CERAMIC FUEL CELLS LIMITED
Clean power for your home

Challenges in Commercialising an Ultra-efficient SOFC Residential Generator

Presented to

IPHE Workshop on Stationary Fuel Cells

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www.cfcl.com.au

Introduction

Ceramic Fuel Cells Limited (CFCL)

- Formed in 1992
  - Spinout from CSIRO (Australia's premier R&D organisation)
  - About 120 staff
  - Head Office in Melbourne, Australia (5000 m^2 of R&D and prototyping facilities)
  - Subsidiaries in Heinsberg, Germany and Bromborough, UK
- Development of highly efficient electricity generators (micro-CHP) for the residential market based on SOFC technology
- Development strategy focused on optimising SOFC advantages (high electrical efficiency and load following at high efficiency)
- Since 2006 of 300000 hours of field testing experience in 9 countries
- Installed volume production facilities for stacks (10000 per year) and Bluegen systems (1000 per year) in the Heinsberg facility
- To date spent AUD 268 million for development

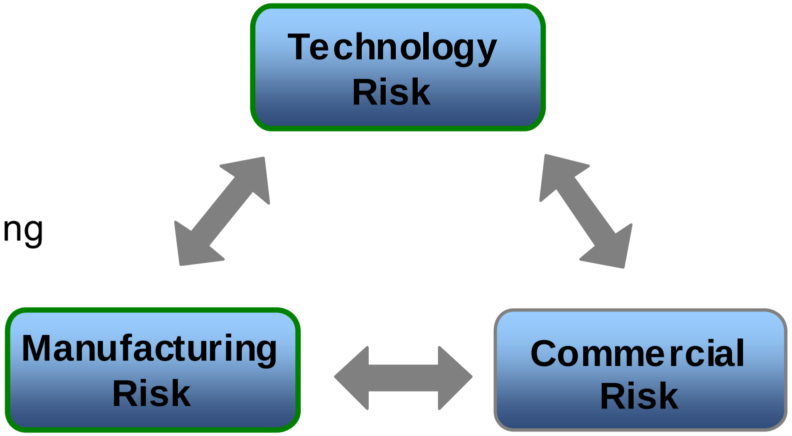
Commercialisation Challenges

Commercialization of fuel cells…

- Exactly the same challenges as many other technologies;
  1) Fundamental discovery
  2) Validation of technology & manufacturing
  3) Volumes up to drive the cost down (volume-cost learning curves: high tech products ~ 15-20%)
  4) Establishing commercial offering

- Technical:
  - Achievement and validation of commercial targets (key product features, differentiation from existing solutions; operational performance)

- Key focus, build volume to reduce costs;
  - Product manufacturability and manufacturing infrastructure
  - Identify cost volume curve
  - Identify markets to match cost profile
  - Build volume (aggregated across many markets…
    - *Thereby taking a 'platform' approach:*



Technical Challenges

The Residential Product – Design requirements

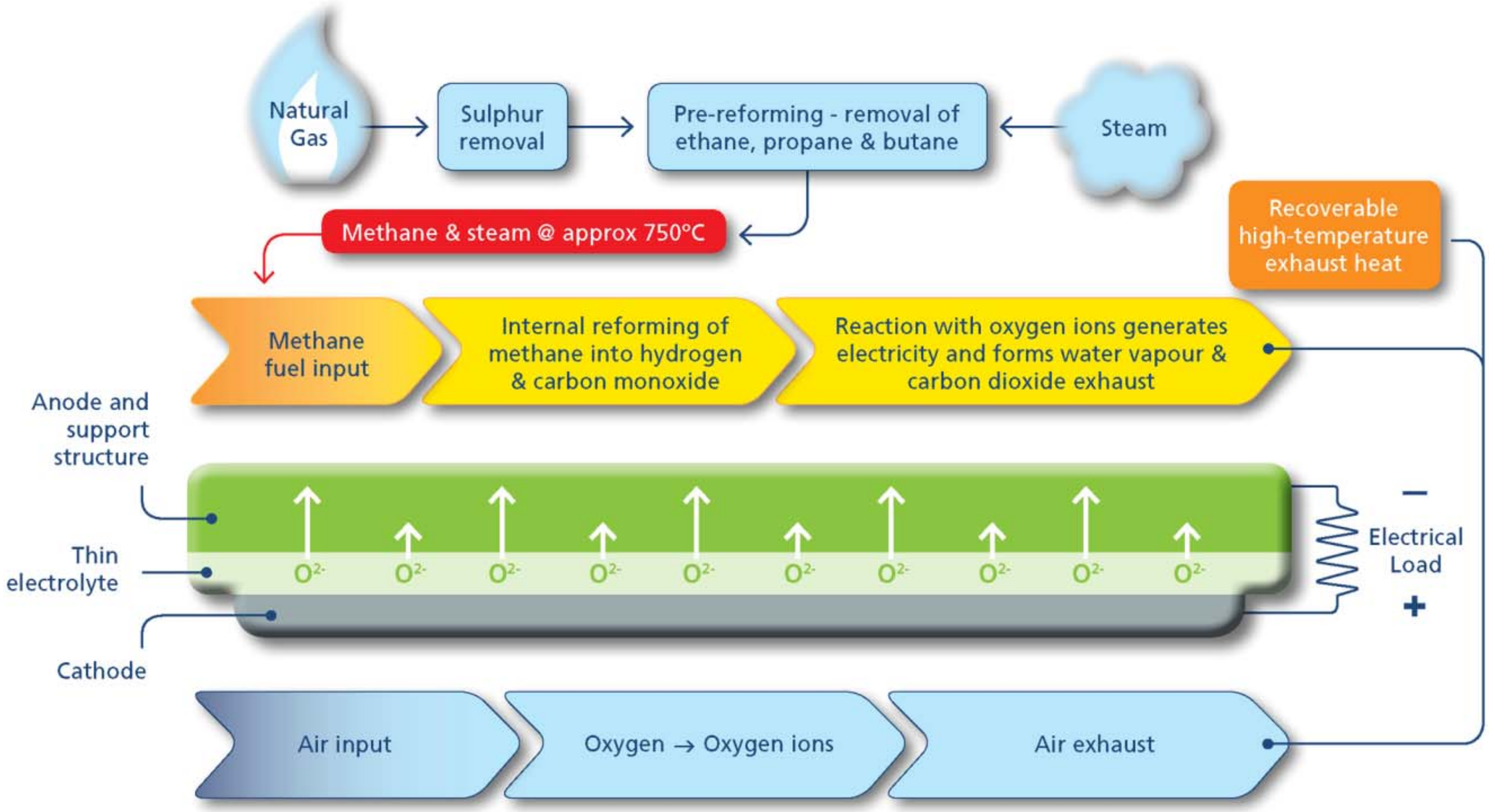
True Distributed Power Generation NOT electricity producing heating system

- **Home generator recovering its waste heat**

  Electricity Generator with heat recovery (option of full home energy system through coupling with highly efficient boiler)

- **Ideal application for high temperature fuel cells**
  - Electrical efficiency substantially higher than the grid (up to 60% at user site) and other micro-CHP appliances
  - Generator produces small amounts of heat (heat to power <0.5) but with heat recovery >80% total efficiency
  - All year round operation
  - Low emissions and noise and vibration – easy siting – “the Power Station in the home”.

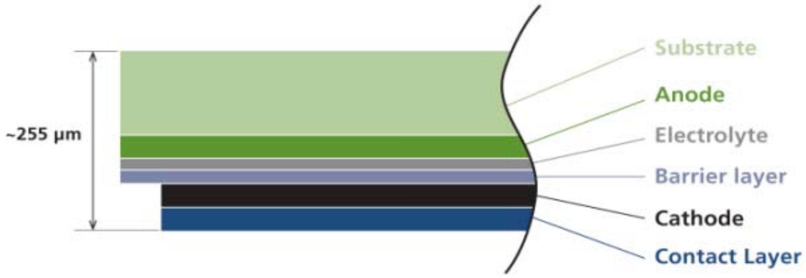
Key SOFC Technologies - Internal reforming



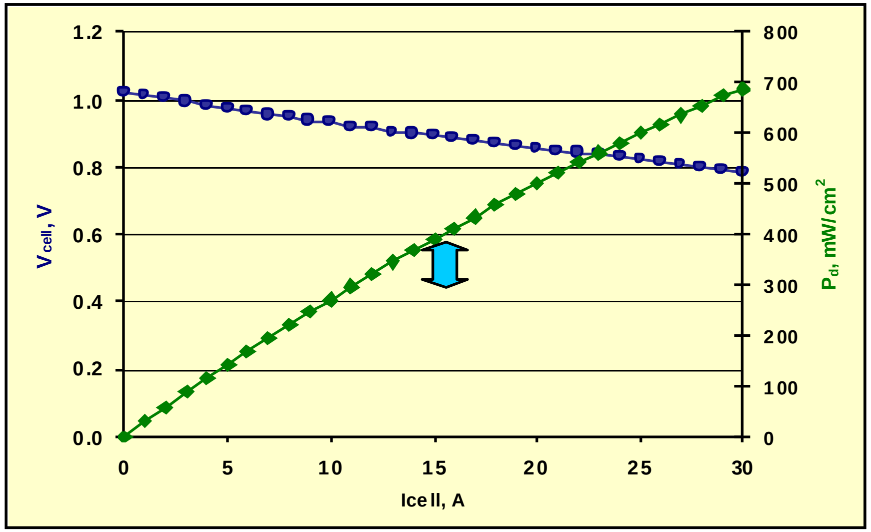
Key SOFC Technologies - High Performance Cells

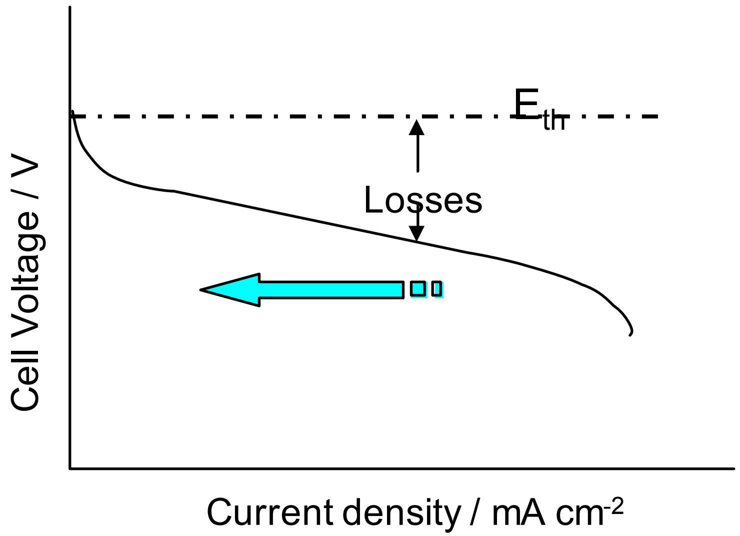
Structure and Performance

- Anode supported cell
- Test under real conditions:
  - Fuel: NG, 10% pre-reformed and de-sulfurized
  - Temperature: 750°C
  - 100% Direct Internal Reforming
  - Fuel Utilization: up to 90% in single pass
  - Gross η_e: >70% in single pass

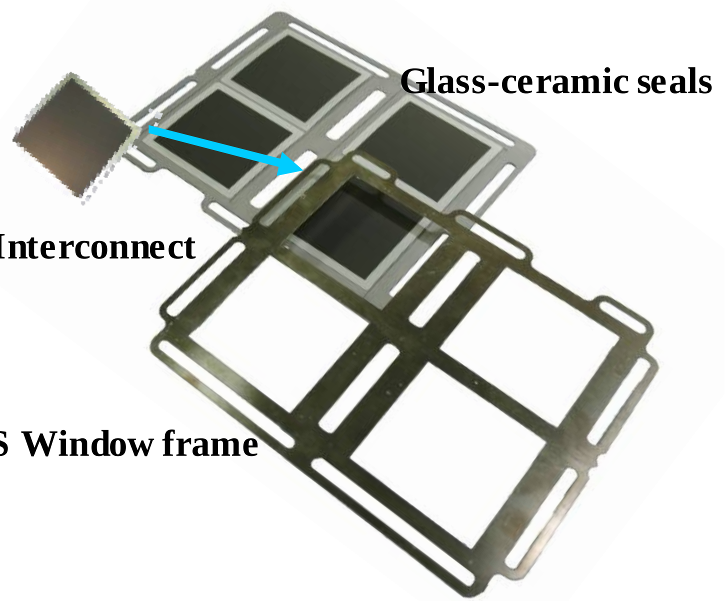


6-layer ASC (70x70mm)

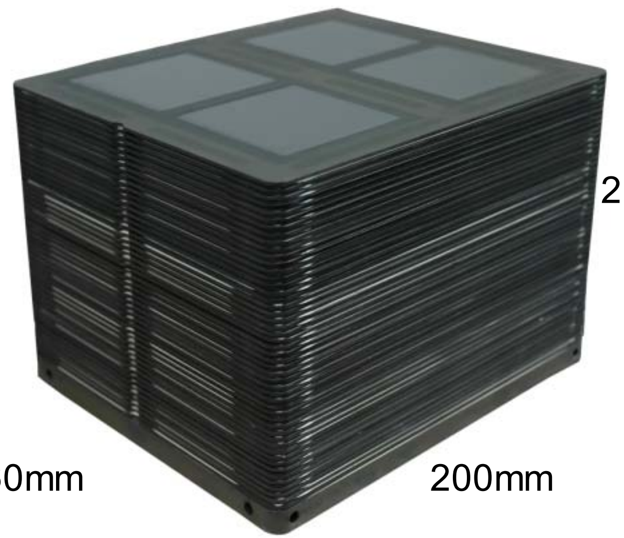




Key SOFC Technologies - Stack Design



4x4 Array Design



Performance

Operating temperature 750 °C (average)
Direct internal reforming
High fuel utilisation - approx 85%
Gross electrical output up to 2.3 kWe
Gross stack electrical efficiency >68 %

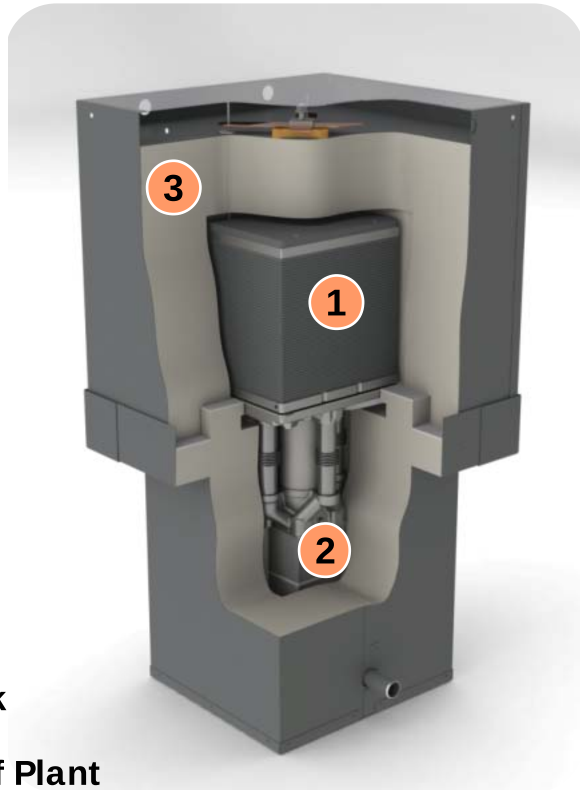
Lifetime:

23000 hour stack test in test stand
Voltage degradation of 0.3%/1000 hours

Key SOFC Technologies – Module Design

Overview

- Stack designed for high efficiency (operation at cell voltages >0.8 V and $U_f \geq 85\%$)
- Extremely compact & efficient 4-way heat exchanger
- Compact and tightly integrated design to minimize heat loss & maximize efficiency
- Low pressure drop
- Unique burner for both start-up and operation
- Ease of manufacturing with high reliability
- Proven design across many systems



GENNEX fuel cell module

"…the heart of BlueGen…"

1. **Fuel Cell Stack**
2. **Hot Balance of Plant** (air & fuel heat exchanger, steam generator & burner)
3. **High Temperature Insulation**

Product Options

Common technology platform creates different products and customer offerings

GENNEX fuel cell module

Fully integrated mCHP

- *Power + hot water and space heating*
- *For markets & customers needing a complete heating solution*

Modular Co-Gen

- *Power + hot water*
- *For markets with lower heating demand (Australia, Japan, US)*
- *And customers with existing heating systems (EU retrofit)*

with partners

e·on UK

GDF SUEZ

EWE

CFCL

BlueGEN

BlueGEN

Residential Generator

- Dispatchable base load power

Electrical Output:
0 to 2kW modulated

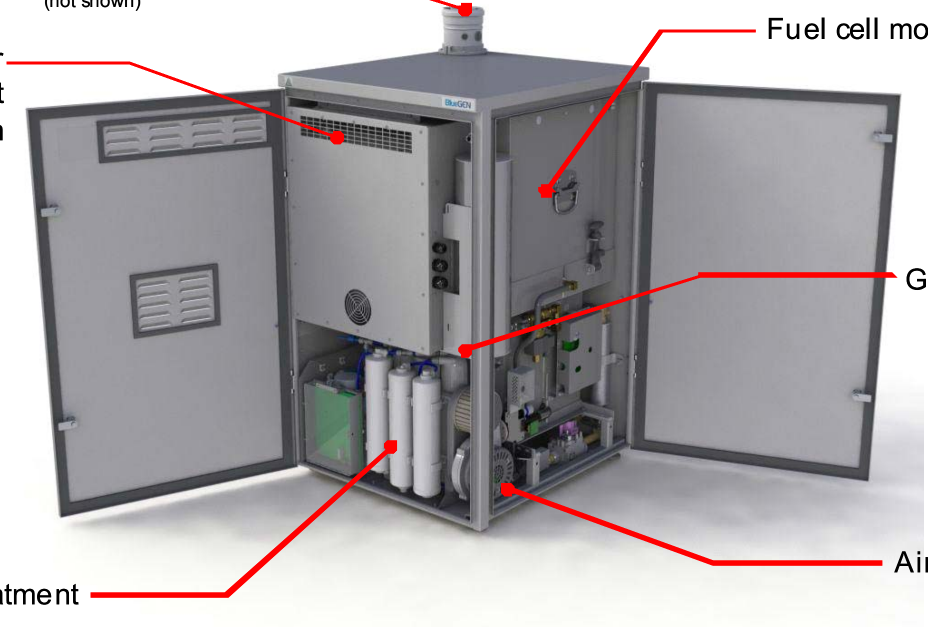
Thermal output:
0.3 to 1 kW

Peak electrical efficiency:
60% at 1.5 kW

Size of a home dishwasher:
660 mm (D); 600 mm (W);
1010 mm (H)

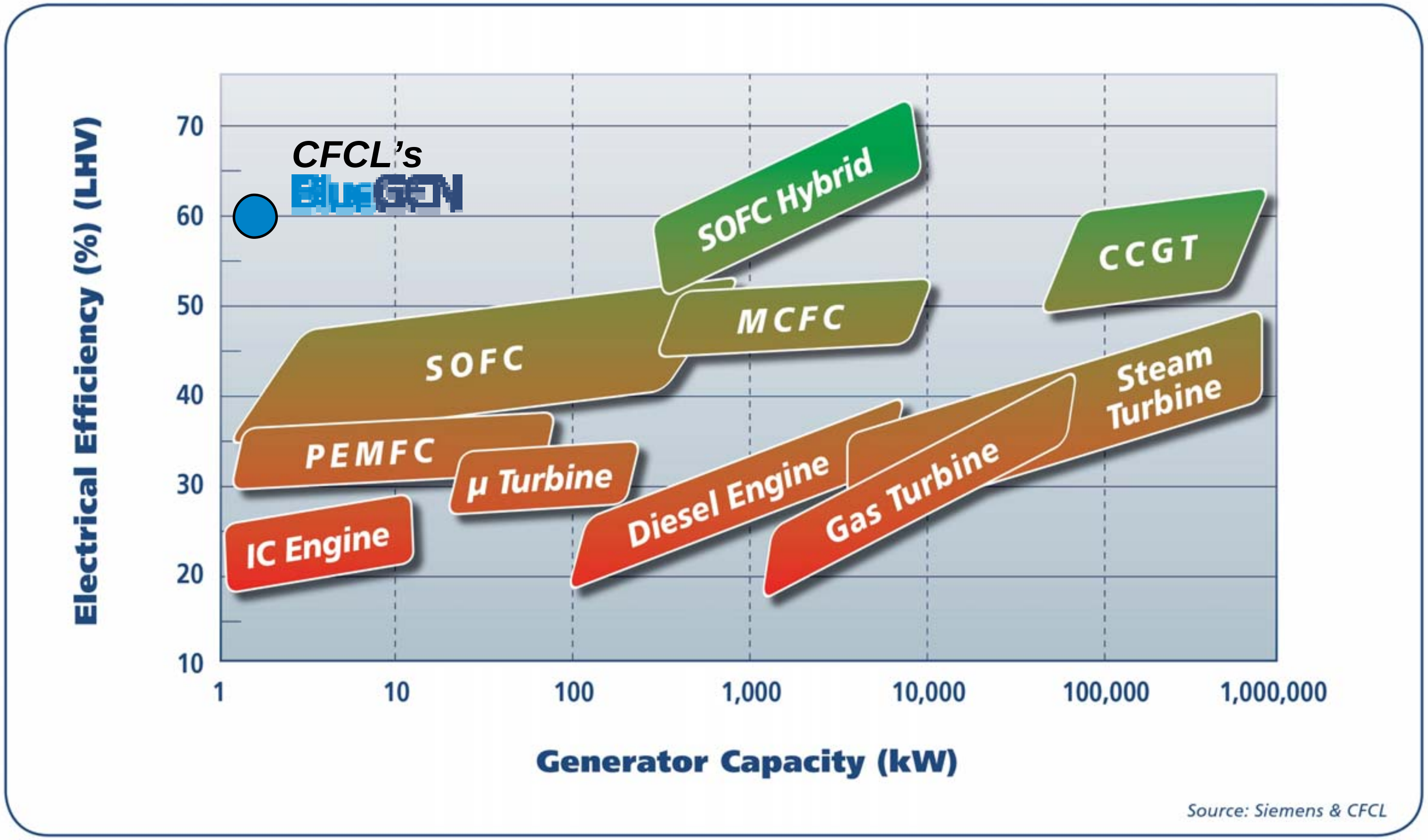
Control:
Remote via Internet

Installation:
Simple, standard connections

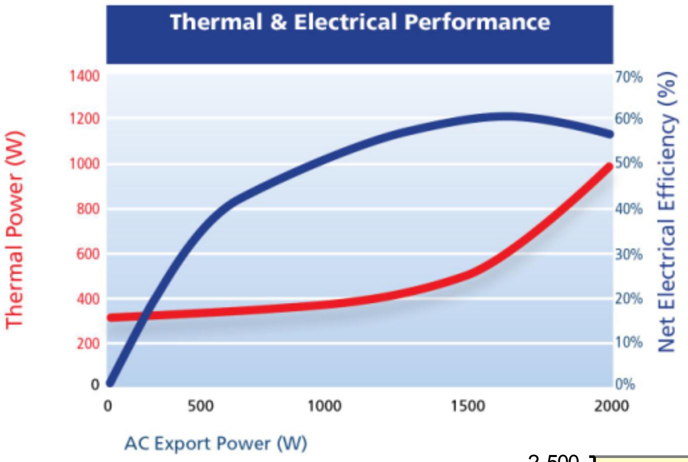


Prime Achievements

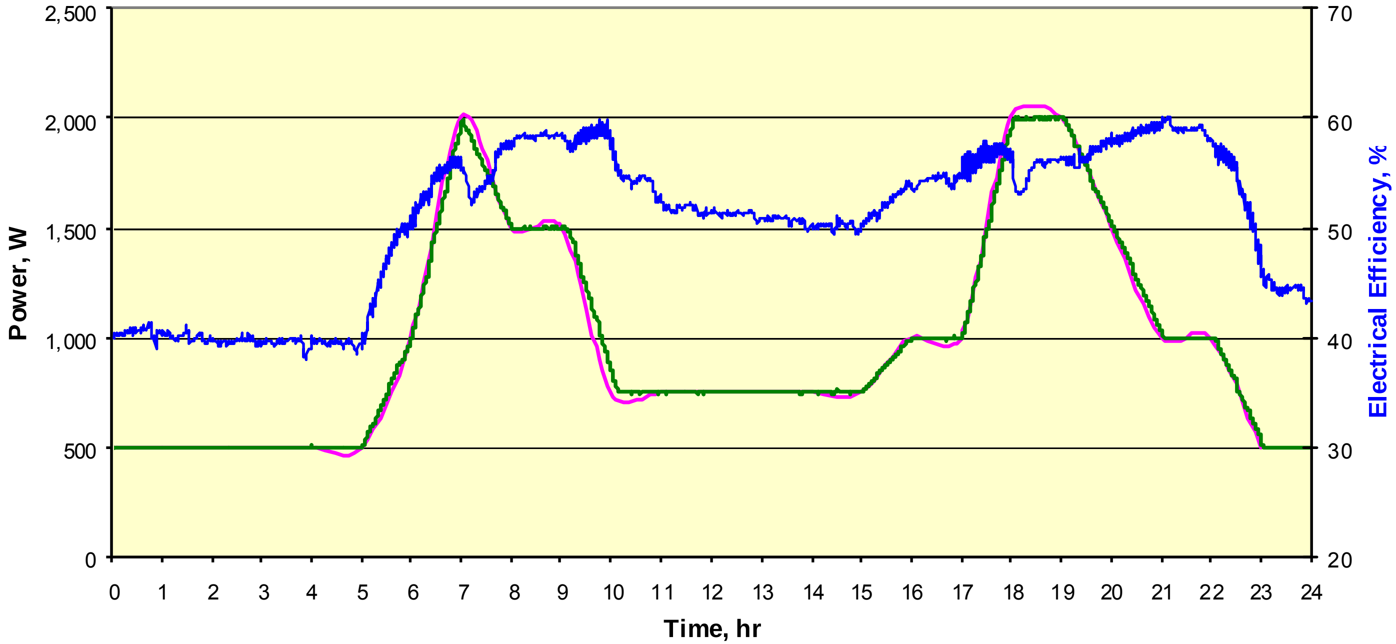
Highly efficient electricity generation



Prime Achievements



MODULATION
Av. Daily Load: 979 W
Av. Daily Efficiency: 51 % (Net AC export, LHV)



Technology Demonstration and Validation

Selected Installations

e·on Ruhrgas Germany

alliander Germany

Paloma Japan

gwi
German Gas &
Heating Institute

EWE Germany

EnergyAustralia
Australian
Utility

Operational Experience

Learning from 'real-world' experience…

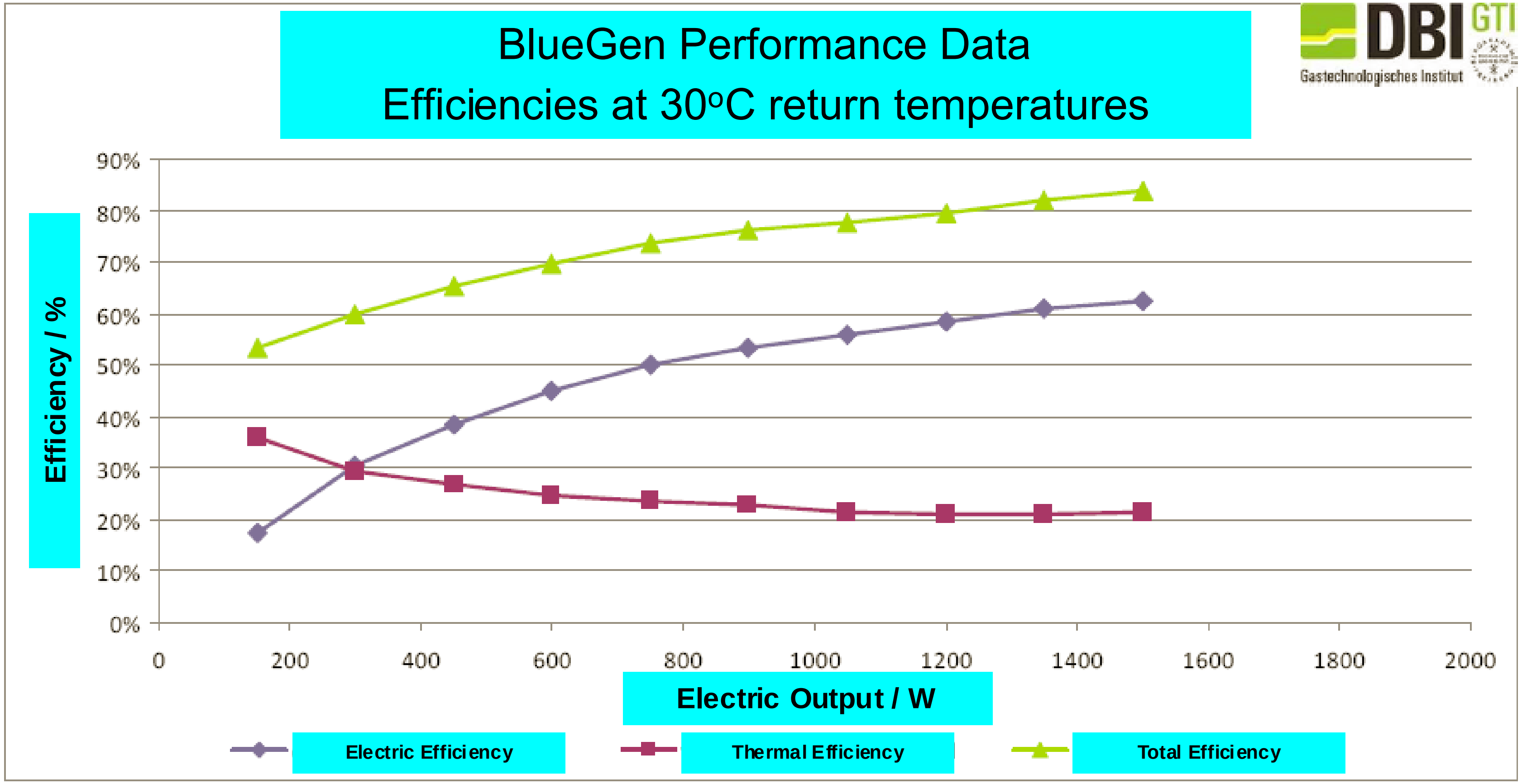
- Since 2005, CFCL has benefited from years of field trials
- Limitations on laboratory trials
  - System optimization most beneficial from customer feedback

Stack technology	All-ceramic		Metal-ceramic	High-efficiency metal-ceramic	
Product	Version 1	Version 2	Version 3	GENNEX	BlueGEN
Deployment	2005 - 07	2006 - 08	2006 - 10	2009 +	2009 +
No. of systems commissioned	4	3	14	8	33 *
Operating hours	21,521	14,232	112,329	44,081	116,649

Operating hours in the field 308,812

** As of 1-Feb-2011*

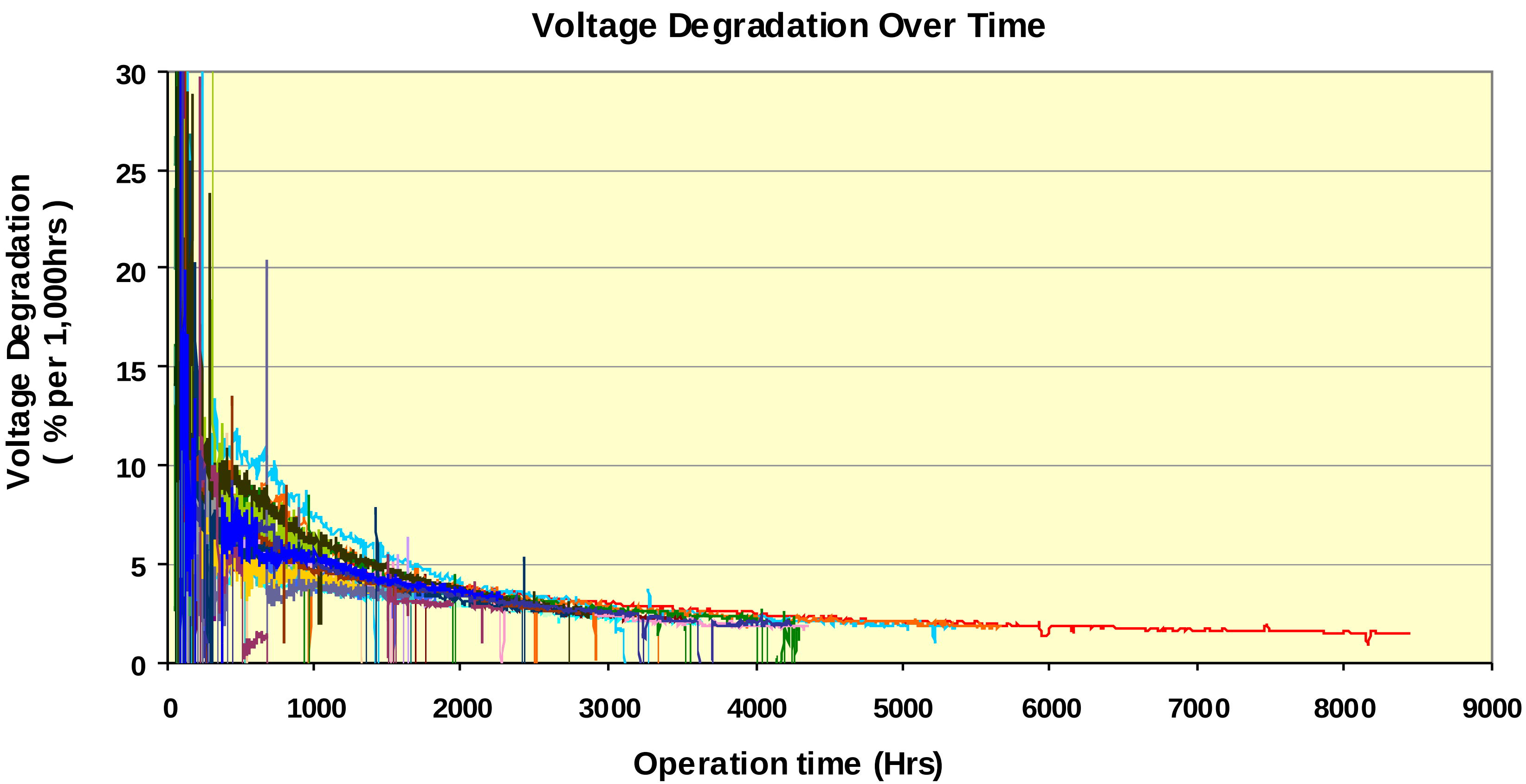
Performance Data



Latest Trials – Voltage Degradation

Individual system characteristics are similar…

- Initial degradation decreasing to about 1% / 1,000hrs



BueGen + Smart Home - EnergyAustralia

BlueGen and the Smart Home:

- Public showcase of energy initiatives within a residential context
  - Led by EnergyAustralia & Sydney Water

- Renovated home in a suburb of Sydney, featuring;
  - Passive design, sustainable furnishings
  - Energy efficient appliances & initiatives
    - *Including a Mitsubishi i-MiEV electric car*
  - Harness the power from the sun
  - Generate efficient electricity on-site – via BlueGen

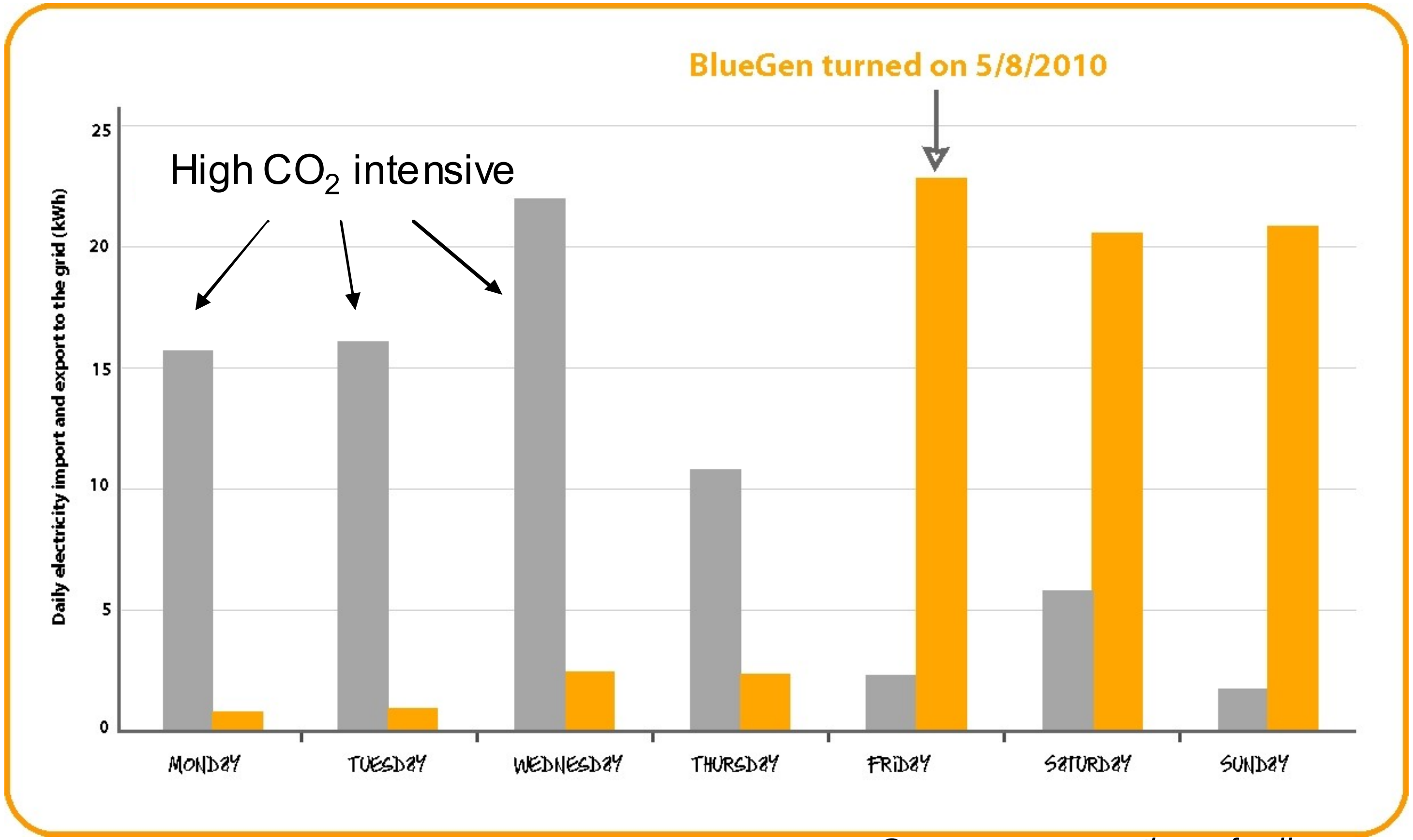
- Road-tested by real people
- Family of three living in the Smart Home and sharing their experiences
  - Blog : www.smarthomefamily.com.au

BueGen + Smart Home - EnergyAustralia

Power import and export:

Electricity Exported

Electricity Imported



Source: www.smarthomefamily.com.au

CO_2 Savings – BlueGen vs. 2kW Solar PV

Higher Carbon Dioxide Savings due to constant operation:

- High electrical efficiency = longer operation, = more CO_2 savings
  - Even when using natural gas as a fuel source

House with solar PV

- 2 kW peak output
- ~3,000 kWh per year
- CO_{2}-e savings per year:
  - 3.2 tonnes (Vic)
  - 2.9 tonnes (NSW)

Up to 4 x more CO_2 is saved using BlueGen

House with BlueGen

- 1.5 kW constant output
- ~12,000 kWh per year
- CO_{2}-e savings per year:
  - **12.9 tonnes** (Vic)
  - **9.2 tonnes** (NSW)

Building Manufacturing Capability

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Higher Volumes = Lower Costs

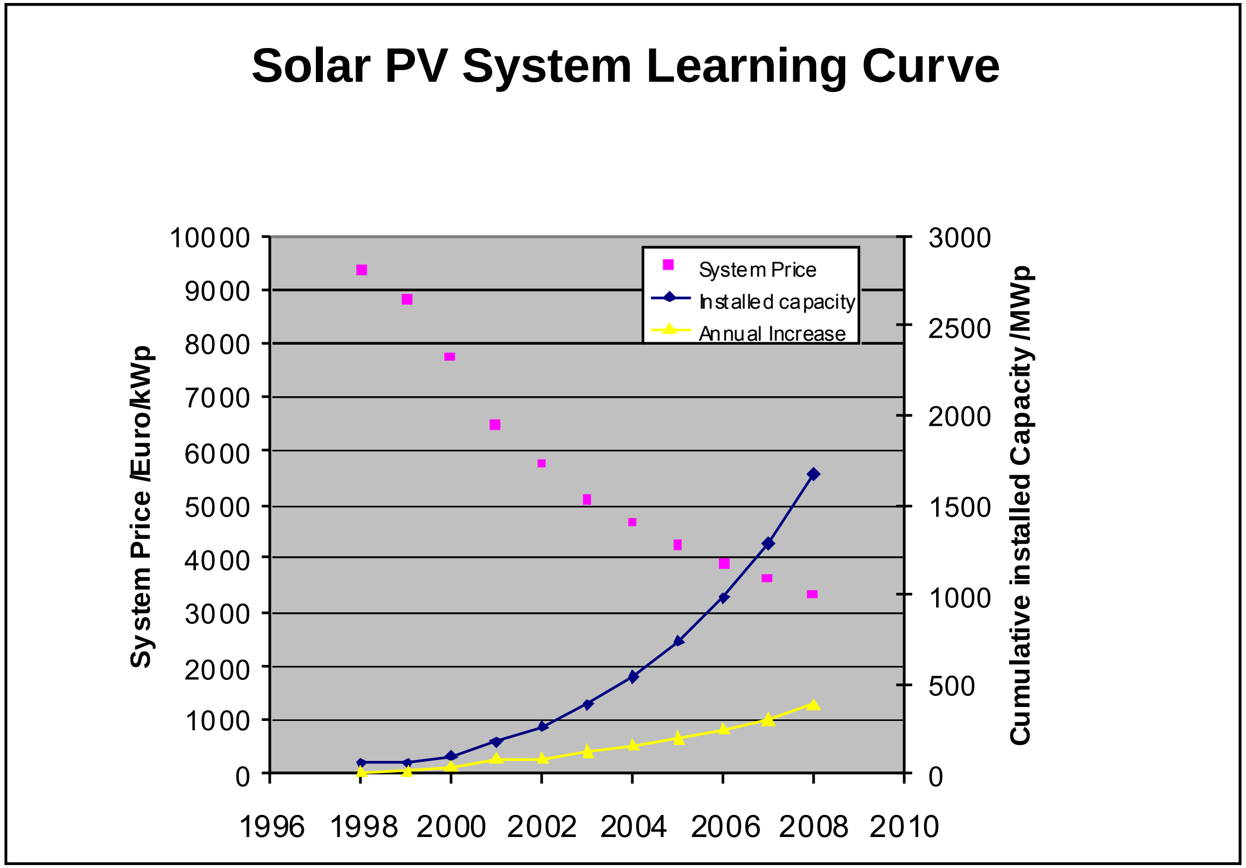
“Cost curve” or “learning curve” applies to many activities and manufacturing

Every time the production quantity is doubled, the unit cost falls by X%

X% varies across products but the costs keep reducing even as volumes get very large

Applies to well known everyday products - mobile phones, flat screen TVs…

As well as large, complex machines – aerospace, shipbuilding…



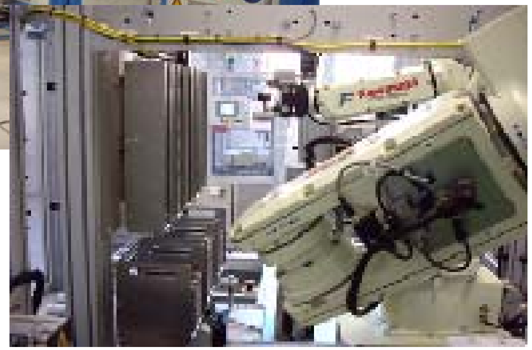
Costs of fuel cell products will also come down as volumes increase

Solar PV is a good example. Each time volume doubles, costs reduce by 20-24% for modules, 17% for complete systems

Building Manufacturing Capacity

- **Fuel cell plant in Heinsberg, Germany**
  - 10 million Euro investment
  - Capacity: 10000 stacks pa
  - Expandable to meet future demand

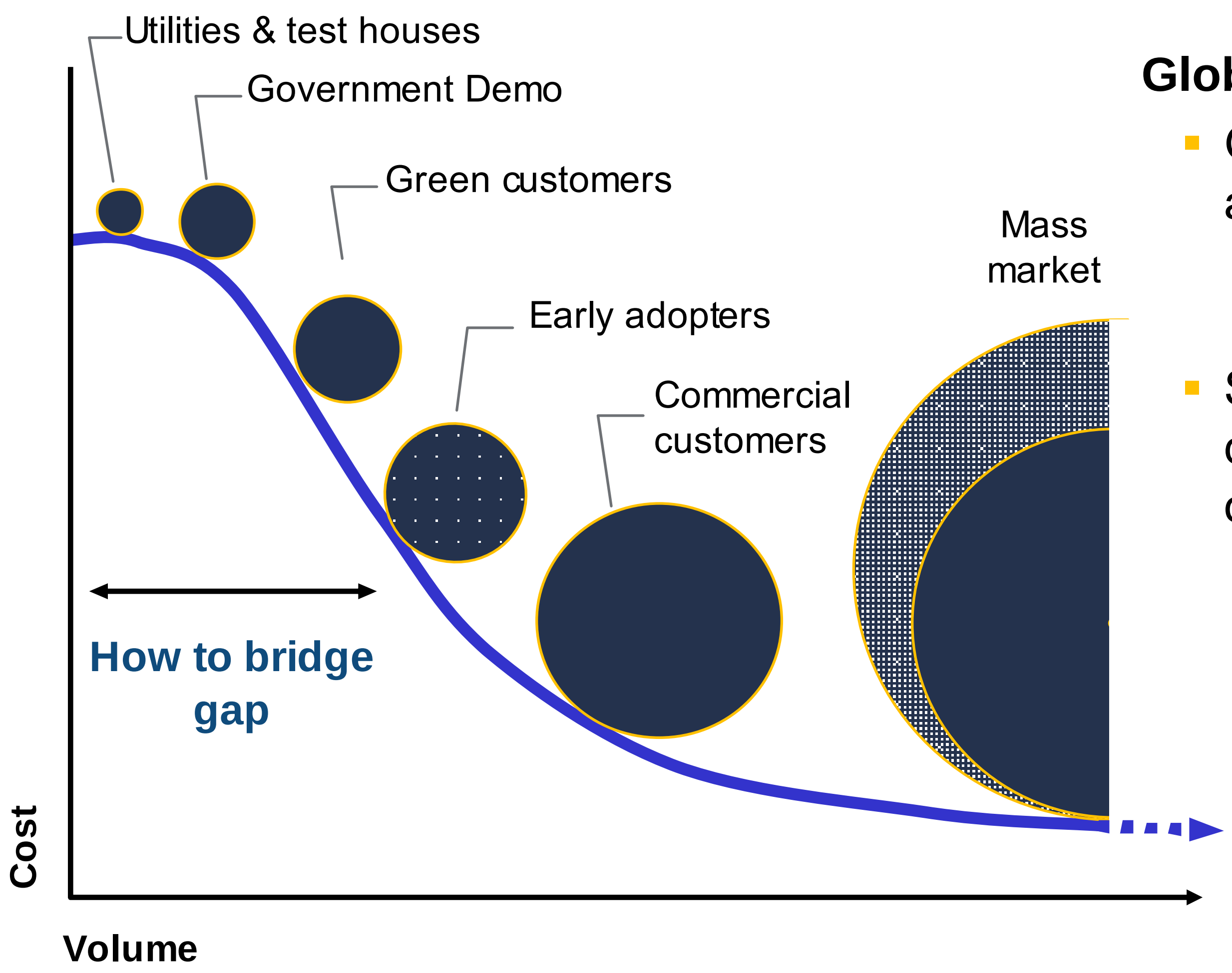
- **BlueGen assembly in Heinsberg from January 2011**



Infrastructure in place need orders

Commercial Challenges
Challenges

Identifying Early Customers



Global perspective…

- Green customers & early adopters important
  - e.g. Germany
- Seek specific customers depending on the state of the technology:
  - Unit cost
  - Technology maturity

Market Introduction Incentives

How to bridge initial cost – volume gap “valley of death”

- **Government sponsored large field test programs:**
  - **Japan Residential fuel cell demo (about 3000 systems)**
  - **Germany: Callux residential demo program (800 systems)**
  - **Need ambitious targets otherwise act as hurdle**
- **Market Introduction Programs**
  - **Example Solar PV: Germany 100000 roof program;**
  - **Feed-in tariffs in many countries:**
    - Excellent introductory initiative: awards good technologies;
    - Reducing over time to encourage challenging cost reductions.
  - **Capital Subsidies:**
    - USA for fuel cells
    - Germany (until mid 2010) for micro-CHP
    - Needs to be time restricted (force commerciality of technology)
    - Mechanisms to subsidise only promising technologies

Conditions in Australia currently not beneficial → focus on other markets

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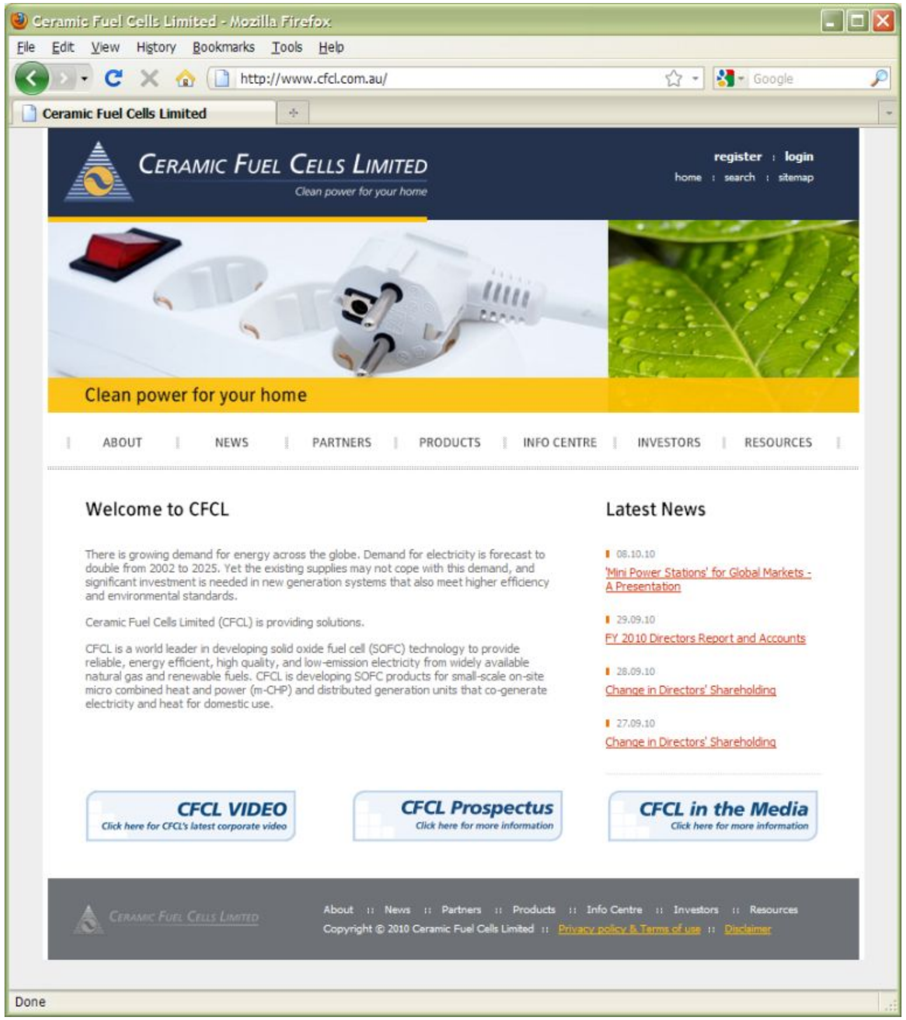

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