Fuel cells & their potential to revolutionise the domestic gas market

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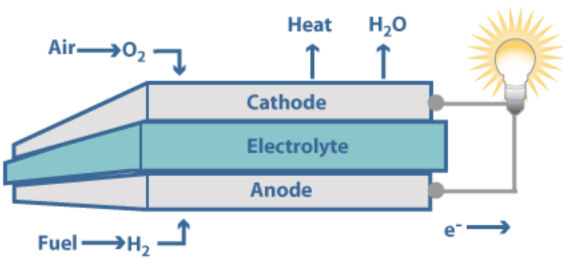
Australian Domestic Gas Outlook Conference 2013

11 April 2013

Outline

- Fuel cell technology – status & prospects
- Opportunities for fuel cell distributed generation in the Australian National Electricity Market
- Implications for the domestic gas market

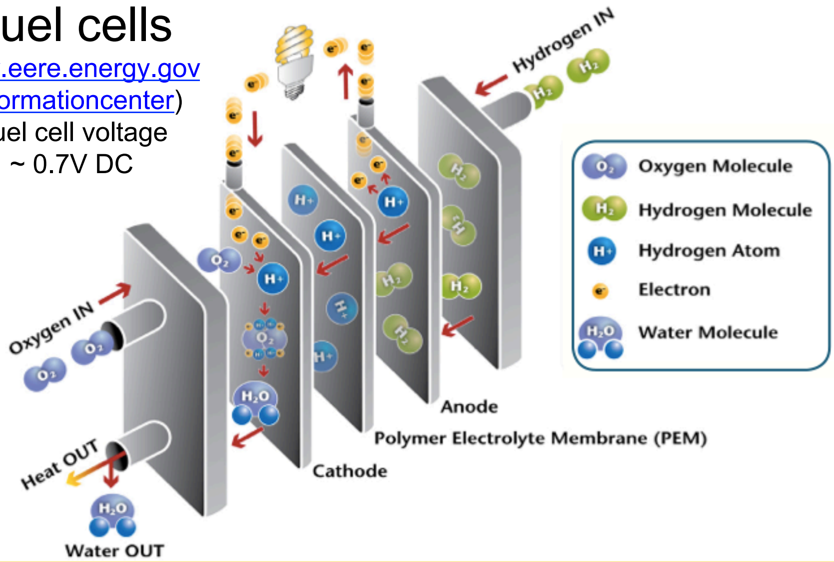


http://www.nfcrc.uci.edu/2/FUEL_CELL_INFORMATION/FCexplained/FC_howItWorks.aspx

Fuel cells

www.eere.energy.gov/informationcenter)

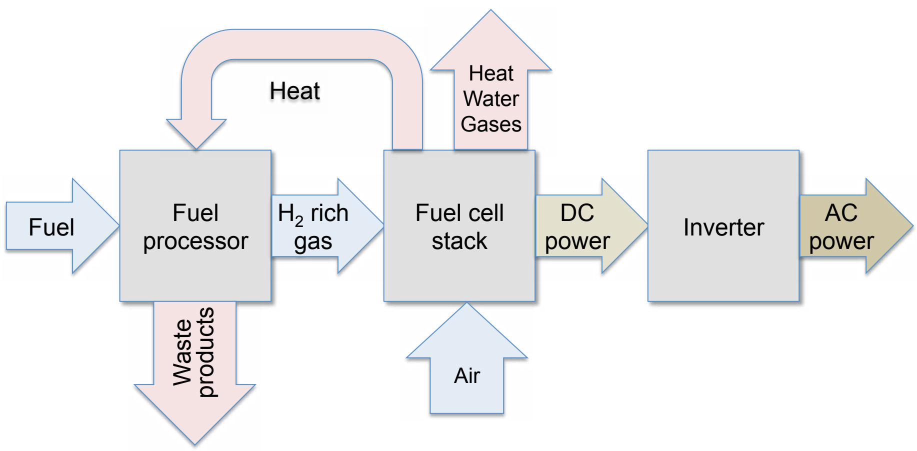
Fuel cell voltage ~ 0.7V DC



Fuel cells directly convert the chemical energy in hydrogen to electricity, with pure water and potentially useful heat as the only byproducts. Hydrogen-powered fuel cells are not only pollution-free, but also can have more than two times the efficiency of traditional combustion technologies.

Fuel cell components & flows

http://www.nfcrc.uci.edu/2/FUEL_CELL_INFORMATION/FCexplained/FC_Comp.aspx



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FUEL CELL TECHNOLOGIES PROGRAM

Comparison of Fuel Cell Technologies

Fuel Cell Type	Common Electrolyte	Operating Temperature	Typical Stack Size	Efficiency	Applications	Advantages	Disadvantages
Polymer Electrolyte Membrane (PEM)	Perfluoro sulfonic acid	50-100°C 122-212° typically 80°C	< 1kW–100kW	60% transportation 35% stationary	• Backup power • Portable power • Distributed generation • Transporation • Specialty vehicles	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up	• Expensive catalysts • Sensitive to fuel impurities • Low temperature waste heat
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90-100°C 194-212°F	10–100 kW	60%	• Military • Space	• Cathode reaction faster in alkaline electrolyte, leads to high performance • Low cost components	• Sensitive to CO_2 in fuel and air • Electrolyte management
Phosphoric Acid (PAFC)	Phosphoric acid soaked in a matrix	150-200°C 302-392°F	400 kW 100 kW module	40%	• Distributed generation	• Higher temperature enables CHP • Increased tolerance to fuel impurities	• Pt catalyst • Long start up time • Low current and power
Molten Carbonate (MCFC)	Solution of lithium, sodium, and/ or potassium carbonates, soaked in a matrix	600-700°C 1112-1292°F	300 kW-3 MW 300 kW module	45-50%	• Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP	• High temperature corrosion and breakdown of cell components • Long start up time • Low power density
Solid Oxide (SOFC)	Yttria stabilized zirconia	700-1000°C 1202-1832°F	1 kW–2 MW	60%	• Auxiliary power • Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte • Suitable for CHP & CHHP • Hybrid/GT cycle	• High temperature corrosion and breakdown of cell components • High temperature operation requires long start up time and limits

For More Information

More information on the Fuel Cell Technologies Program is available at http://www.hydrogenandfuelcells.energy.gov.

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Fuel tolerance of fuel cell types

http://www.nfcrc.uci.edu/2/FUEL_CELL_INFORMATION/FCexplained/Fuels.aspx

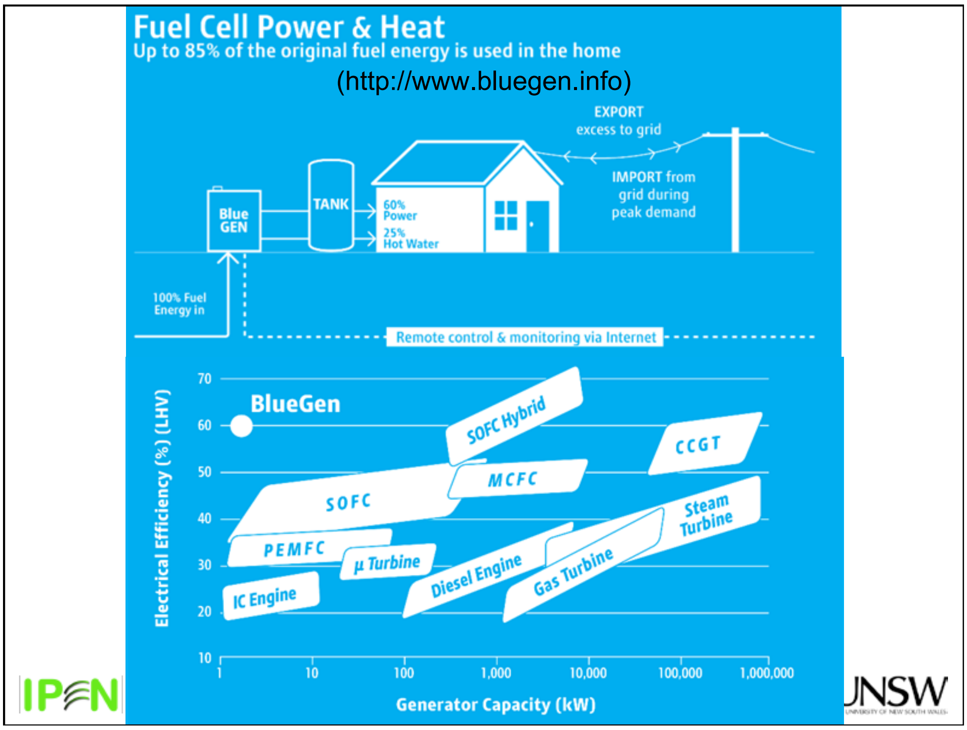
Gas species	PAFC	MCFC	SOFC	PEMFC
H_2	Fuel	Fuel	Fuel	Fuel
CO	Poison	Fuel	Fuel	Poison
CH_4	Diluent	Diluent	Fuel if dilute	Diluent
CO_2 & H_2O	Diluent	Diluent	Diluent	Diluent
H_2S & COS	Poison	Poison	Poison	Poison

IPEN UNSW THE UNIVERSITY OF NEW SOUTH WALES

Blue Gen, SOFC, Ceramic Fuel Cells Ltd
(www.bluegen.info; www.cfcl.com.au)

IPEN UNSW

BlueGen fuel cell generator	(http://www.bluegen.info)
Performance	
Electrical output	0.5–1.5 kW
Peak electrical efficiency	60% (at 1.5 kW)
Thermal output	0.3– 0.54 kW
Thermal efficiency	up to 25%
Total efficiency	85%
Connections	
Natural gas	1/2 inch BSP female
Water	1/4 inch quick connect *John Guest*
Electricity	Hardwired via junction box
Flue	Balanced flue with standard concentric flue 100/60mm
Communications	Standard Ethernet port
Heat recovery	3/4 inch BSP female
Operation	
Electrical	230V ± 10%, 50Hz (single phase AC parallel grid connected)
Noise level	~ 47 dBa @ 1m
CO2 emissions	340g/kWh
Maintenance	Minor service: air filters, water filters and gas cleaning Major service: fuel cell stack
Physical	
Dimensions	600 x 660 x 1010mm
Installation	Indoors or outdoors (above freezing)


Fuel Cell Power & Heat
Up to 85% of the original fuel energy is used in the home
(http://www.bluegen.info)
EXPORT excess to grid
IMPORT from grid during peak demand
Blue GEN
TANK
60% Power
25% Hot Water
100% Fuel Energy in
Remote control & monitoring via Internet
BlueGen
SOFC Hybrid
CCGT
MCFC
SOFC
Steam Turbine
PEMFC
µ Turbine
Diesel Engine
Gas Turbine
IC Engine
Electrical Efficiency (%) (LHV)
Generator Capacity (kW)

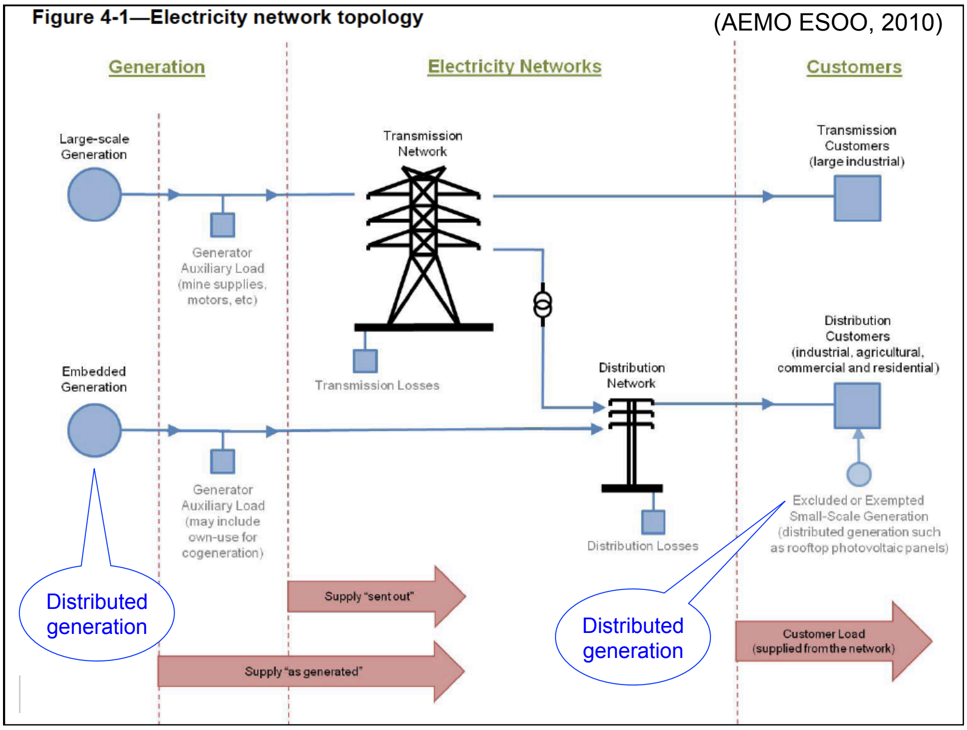
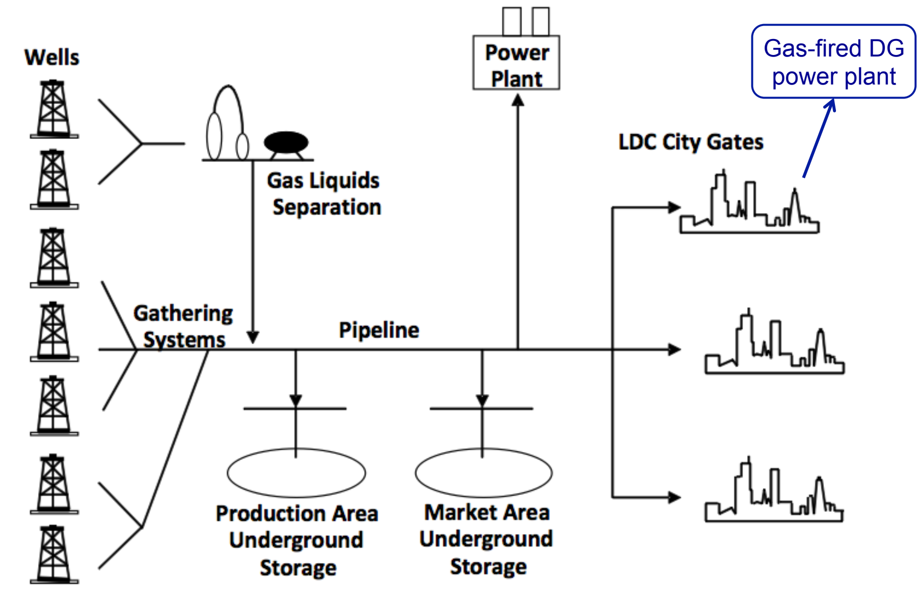


Figure 4-1—Electricity network topology
(AEMO ESOO, 2010)
Generation
Electricity Networks
Customers
Large-scale Generation
Transmission Network
Transmission Customers (large industrial)
Generator Auxiliary Load (mine supplies, motors, etc)
Transmission Losses
Distribution Customers (industrial, agricultural, commercial and residential)
Embedded Generation
Distribution Network
Generator Auxiliary Load (may include own-use for cogeneration)
Distribution Losses
Excluded or Exempted Small-Scale Generation (distributed generation such as rooftop photovoltaic panels)
Distributed generation
Supply "sent out"
Supply "as generated"
Distributed generation
Customer Load (supplied from the network)

FIGURE 3-1: SIMPLIFIED OVERVIEW OF THE STRUCTURE OF THE NATURAL GAS INDUSTRY

(Gas-Electricity Interdependency, USA, NERC, Dec 2011)



The Future of the Electric Grid, MIT Interdisciplinary Study, http://web.mit.edu/mitei/research/studies/the-electric-grid-2011.shtml

Table 5.1 Theoretical Benefits of Distributed Generation

Reliability and Security Benefits	Economic Benefits	Emission Benefits	Power Quality Benefits
• Increased security for critical loads • Relieved transmission and distribution congestion • Reduced impacts from physical or cyberattacks • Increased generation diversity	• Reduced costs associated with power losses • Deferred investments for generation, transmission, or distribution upgrades • Lower operating costs due to peak shaving • Reduced fuel costs due to increased overall efficiency • Reduced land use for generation	• Reduced line losses • Reduced pollutant emissions	• Voltage profile improvement • Reduced flicker • Reduced harmonic distortion

Source: U.S. Department of Energy, *The Potential Benefits of Distributed Generation and Rate-Related Issues that May Impede Their Expansion: A Study Pursuant to Section 1817 of the Energy Policy Act of 2005* (Washington, DC, 2007); and P. Chiradeja and R. Ramakumar, "An Approach to Quantify the Technical Benefits of Distributed Generation," *IEEE Transactions on Energy Conversion* 19, no. 4 (2004): 764–773.

Main types of distributed generation (DG)

Fossil fuel (usually gas) **DG**	**Renewable energy DG**
Reciprocating engines	Solar PV
Gas turbines	Micro & Mini hydro
Steam turbines	Individual wind turbines
Microturbines	Small wind farms
Fuel cells	Biofuel fossil fuel substitutes
Stirling engines	

DG applications & their requirements

(Goldstein et al, 2003)

Application	DG requirements
Standby power	Low installed cost, fast start, high reliability, low fixed maintenance cost
Base-load power	High efficiency, low variable costs & emissions, high reliability *(use of local renewable energy fluxes similar)*
Demand response	Low installed cost, low fixed maintenance, fast start
Peak shaving	Low installed cost, low fixed maintenance, fast start
Premium power	High efficiency, low variable costs & emissions, high reliability
Grid support	Low installed cost, high reliability, low fixed maintenance cost
Cogeneration & Trigeneration	High useable thermal output, low variable costs & emissions, high reliability

(Goldstein et al, 2003)

Table 1. Applications and Markets for Gas-fired DG Technologies

Also cooling

DG Technologies	Standby Power	Baseload Power Only	Demand Response Peaking	Customer Peak Shaving	Premium Power	Utility Grid Support	Combined Heat and Power[1]	Applicable Market Sectors
Reciprocating Engines (50 kW to 5 MW)	×	×	×	×	×	×	×	Commercial Buildings, Light Industrial, Utility Grid (larger units), Waste Fuels
Gas Turbines (500 kW to 50 MW)		×		×	×	×	×	Large Commercial, Institutional, Industrial, Utility Grid, Waste Fuels
Steam Turbines (500 kW to 100 MW)		×			×		×	Institutional Buildings/Campuses, Industrial, Waste Fuels
Microturbines (30 kW to 250 kW)	×	×	×	×	×	×	×	Commercial Buildings, Light Industrial, Waste Fuels
Fuel Cells (5 kW to 2 MW)		×			×	×	×	Residential, Commercial, Light Industrial

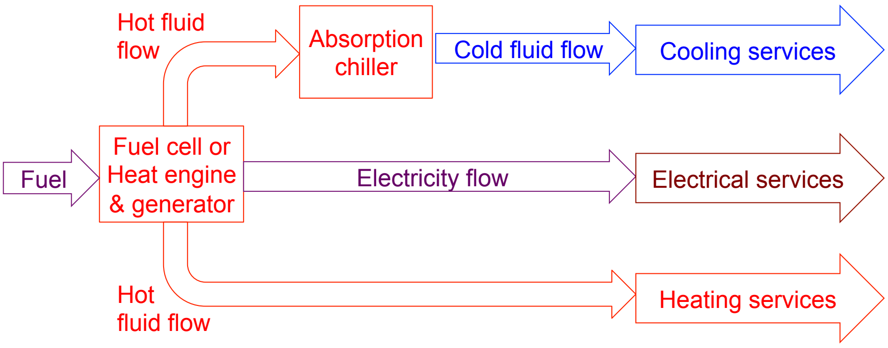
Goldstein et al (2003)

Table 2. Comparison of DG Technologies

	Recip Engine	Gas Turbine	Steam Turbine	Microturbine	Fuel Cells
Technology Status	Commercial	Commercial	Commercial	Early entry	Early entry/ development
Size (MW)	0.01-5	0.5 - 50	0.05-50	0.03-0.25	0.005-2
Electric Efficiency (HHV)[2]	30-37%	22-37%	5 – 15%	23-26%	30-46%
Total CHP Efficiency (HHV)[3]	69-78%	65-72 %	80 %	61-67%	65-72%
Power-Only installed cost ($/kW)[4]	700-1,000	600-1,400	300-900[5]	1,500-2,300	2,800-4,700
CHP installed cost ($/kW)[3]	900-1,400	700-1,900	300-900[4]	1,700-2,600	3,200-5,500
O&M Cost ($/kWh)	0.008-0.018	0.004-0.01	<0.004	0.013-0.02	0.020.04
Availability	> 96%	>98%	Near 100%	95%	90%
Equipment Life (years)	20	20	>25	10	10
Fuel pressure (psi)	1-65 (may require fuel compressor)	100-500 (may require fuel compressor)	n/a	55-90 (may require fuel compressor)	0.5-45
Fuels	natural gas, biogas, liquid fuels	natural gas, biogas, distillate oil	all	natural gas, biogas	hydrogen, natural gas
NO_x Emissions (lb/MWh)[6]	0.2-6	0.8-2.4	Function of boiler missions	0.5-1.25	<0.1
Uses for Heat Recovery	hot water, low pressure steam, district heating	direct heat, hot water, LP-HP steam, district heating	LP-HP steam, district heating	direct heat, hot water, low pressure steam	hot water, low pressure steam
Thermal Output (Btu/kWh)[7]	3,200-5,600	3,200-6,800	1,000-50,000	4,500-6,500	1,800-4,200

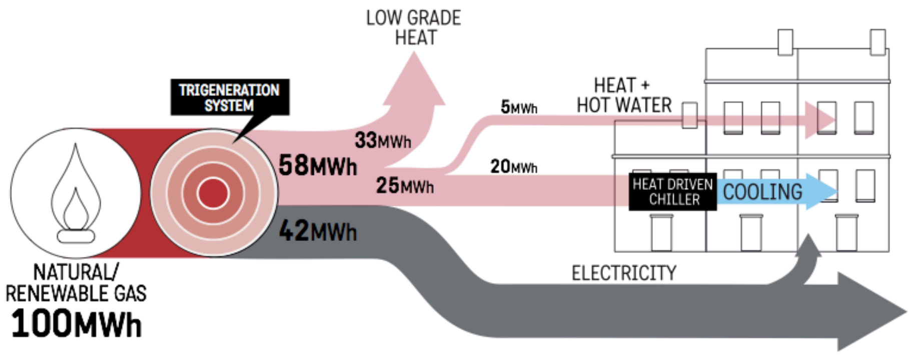
Also cooling

Trigeneration or CCHP
(combined cooling, heating and power)



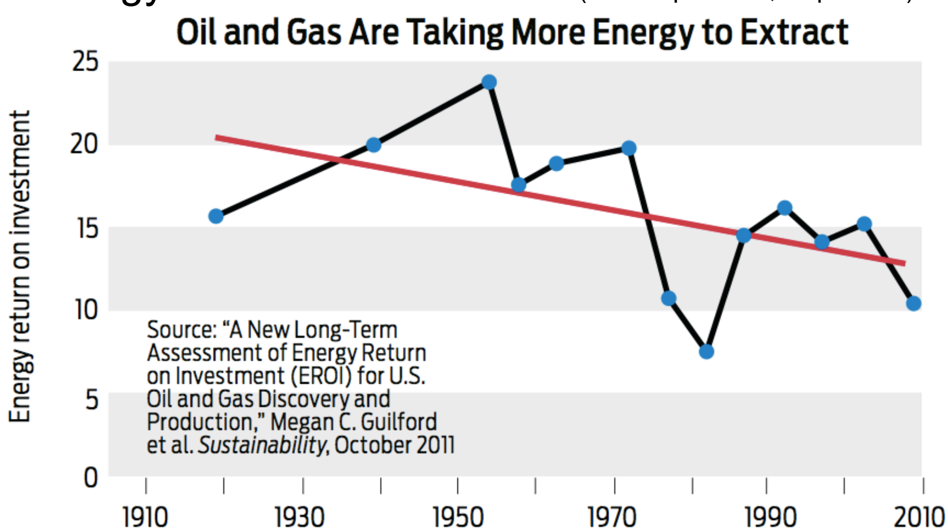
Note: Cogeneration or CHP does not have a chiller. It provides electrical & heating services but not cooling services

Indicative energy flow distribution in a gas engine trigeneration system



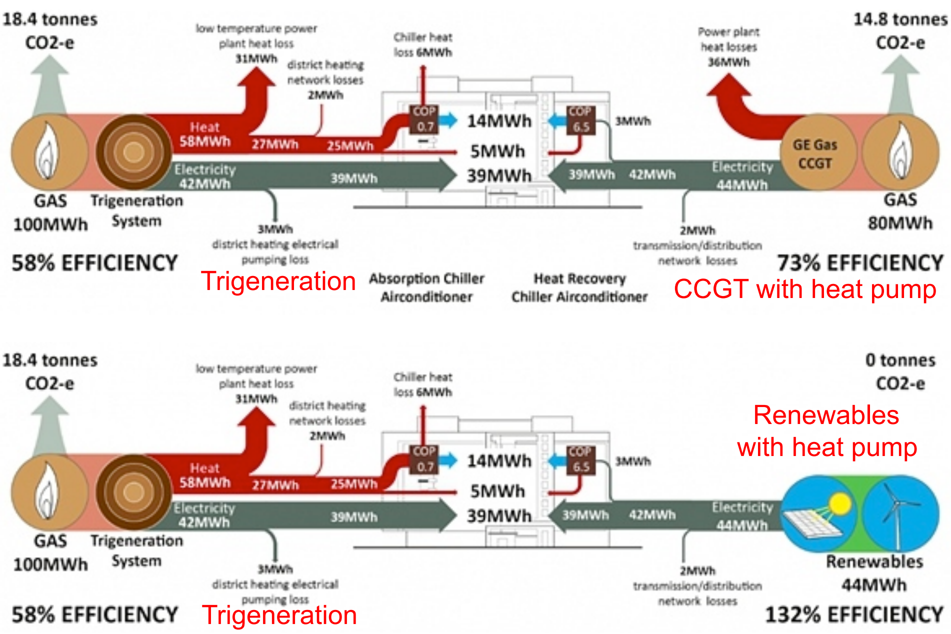
(From City of Sydney, Decentralised Energy Master Plan, 2012, which proposed ~ 360MWe reciprocating gas engines for central Sydney after considering gas turbines but not fuel cells as alternatives. The gas network in central Sydney would have to be upgraded)

Energy return on investment (IEEE Spectrum, Sept 2012)



Energy return on investment, the amount of energy produced divided by the energy needed to acquire it, has been on the decline in the United States [above] and the rest of the world.

Comparison of energy & CO2 outcomes (Wright, 2012)



Conclusions

- Fuel cells are one of several types of gas-fired distributed generation technology
- They are most likely to be deployed as small-scale cogeneration or tri-generation
- At present, they don't appear to have strong prospects in the Australian NEM:
  - Reciprocating engine tri-generation systems, solar PV & solar water heating have been more successful to date
  - Gas for DG is usually drawn from gas distribution networks in relatively small quantities per site

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Hugh retired in 2007 after a 35-year career at the University of New South Wales, most recently as Presiding Director, Centre for Energy and Environmental Markets and Head, Electrical Energy Research Group, School of Electrical Engineering and Telecommunications.

During his career, Hugh has been a Fulbright Senior Fellow at the University of California Berkeley, a Member of the National Electricity Tribunal, a Member of the New South Wales Licence Compliance Advisory Board, a Board Member of the Australian Cooperative Research Centre for Renewable Energy, an Associate Director of UNSW's Centre for Photovoltaic Devices and Systems, a Member of CSIRO's Energy Flagship Advisory Committee and a Lead Author for the IPCC Special Report on Renewable Energy Sources & Climate Change Mitigation, 2011.

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