.0 tonnes	~ 8.9 tonnes
USA	~ 6.6 tonnes	~ 9.9 tonnes

Table 2 Typical Annual CO_2 savings from BlueGen™

Counter intuitively, a BlueGen™ unit fueled by natural gas *actually* saves more CO_2 compared to a solar PV installation over the course of a year.

A report by the Australian Government scientific & industrial research organization concluded that a BlueGen™ unit operating at 1.5 kW could save up to four 4 times more CO_2 than a 2 kW solar PV installation[5] in the state of Victoria.

Measure	Unit	House with Solar PV	House with BlueGen
Output	kW	2.0 peak	1.5 constant
Annual electricity production	kWh	~ 3,000	~ 12,000
Annual CO_2-e savings	Tonnes	~ 3.2	~ 12.9

Table 3 CO_2 savings between BlueGen™ and Solar PV in the Australian state of Victoria

BlueGen™ achieves these remarkable figures through high electrical efficiency and constant operation 24/7 - unaffected by nightfall and cloudy, or inclement weather.

4 CASE STUDIES

The following sections highlight case studies based on CFCL's real-world experience with BlueGen™.

4.1 Germany

In Germany, city utilities (Stadtwerke) are dominant suppliers of electricity, gas, water, and heating contracts to end customers. Of the 900 German retail companies for electricity - 700 are Stadtwerke. Overall, they retail 54 per cent of electricity, 52 per cent of gas, 77 per cent of water and 54 per cent of heat contracts. However, Stadtwerke are relatively small producers of electricity – with an estimated 14 GW (or 9 per cent) of Germany's power generation. Most of this 14 GW is generated with Combined Heat & Power (CHP) and Renewables. Stadwerke are planning to increase this share through growth in energy-efficient and renewable power production. Profitability has been eroded due to; i) highly competitive electricity pricing (small margins), ii) a significant fall in gas sales due to rapidly increasing thermal efficiency of buildings, and iii) difficulties to retain customers in the deregulated environment. Stadtwerke are increasingly offering *complete* energy services to their customers in the areas of energy efficiency - in particular, consulting and contracting of heat and electricity – and using their experience in CHP and Renewables. BlueGen™ is ideal for Stadtwerke as the generation asset can be embedded in the customer's residence under 'energy' supply contracts. A number of Stadtwerke are trialing BlueGen™.

4.2 Australia

The Australian market shares similarities with Europe and the USA. Building stock and climatic conditions are closer aligned to the USA, with many homes using air

conditioning for heating and cooling. However, like Europe, the Australian energy market is 'fully contestable' – with the state of Victoria and the UK cited as the most competitive energy markets in the world (on customer switching rates)[6]. Coupled with ageing infrastructure, Australian utilities are faced with investing in peaking generation and distribution networks that are utilized less than one per cent of the year (summer electricity demand).

Ausgrid is an integrated utility based in the state of New South Wales supplying gas and electricity to end-users. During 2010, the company renovated a typical dwelling into a SmartHome, incorporating solar panels, energy efficient appliances, an EV and a BlueGen™ unit. A family of three moved into the house and blogged about their experiences. After half a year, the BlueGen™ produced more electricity than the home's demand (with the excess being exported to the grid). During peak times, the cost of electricity produced from BlueGen™ was approximately half the retail cost[7]. The CO_2 savings over the same period were also significant – approximately 4.2 tonnes. Ausgrid is planning to deploy BlueGen™ into Australia's first commercial scale Smart Grid project.

5 BUSINESS MODELS

With the three key features of BlueGen™:

- High electrical efficiency of 60 %
- Low heat outputs for year-round operation
- Ease of installation and remote control

BlueGen™ plays a vital 'enabler' role in new, innovative business models within the energy market. CFCL is working with a number of organizations world-wide to deploy BlueGen™ in volume.

5.1 Regulatory Environment Importance

Every energy market is different. Even in close-coupled markets, such Europe, a disparate market picture exists - the key differentiator is the regulatory environment for each country. Policy, market regulations, and economic incentives drive the market structure. In contestable or deregulated markets; incumbent suppliers, new entrants and consumer preferences interact to shape the energy supply. Unlike other technology companies, CFCL spends significant effort working with partners to understand the regulatory environment – as the regulatory environment (along with consumer preferences) shape the final co-generation product. Especially, *who* should own the unit and *how* the unit should operate.

5.2 Building or Homeowner Model

One obvious business model is where the homeowner purchases and operates the BlueGen™ unit:

Benefits

- Reduce or offset the cost of imported electricity
- Heat recovery from the fuel cell is straightforward
- Strong economic incentives for homeowners who can utilize *all* the generated and recovered heat.

Challenges

- The homeowner often has a narrow 'spark spread' - *i.e. narrow gap between gas and electricity prices*
- Purchase, installation, operation, and maintenance costs many not be tax effective – *i.e. not recoverable*
- May not utilize all of the generated electricity – *i.e. payment for exported energy is necessary.*

Typically, without external stimulus or economic incentives, the homeowner business model yields lower financial returns. However, the homeowner model can exploit market introduction incentives (Feed in Tariffs, Self Generation Incentive Programs) in the short term.

5.3 Utility (or Commercial Entity) Model

Depending on market regulations, opportunities exist for either; i) incumbent players or, ii) new entrants to deploy BlueGen™ units. The commercial entity model allows higher and faster returns, as commercial entities can aggregate additional benefits from deploying multiple units:

Benefits

- The most efficient method of generating controllable electricity – *i.e. more electricity for less fuel*
- Smart Grid & virtual power plant style operation for electricity trading
- Monetization of CO_2 savings through aggregating multiple units
- Improved utilization of distribution assets along with deferring investment into infrastructure
- Operation & maintenance becomes tax effective
- Retention of customers outside existing contract periods – *i.e. ideal for non-utility organizations*

Increasingly, CFCL is seeing many non-utilities showing interest in BlueGen™ as a way to compliment existing relationships and services with consumers.

REFERENCES

[1] Go switch, www.goswitch.com.au.

[2] Australian Financial Review, 8 July, 2010.

[3] Günther Oettinger, Belgian Presidency Conference on Infrastructure of Energy research, 2010.

[4] Boston Consulting Group, "Toward a Distributed-Power World: Renewables and Smart Grids Will Reshape the Energy Sector", 2010.

[5] Peter K. Campbell, CSIRO, "Desktop Greenhouse Gas Emission Comparison of the BlueGen Fuel Cell Unit with Other Means of Providing Electricicty and Heat to Australian Homes", 2010.

[6] Vaasa-ett, "Utility Customer Switching Research Project - Latest World Energy Retail Market Rankings", 2010.

[7] Smart Home Family Blog, "BlueGen Cutting Down Carbon Emissions", Feb 2011, www.smarthomefamily.com.au.