WOOD-FIRED FUEL CELLS IN AN ISOLATED LOCATION

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Biomass

Biomass is one of the renewable energy sources which is:
not intermittent,
not location-dependent
or very difficult to store.

If grown sustainably,
biomass can be considered CO2 neutral.

Fuel Cells

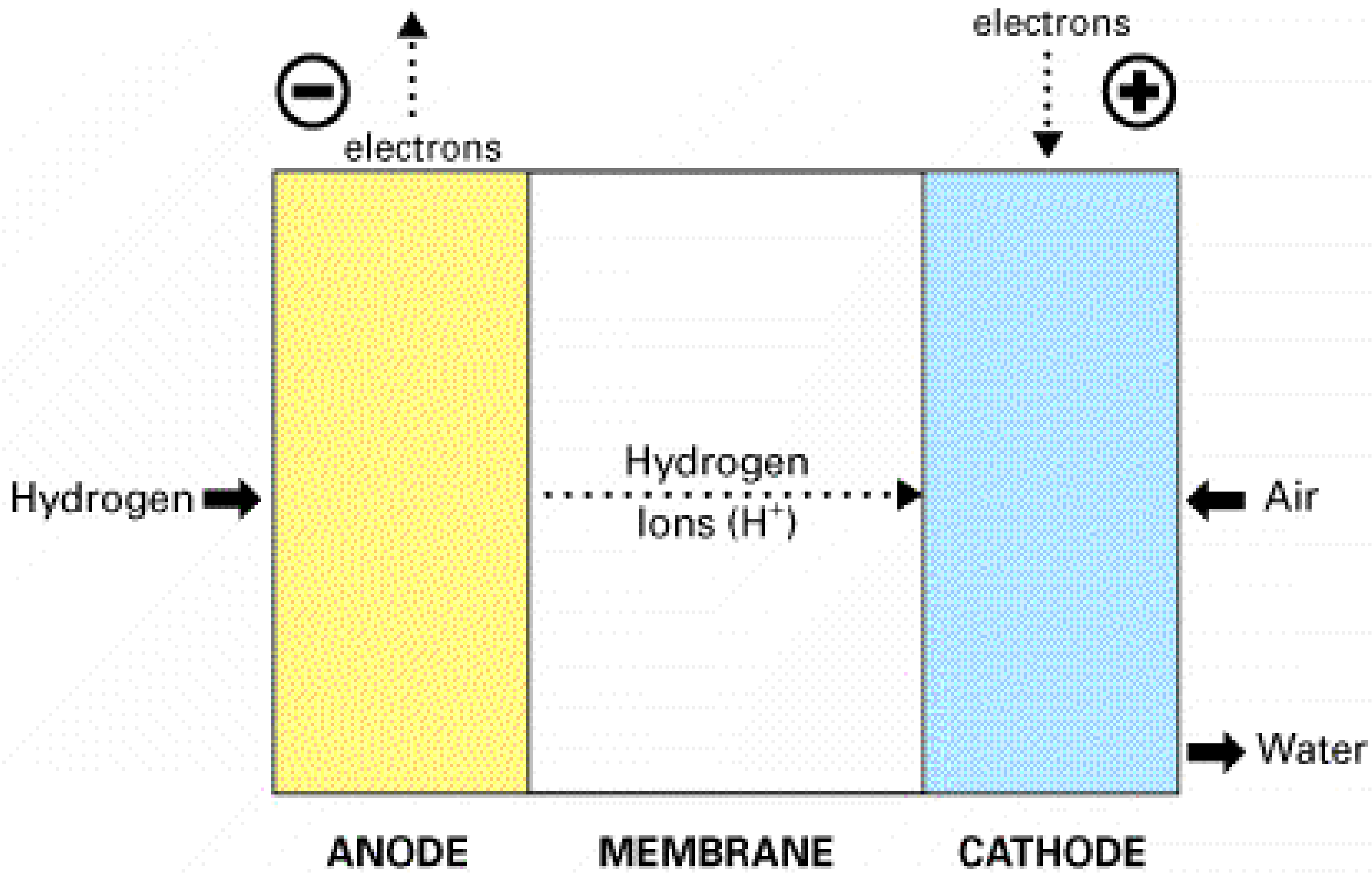
Can generate electricity very efficiently …

Even at small scale …

Can we find a way to combine the advantages of both biomass and fuel cells?

We propose:
Integrating a biomass gasifier with a fuel cell.

Fuel Cells



electrons
electrons
Hydrogen
Hydrogen
Ions (H+)
Air
Water
ANODE
MEMBRANE
CATHODE

Fuel Cells – Phosphoric Acid PAFC

Phosphoric acid fuel cells (PAFC) operate at temperatures around 150 to 200 C.

As the name suggests, PAFCs use phosphoric acid as the electrolyte.

Positively charged hydrogen ions migrate through the electrolyte from the anode to the cathode.

Electrons generated at the anode travel through an external circuit, providing electric power along the way, and return to the cathode.

At the cathode the electrons, hydrogen ions and oxygen form water, which is expelled from the cell.

A platinum catalyst at the electrodes speeds the reactions.

Fuel Cells - Molten Carbonate MCFC

In a molten carbonate fuel cell (MCFC), carbonate salts are the electrolyte.
Heated to 650C, the salts melt and conduct carbonate ions (CO_3) from the cathode to the anode.
At the anode, hydrogen reacts with the ions to produce water, carbon dioxide, and electrons.
The electrons travel through an external circuit, providing electrical power along the way, and return to the cathode.
There, oxygen from air and carbon dioxide recycled from the anode react with the electrons to form CO3 ions that replenish the electrolyte and transfer current through the fuel cell.

Fuel Cells -Comparison

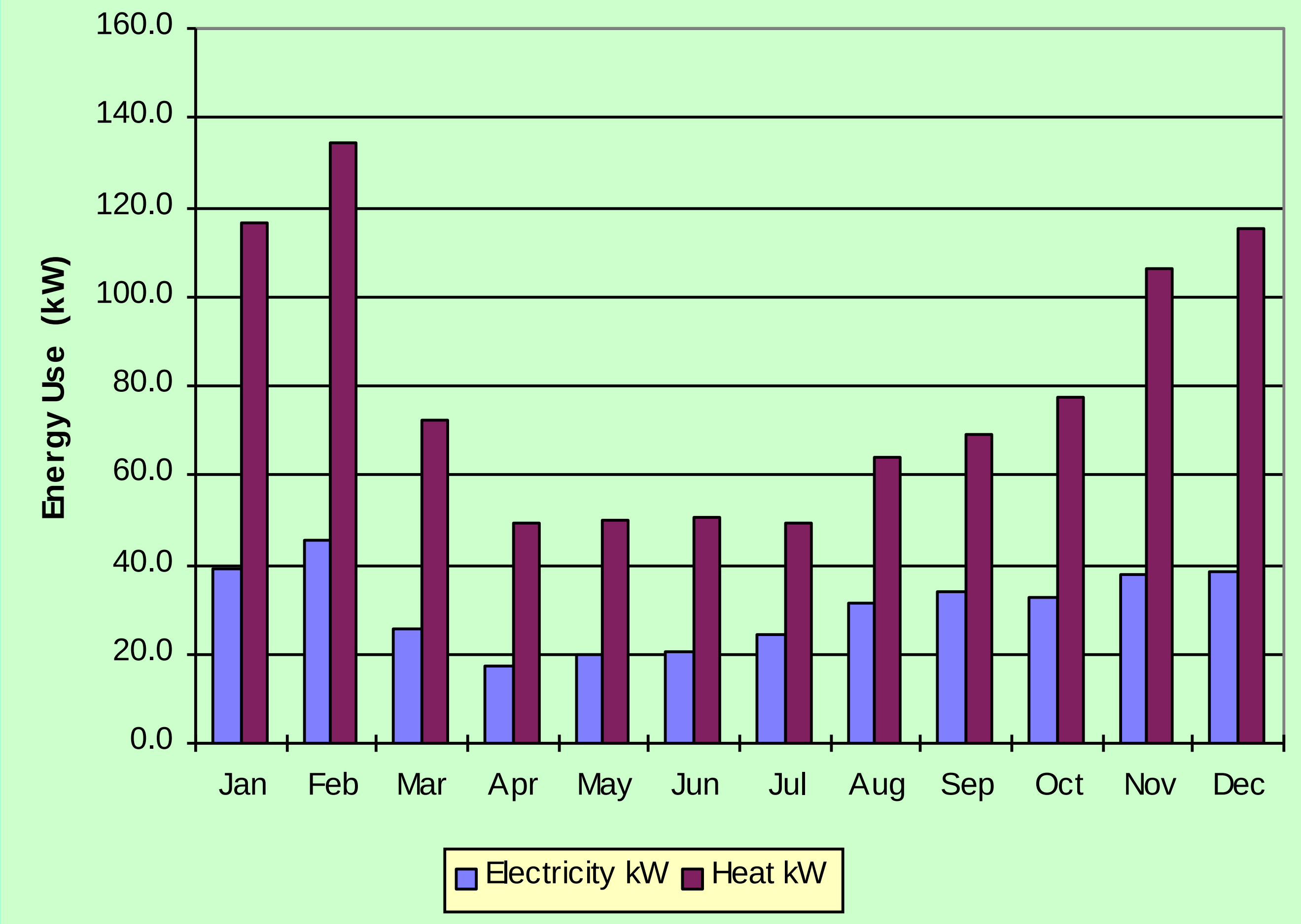
Type	PEM	PAFC	MCFC	SOFC
Electrolyte	Ion Exchange Membrane	Phosphoric Acid	Alkali Carbonates Mixture	Yttria Stabilized Zirconia
Operating Temp. °C	80	200	650	1,000
Charge Carrier	H^+	H^+	$CO_3^=$	$O^=$
Electrolyte State	Solid	Immobilized Liquid	Immobilized Liquid	Solid
Cell Hardware	Carbon or Metal Based	Graphite Based	Stainless Steel	Ceramic
Catalyst	Platinum	Platinum	Nickel	Perovskites
Cogeneration Heat	None	Low Quality	High	High
% Fuel Cell Efficiency	<40	40-45	50-60	50-60

Scope of the Paper

A system consisting of a fuel cell integrated with wood gasification may offer a combination for delivering heat and electricity cleanly and efficiently, even at small scales, for an “isolated community” (IC) which could be an island, or simply where grid-supplied electricity is weak or non-existent.

This system was **modelled** for two different types of fuel cell, the Molten Carbonate and the Phosphoric Acid.

Energy Demand Profile for Isolated Community (200 people)



The “isolated community” (IC) could be on an island, or simply where grid-supplied electricity is weak or non-existent. The chosen IC has a peak demand of about 75 kW electricity and a maximum heat/electricity requirement of around 3:1, with an approximate availability of 40% .

Choice of Fuel Cells

Two fuel cell types are considered here, the *phosphoric acid* fuel cell (PAFC) and the *molten carbonate* fuel cell (MCFC).

The PAFC can only tolerate 1-2% CO at the operating temperature of 200°C, so a "shifter" must be employed to convert the CO to hydrogen.

Steam is required for the shift reaction.

The MCFC operates at 650°C and uses both hydrogen and CO in electricity production, so it does not require a shifter.

Choice of Fuel Cells (II)

Fuel cell systems have not been in use for a long time, so there is great uncertainty in their operating lifetimes and their capital costs.

This makes their economics even more uncertain.

For the systems assessed here, values of 5, 10 and 15 years for the fuel cell lifetime

and capital cost rates of £500, £750, £1000, £1500 and £2000/kWe for the fuel cell have been considered.

Table 1. Comparison of Gasifier Technologies

Gasifier Type	***LPO***	***HPO***	***IND***
Pressure (bar)	1.013	34.4	1.013
Temperature (°C)	980	980	980
Dry Gas Production (Nm^3/tonne)	1,347.5	1,065.8	1,027.2
Dry Gas Composition (mol %)			
H_2	36.2	30.9	30.6
CO	44.4	19.8	41.2
CO_2	19.1	36.2	10.9
CH_4	0.3	13.1	14.0
C_2	-	-	3.3
H_2/CO	0.82	1.56	0.74

Choice of Gasifier

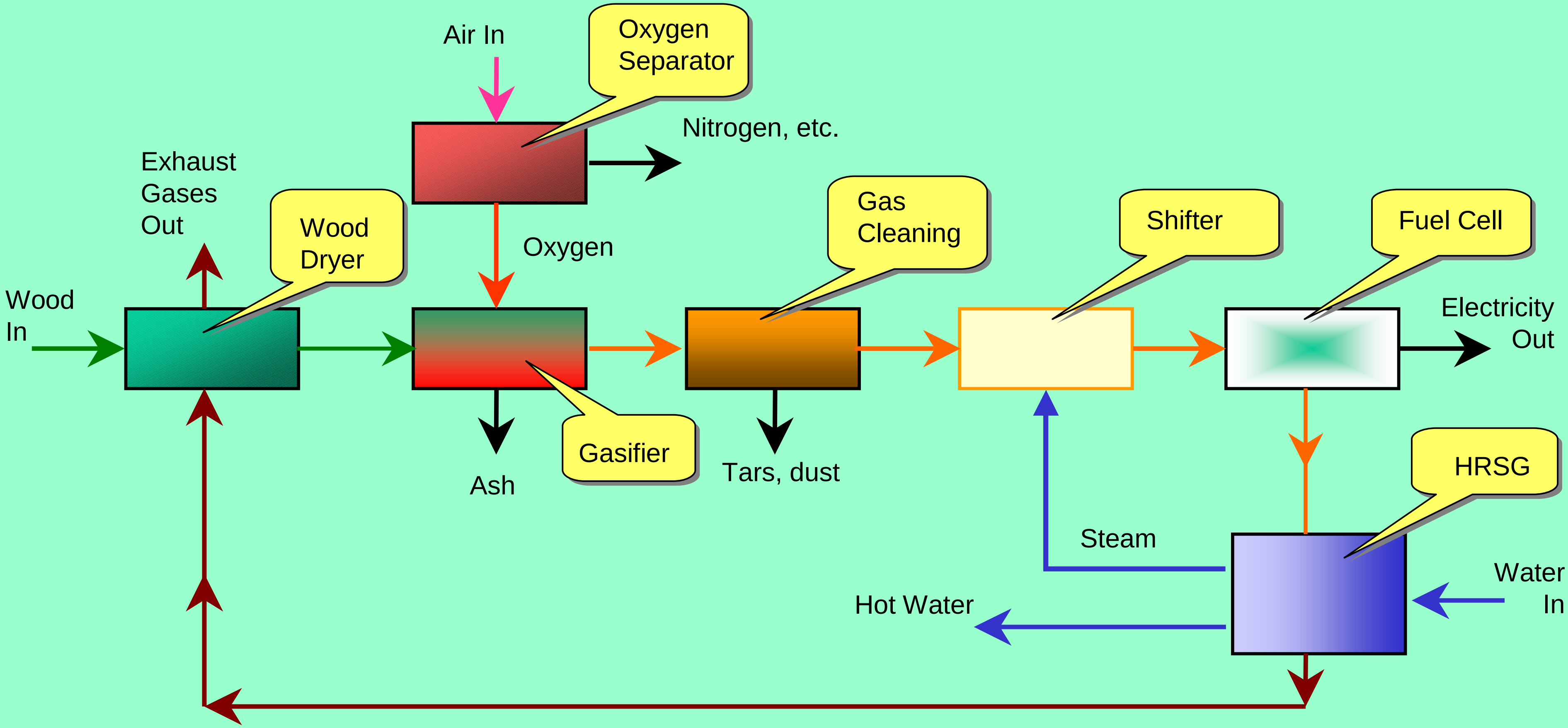
A range of gasification technologies was examined.

The **LPO gasifier is chosen since it gives a gas low in methane. This means that no reformer is necessary**. Oxygen separation adds an additional expense to the system, but the gas produced from the gasifier will not be diluted with atmospheric nitrogen, and hence the rest of the gas-handling equipment can be of a smaller scale (and less expensive) than that associated with air-blown gasifiers.

A system comprising a low-pressure oxygen (LPO) wood gasifier, a wood drying stage, cold gas cleaning and a fuel cell and giving approximately 75-80 kWe output is proposed.

Integrated Wood LPO Gasification - Phosphoric Acid Fuel Cell System

(Has Shifter, but no reformer)



PAFC in the system

An oxygen-separation plant extracts oxygen from air to supply the gasifier. Steam is raised using some of the waste heat from the fuel cell and is added at 175°C to the gas leaving the gasifier. The gas/steam mixture transfers heat to the air used by the fuel cell (and provides some hot water at 85°C) before entering the Shifter. The shifted gas is cooled, cleaned in a conventional scrubber and fed to the fuel cell. The PAFC operates at 200°C for the PAFC, with the waste heat providing steam and hot water (85°C) for possible CHP applications.

The system is scaled so that this results in a net ac output of approximately 100 kWe from the fuel cell and around 75 kWe from the whole system.

MCFC in the system

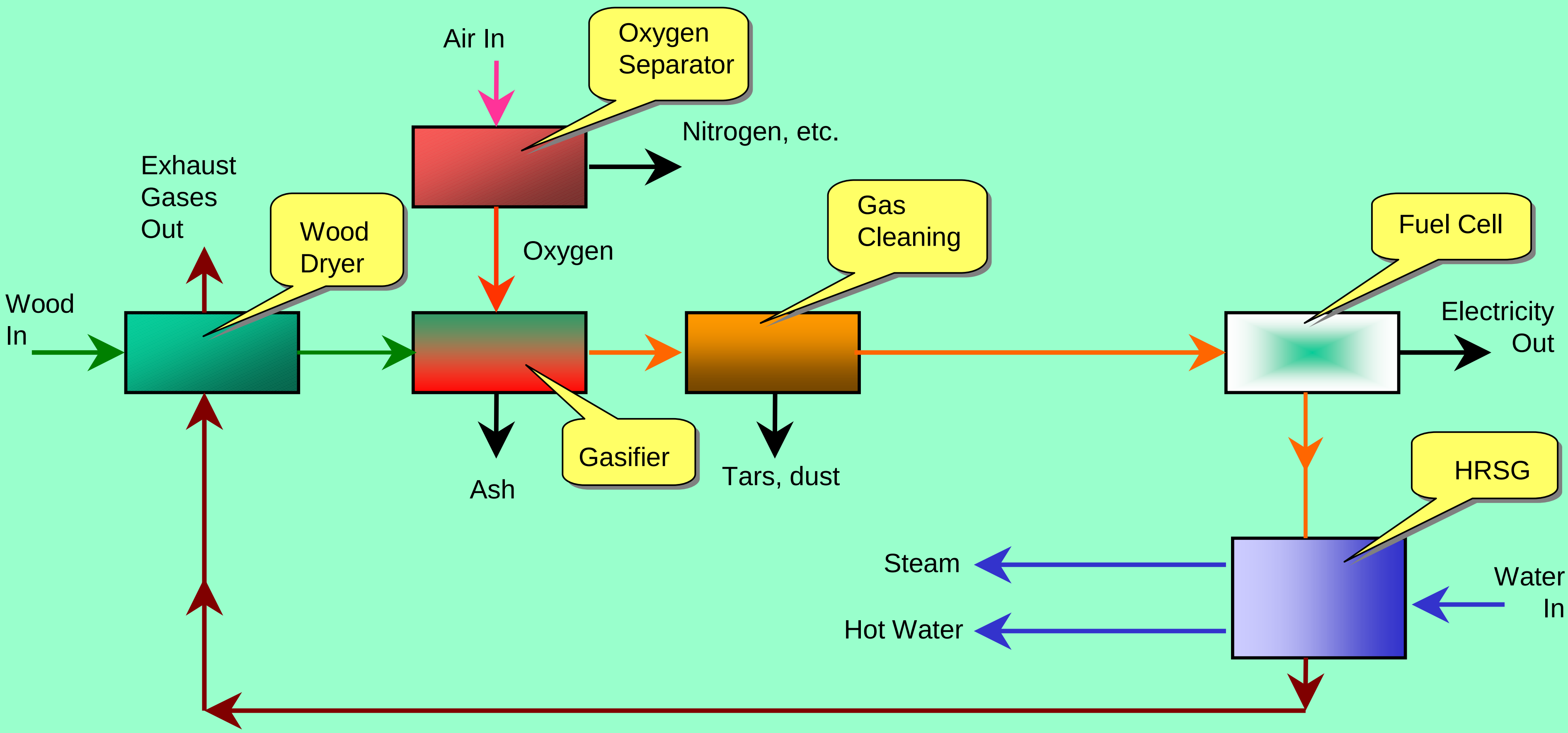
The MCFC operates at 650°C instead of 200°C for the PAFC. Some higher-grade waste heat will be available from a system operating at such a high temperature, which means it could generate steam for other processes or to drive a steam turbine.

Secondly, the conversion efficiency of the MCFC is taken to be 55% compared to 40% for the PAFC, so more of the energy of the wood gas can be converted into electricity.

Finally, the MCFC can use carbon monoxide as well as hydrogen to produce electricity, so **no Shifter** is required in this system.

Integrated Wood LPO Gasification - Molten Carbonate Fuel Cell System

(Has no Reformer or Shifter)



System using the PAFC

The net electrical output was found to be 74.5 kW and the hot water output is 249.3 kW, which comply with the maximum power and the maximum heat/electricity ratio requirements for this isolated community.

The LHV electrical efficiency was found to be 15.4% and the overall LHV energy efficiency 66.6%.
While these efficiencies are low, they are comparable with most other biomass-fed power plants of similar size.

Carbon dioxide emissions were found to be 2,432 g/kWh.
This level of CO_2 emissions is high, due to the low efficiency of the system, but can in fact be considered to be nullified due to re-absorption by growing trees in the sustainably-maintained forest.

There are no other significant emissions

System using the MCFC

The net electrical output was found to be 80.2 kWe, and the waste heat output was 107.2 kW.

An LHV electrical efficiency of 26.8% (HHV η = 24.9%) and an overall LHV energy efficiency of 62.6% (HHV η = 58.2%) was achieved.

Carbon dioxide emissions were found to be high (1,422 g/kWh), lower than for the system with the PAFC.

Table 2 Comparison of wood-fired MCFC and PAFC systems for Isolated Community

Fuel Cell Type	***PAFC***	***MCFC***
Reformer	None	None
Shifter	Yes	No
FC Operating Temperature (°C)	200	650
Wood Input (daf Tonnes/ day)	2.4	1.5
Thermal Input (kW, LHV)	486	299
Net Electrical Output (kWe)	74.5	80.2
Waste Heat Available (kW)	249	107
Electrical Efficiency (LHV, %)	15.4	26.8
Overall Energy Efficiency (LHV, %)	66.6	62.6
CO_2 emissions (g/ kWh)	2,432	1,422
System Capital Costs (£k)	363	297
Specific Investment (£/ kWe)	4,870	3,990
COE (p/ kWh) [electricity only]	27.1	20.0
COE (p/ kWh) [CHP]	24.8	19.0

Economic Analysis

Problems often occur when making an economic analysis of a system containing novel technology.

Novel equipment may only exist at the design or development stage, at a different size (usually at a much smaller scale) than that required, or costs can vary after several examples of the item have been manufactured or when it has been mass-produced.

In addition, the longevity of the equipment may not be known if it is in the early stages of development or testing.

Economic Analysis (II)

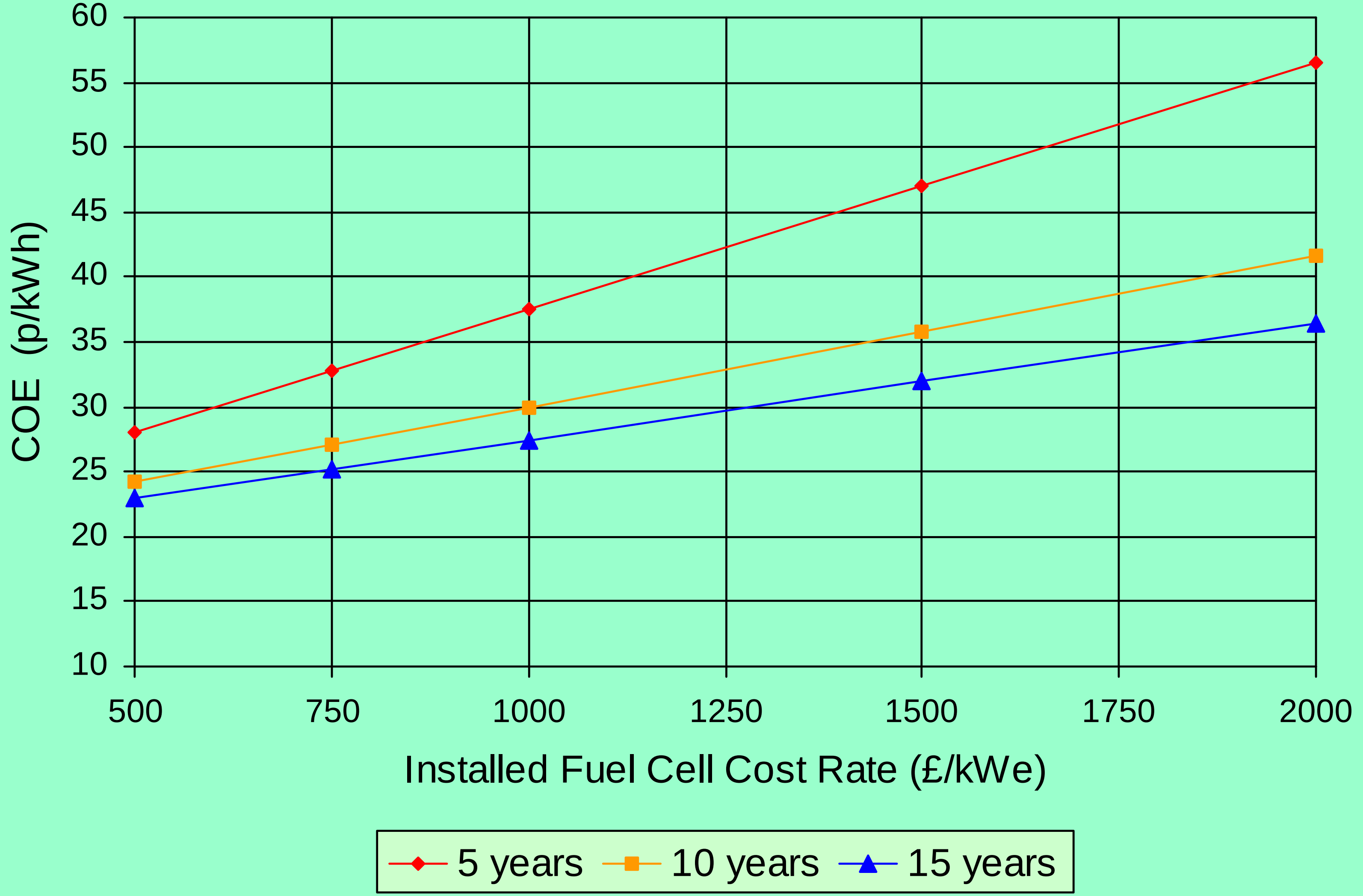
The capital cost of the downdraft gasifier is obtained by scaling the values taken from supplier's lists .
The system availability was taken as 40%.

The total specific investment (SI) for the system depends on the values assumed for the lifetime of the fuel cell and its installed system cost.

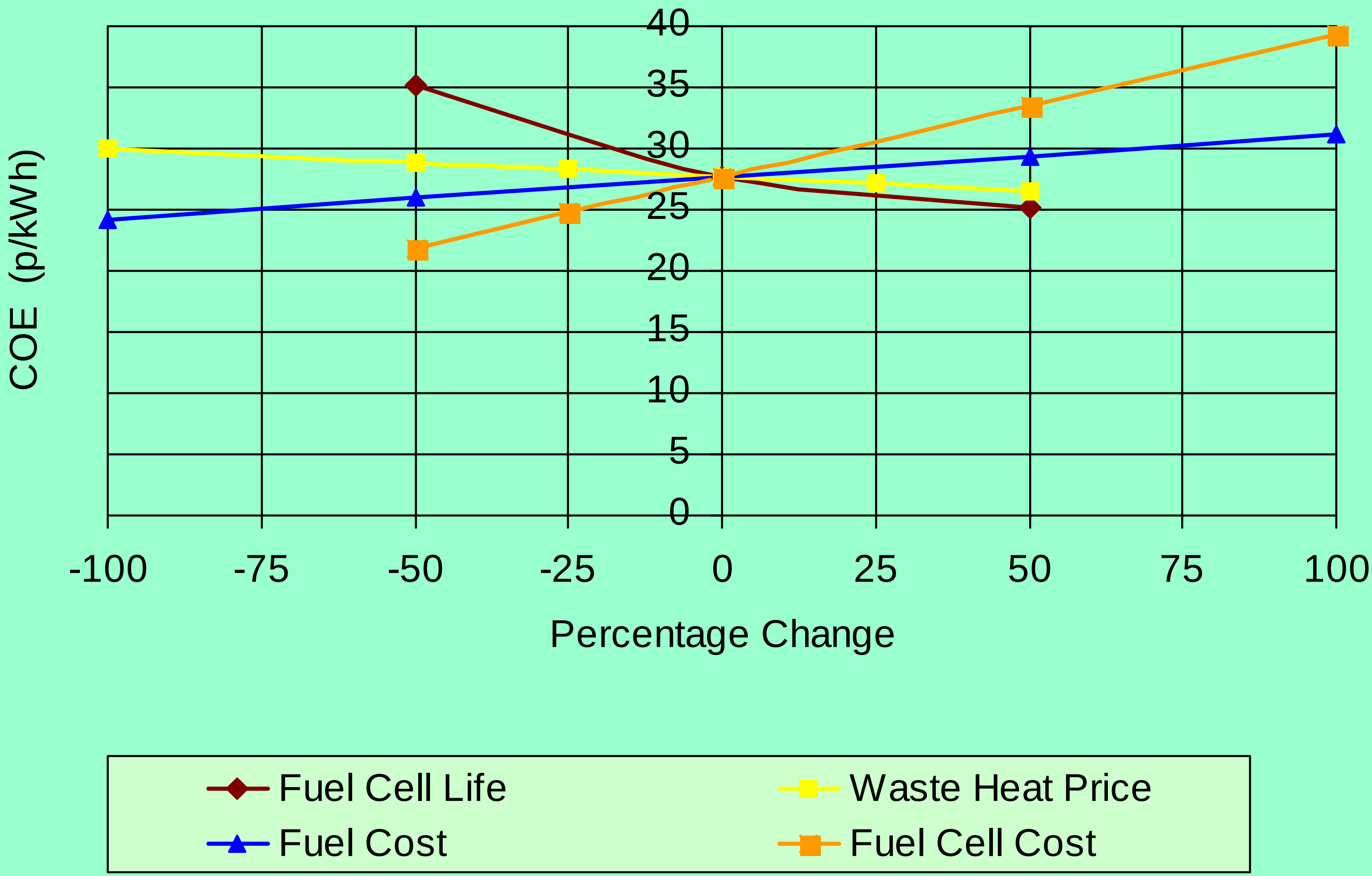
The SI was found to range from £4,010/kWe (£3,130 for the MCFC) for a lifetime of 15 years, Interest Rate of 7.5% and an installed fuel cell cost of £500/kWe, to £10,930/kWe (£10,050 for MCFC) for a lifetime of 5 years, interest rate of 7.5% and an installed fuel cell cost of £2,000/kWe).

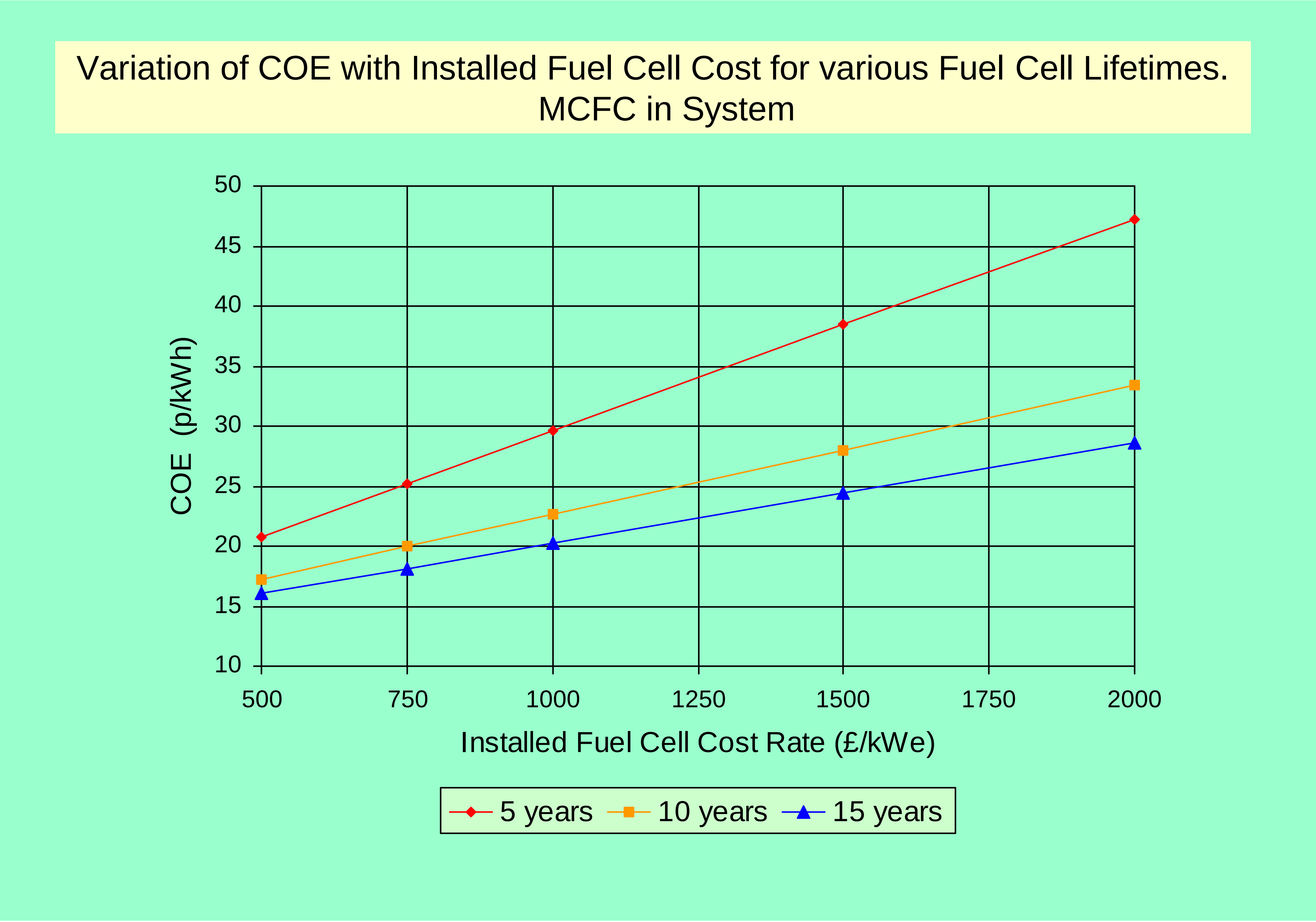
COE ranged from 22.9 (16.1) p/kWh to 56.5 (47.3) p/kWh for the PAFC system.

Variation of COE with Installed Fuel Cell Cost for various Fuel Cell Lifetimes. PAFC in System

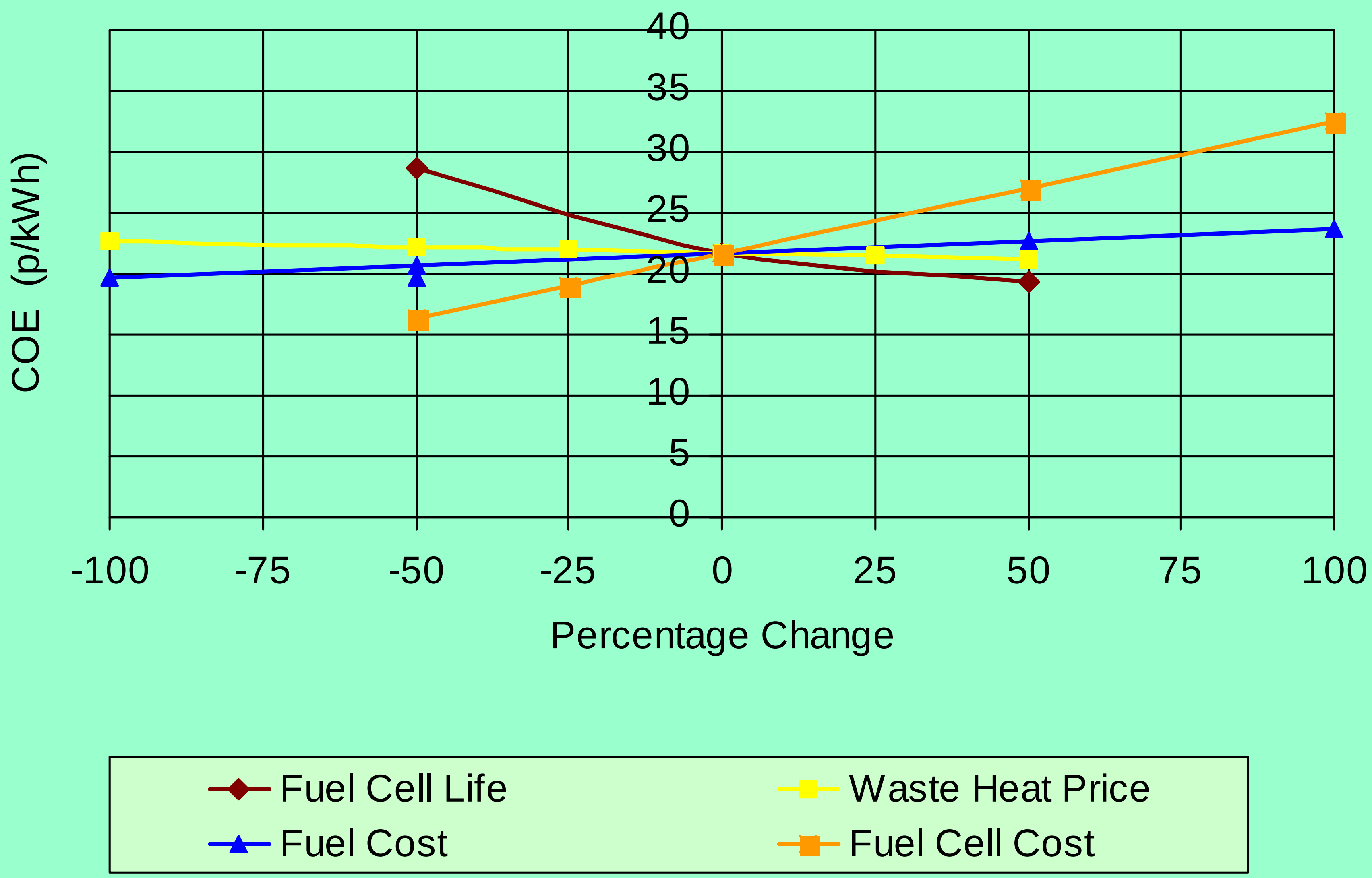


Percentage Change from Base Case for the PAFC System




Variation of COE with Installed Fuel Cell Cost for various Fuel Cell Lifetimes.
MCFC in System
COE (p/kWh)
50
45
40
35
30
25
20
15
10
500
750
1000
1250
1500
1750
2000
Installed Fuel Cell Cost Rate (£/kWe)
5 years
10 years
15 years

Percentage Change from Base Case for the MCFC System



CONCLUSIONS

Wood can be gasified to provide a gas suitable for use in a Phosphoric Acid or Molten Carbonate Fuel Cell to generate electricity and recoverable waste heat.

If the wood is grown in a sustainable fashion, there are negligible net emissions of carbon dioxide.

The wood-fired MCFC can be seen to generate electricity much more efficiently than the wood-fired PAFC.

Consequently, for the same electrical output, the MCFC system would be smaller than the PAFC system, use less fuel, emit less carbon dioxide and waste less energy from the fuel (and produce less waste heat).

CONCLUSIONS (II)

The wood-fired MCFC system is therefore technically and environmentally superior to the wood-fired PAFC system.

The PAFC system can only be preferred where the supply of recoverable waste heat (at low temperatures) is more important than the supply of electricity or high grade waste heat.

WOOD-FIRED PAFC AND MCFC SYSTEMS FOR AN ISOLATED COMMUNITY

This power plant ought to provide all the heat and electricity for a small, isolated community.

It was scaled to provide around 80 kWe to meet the peak electrical demand. Peak heat output should be about three times that of the electricity generated.

The system using the PAFC complies with this requirement, whereas the system with the MCFC provides only about 25% more heat than electricity.

WOOD-FIRED PAFC AND MCFC SYSTEMS FOR AN ISOLATED COMMUNITY (II)

The MCFC system is superior to the PAFC system in most features,

but the ability of the PAFC system to provide all the heat requirements means that it fulfils the selection criteria for providing all the energy needs of the isolated community.

(If an additional wood-fired boiler could be used to make up the shortfall in heat, then the MCFC system should probably be chosen).

Both versions of the system are very expensive, due to the capital costs of the fuel cells, **but could be appropriate in the absence of fossil fuels or grid electricity.**