Power Production in an Isolated Community from an Integrated Wood Gasification - Fuel Cell system

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Scope of the Paper

Fuel cells have the potential for generating electricity very efficiently, and retain the same efficiency at any scale.

Biomass is one of the renewable energy sources which is not intermittent, location-dependent or very difficult to store. If grown sustainably, biomass can be considered CO2 neutral.

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 using the ECLIPSE process simulation software.

The system was found to be expensive, but useful where fossil fuels or grid supplies are unavailable.

Advantages of Biomass

In general small-scale power systems cannot compete on cost with large-scale fossil fuel power generation. In particular, renewable sources have other drawbacks, such as intermittent nature, location dependency, seasonal or diurnal availability, which make them difficult to propose as the sole, reliable source of power for an isolated community. However, some form of biomass can be grown in most places, and in temperate zones there are several options. In this instance coppiced willow will be considered. Willow chips or rods can be easily transported and stored, so that power can be generated when needed.

Isolated Community and its Power Demand

The “isolated community” (IC) could be on an island, or simply where grid-supplied electricity is weak or non-existent. In this case the IC was taken to consist of 200 people and 3 retail outlets and to be located in a Temperate Zone. Heat and electricity use profiles for such an IC have been obtained, and show that the 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% . The system size must be scaled to this power demand.

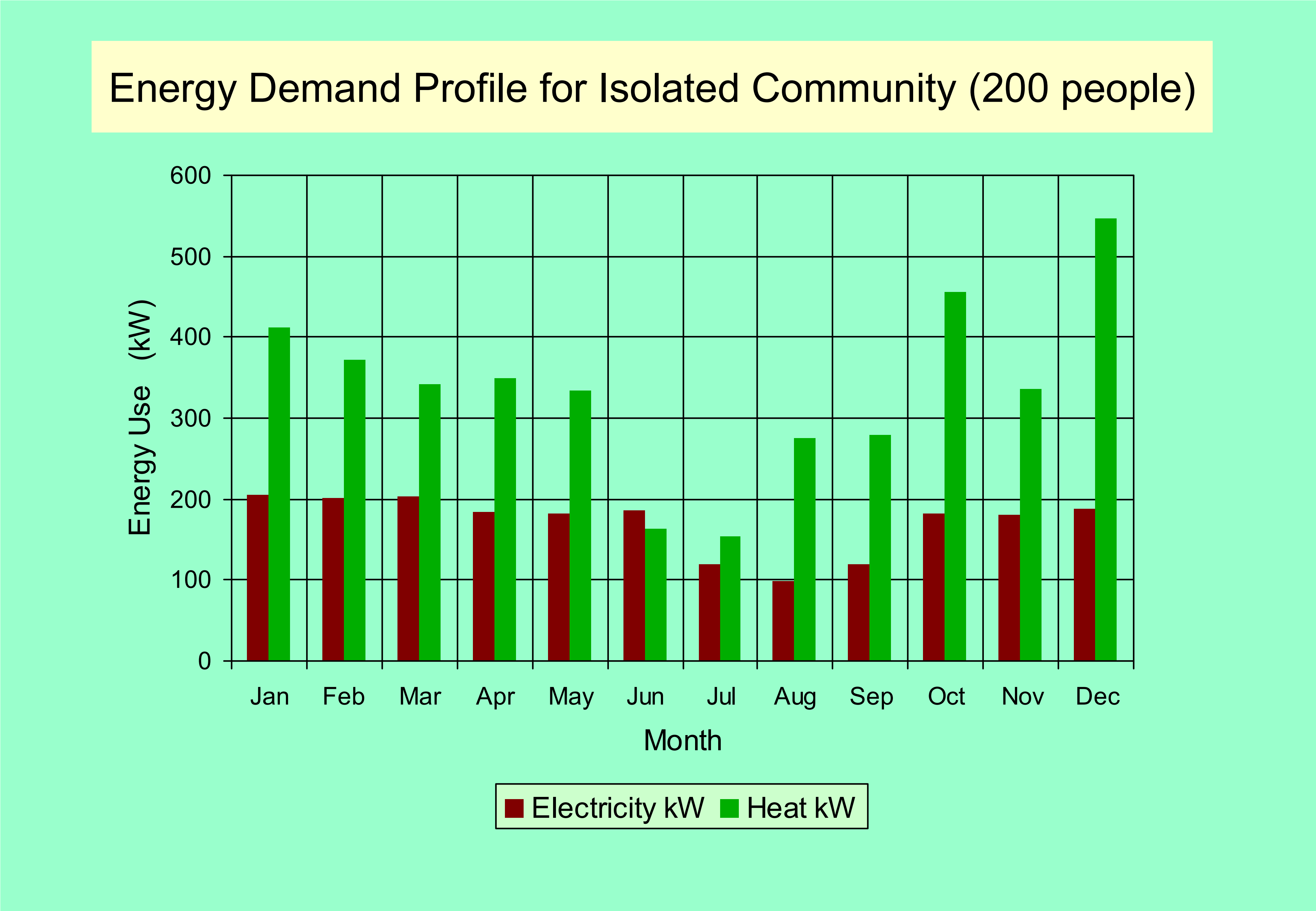

Energy Demand Profile for Isolated Community (200 people)
Energy Use (kW)
0
100
200
300
400
500
600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Electricity kW
Heat kW

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

LPO= low pressure oxygen
HPO= high pressure oxygen
IND= indirect

Choice of Gasifier

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. 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.

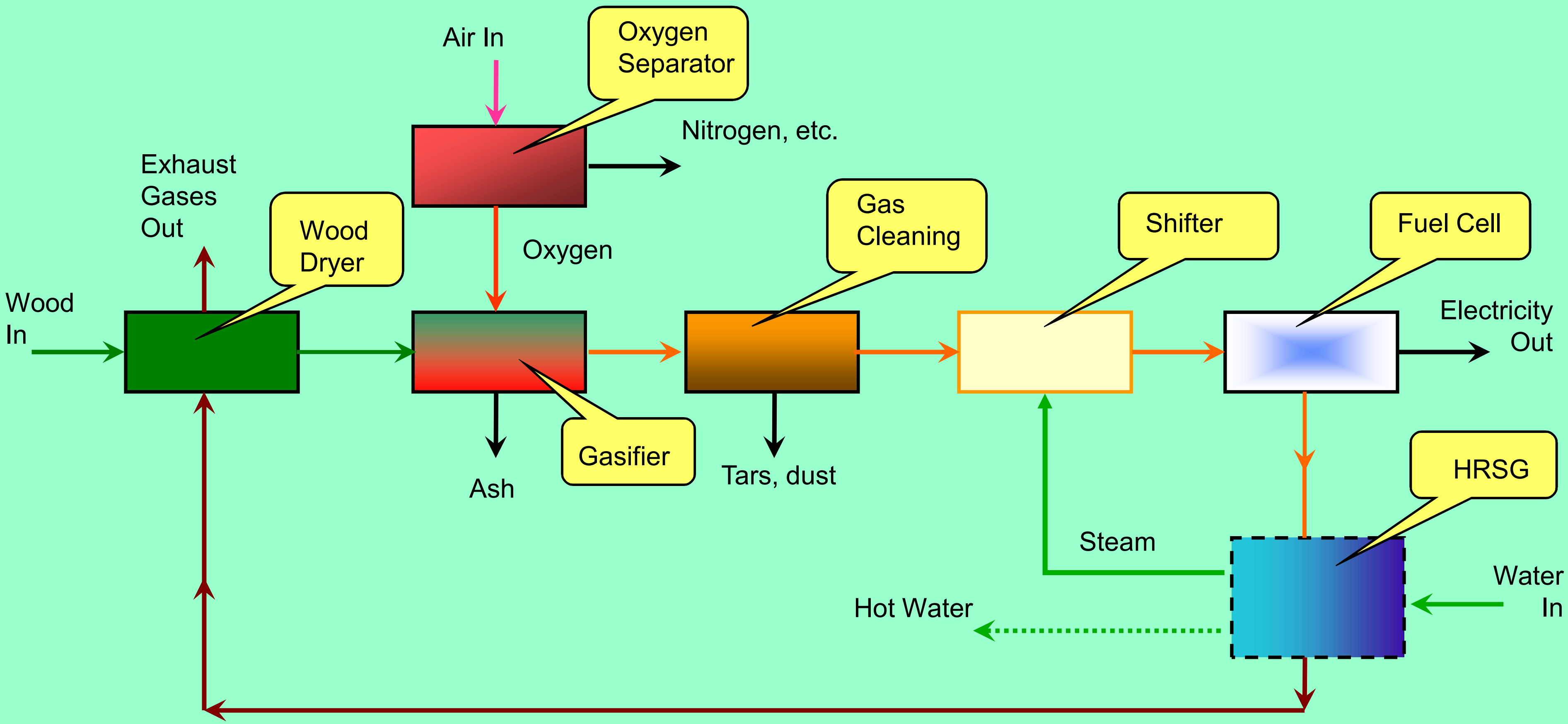
Choice of Fuel Cells

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.

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 10 years for the fuel cell lifetime and a capital cost rate of £750 for the fuel cell have been considered.

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.

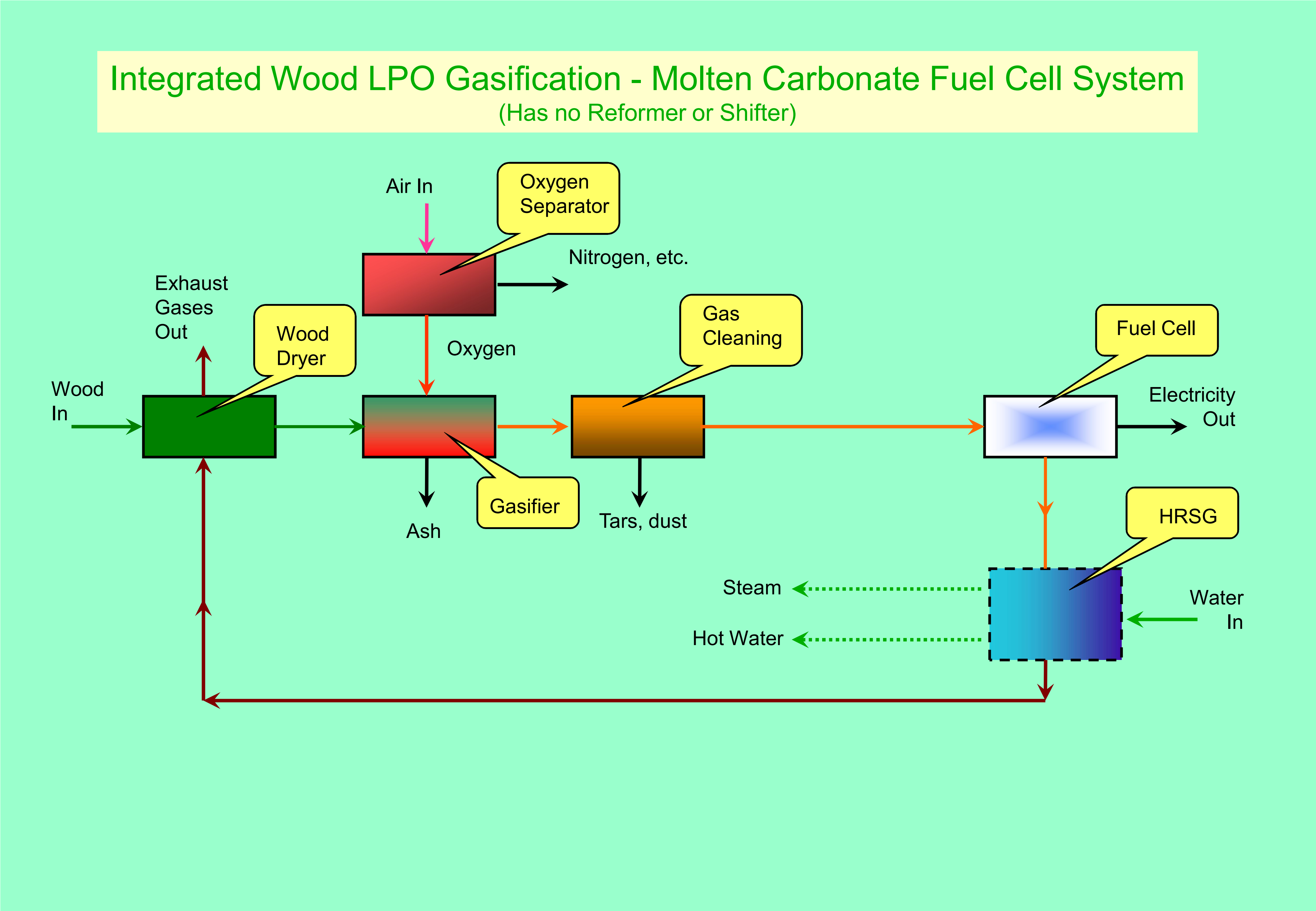
The system is scaled so that this results in a net ac output of approximately 100 kWe from the fuel cell and around 75 kWe from the whole system.

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)
Air In
Oxygen Separator
Nitrogen, etc.
Exhaust Gases Out
Wood Dryer
Oxygen
Gas Cleaning
Fuel Cell
Wood In
Electricity Out
Ash
Gasifier
Tars, dust
HRSG
Steam
Water In
Hot Water

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 CO2 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

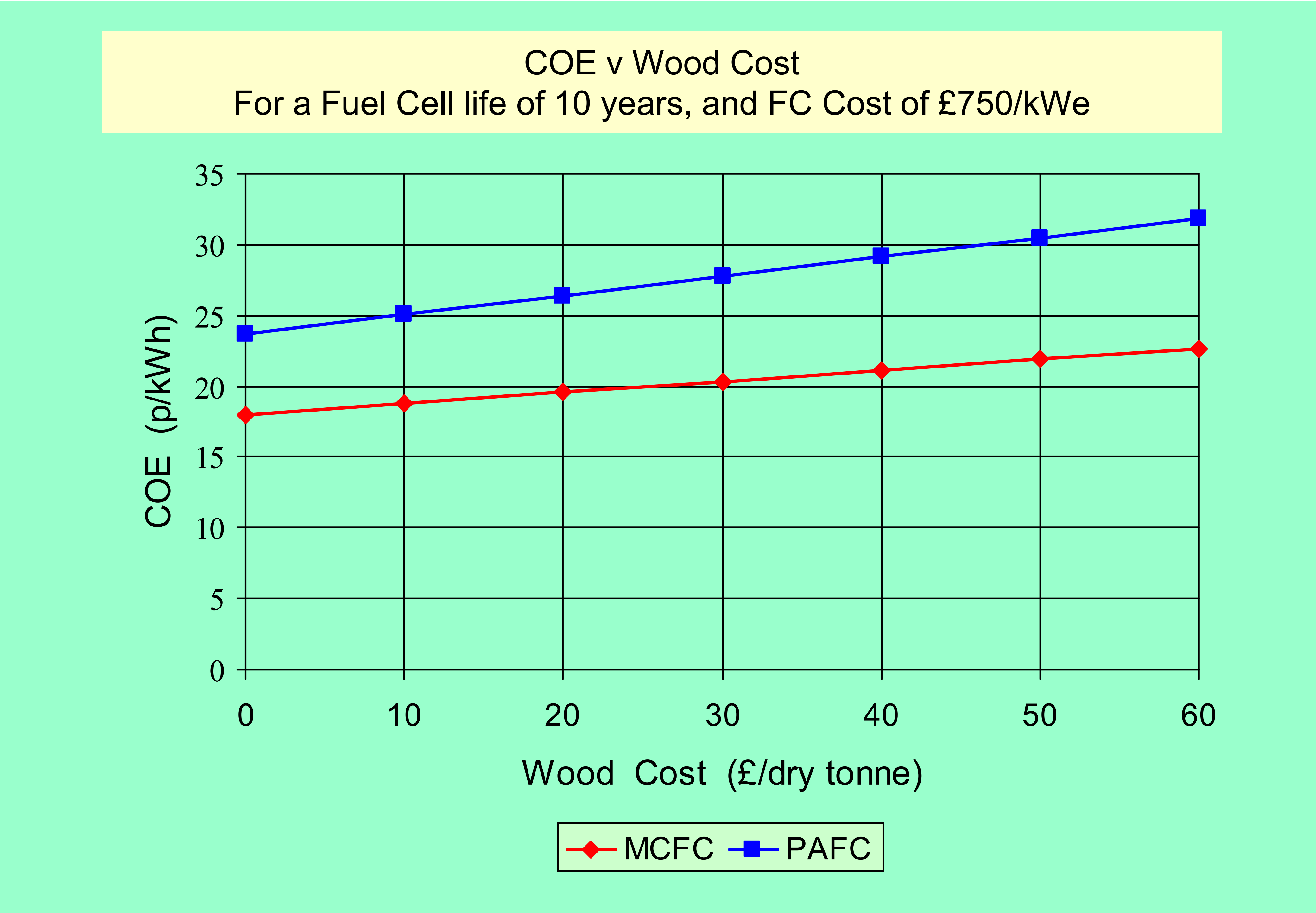
Fuel Cell Type	***PAFC***	***MCFC***
Reformer	None	None
Shifter	Yes	No
FC Operating Temperature (°C)	200	650
Wood Input (daf Tonnes/ day)	2.4	1.5
Thermal Input (kW, LHV)	486	299
Net Electrical Output (kWe)	74.5	80.2
Waste Heat Available (kW)	249	107
Electrical Efficiency (LHV, %)	15.4	26.8
Overall Energy 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

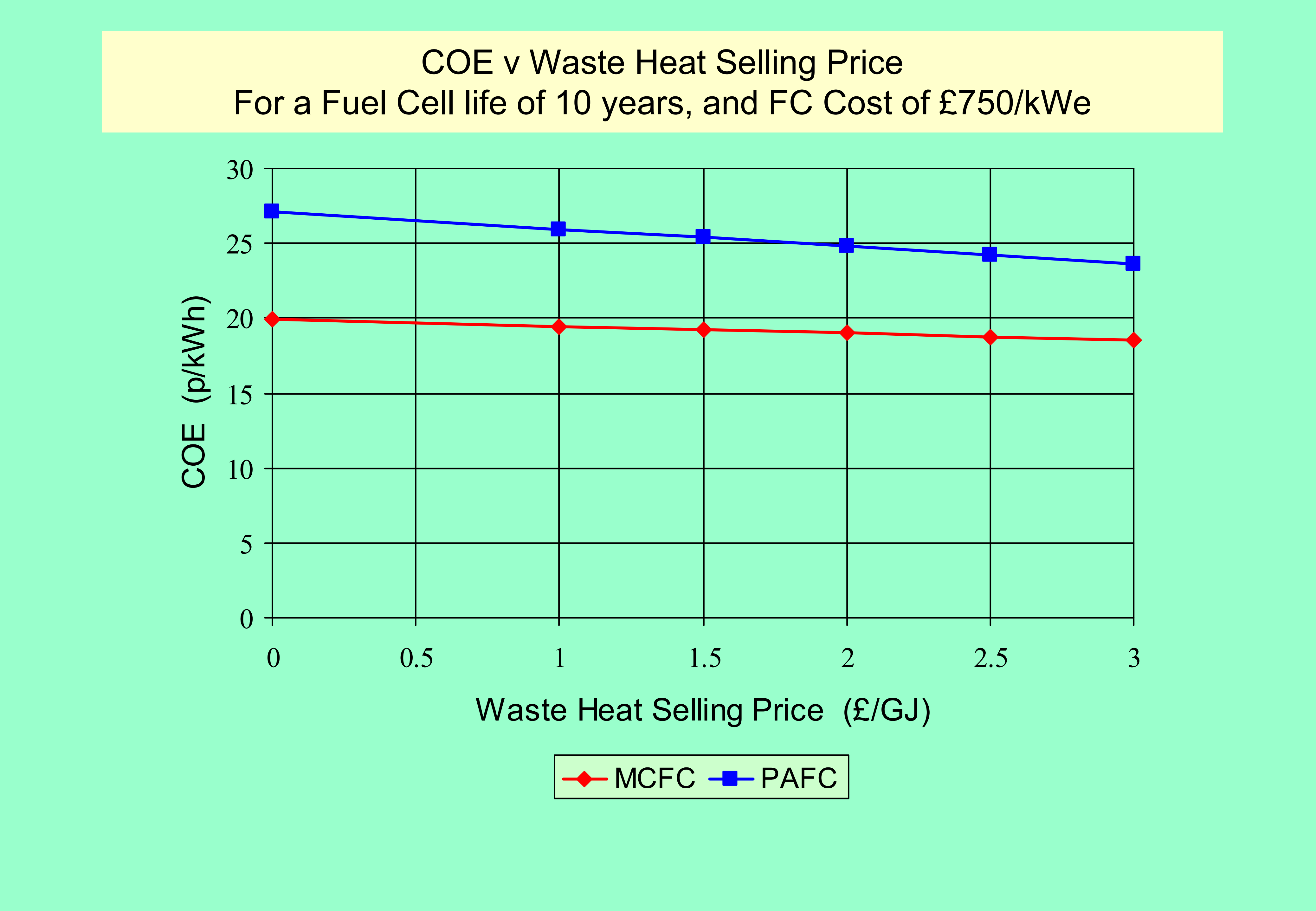
Economic Analysis

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, or at a different size (usually at a much smaller scale) than that required. Estimating the cost of the equipment is also difficult since 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.

In this system the costs of the biomass gasifier , wood conveying, screening, conveying and drying stages have been estimated from sources in the literature. It has been more difficult to find reliable data for the costs and lifetimes for the fuel cells, but the best available estimates have been used.

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 be £4,870/ kWe for the system with the PAFC and £3,990/ kWe for the system with the MCFC, assuming a total plant lifetime of 30 years, but that the fuel cells would need replacing every 10 years, and that the interest rate on capital would be 7.5%.


COE v Wood Cost
For a Fuel Cell life of 10 years, and FC Cost of £750/kWe
COE (p/kWh)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
Wood Cost (£/dry tonne)
MCFC
PAFC


COE v Waste Heat Selling Price
For a Fuel Cell life of 10 years, and FC Cost of £750/kWe
COE (p/kWh)
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
Waste Heat Selling Price (£/GJ)
MCFC
PAFC

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. When the two types of fuel cell systems are compared, 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). 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, and even then, the MCFC system with a supplementary wood-fired boiler to make up any heat deficit may well be preferable.

There are obvious benefits in using wood as a fuel. If a wood-fired power generation system is to be employed, should a fuel cell-based system be chosen?

It is unlikely that a wood-fired PAFC could ever be recommended for electricity generation only. The wood-fired MCFC has a technical and environmental performance equivalent to the best of the current small-scale wood-fired technologies, but is much more expensive . Both these systems could be used in an isolated community, but not where cheap fossil fuels are readily available.

References

McMullan, JT, Williams, BC, Campbell, PE, McIlveen-Wright, DR, Brennan, S and McCahey, S, (1996). “Fuel Cell Optimisation Studies”, the final report for contract JOUL2-CT93-0278 to the European Commission in the Framework of the Non-Nuclear Energy Programme, JOULE II, 126pp.

. McIlveen-Wright, D., McMullan, JT and Williams, BC, (2001), “Biomass-fired Fuel Cells”, Int. J. Global Energy Issues, Vol. 15. Nos 3-4. pp. 220-246.

. Wyman, C.E., Bain, R.L., Hinman, N.D. and Stevens, D.J. (1993) Ethanol and methanol from cellulosic biomass. Chapter 21 of Renewable energy, sources for fuels and electricity, Island Press, Washington DC, pp.865-923.

. Chem Systems (1990) Assessment of cost of production of methanol from biomass. Report DOE/PE-0097P, Chem Systems, Tarrytown, New York.

. Williams, BC, McMullan, J.T., (1996). Techno-economic analysis of fuel conversion and power generation systems - the development of a portable chemical process simulator with capital cost and economic performance analysis capabilities. Int. J. Energy Research , Vol. 20, pp.125-142.

. McIlveen-Wright, DR, (1996). “Wood-fired Fuel Cells”, MSc. Environmental Management thesis, University of Ulster, Coleraine.

. McIlveen-Wright, D, Williams BC and McMullan, JT. (1999). “Options for Small and Medium Scale Power Generation from Biomass”, Developments in Chemical Engineering and Mineral Processing – The Australasian Research Journal. Curtin University of Technology, Western Australia, Vol. 7, Nos 1-2, pp 85-114.

. Solantausta Y., Bridgwater A.V. and Beckman D., (1995). "An Assessment of Biomass-based Power Systems", a report for the International Energy Agency Bioenergy Agreement, (VTT).

. Bridgwater A.V. and Double J.M., (1991). "Technical and Economic Modelling of Processes for Liquid Fuel Production in Europe", in the contractor's report No. EN3V-0012-UK (RH), Non-Nuclear R&D Programme "Production and Utilization of New Energy Vectors" of the CEC.