WOOD GASIFICATION INTEGRATED WITH FUEL CELLS

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ABSTRACT

Techno-economic assessments of systems which integrate biomass gasification with fuel cell modules (molten carbonate or phosphoric acid) for electricity generation are presented. The wood-fired Phosphoric Acid Fuel Cell was found to be suitable where high heat/electricity values were required, but had low electrical efficiency. Electrical efficiencies of 13 - 17% are typical for these systems, as are Break-even Electricity Selling Prices (BESPs) of 10 to 20 p/kWh and specific investments of around £3,000/kWe to £7,500/kWe. This technology is unlikely to be considered for further development as an electricity generation system.
The wood-fired Molten Carbonate Fuel Cell was found to be quite efficient and suitable for small-scale electricity generation purposes. Electrical efficiencies of 25 - 28% are typical for these systems, as are Break-even Electricity Selling Prices of 6 to 12 p/kWh and specific investments of around £2,000/kWe to £5,000/kWe. This technology could be considered for further development in the future, if the lifetime and capital costs of molten carbonate fuel cells can be improved. The problems in assessing future capital costs makes the economic viability of such systems difficult to determine.

KEYWORDS

Biomass gasification; fuel cells; electricity generation; computer modelling; carbon dioxide reduction.

INTRODUCTION

The emission of carbon dioxide from fossil fuel-fired power generation plants and the consequent effect on the global environment is a major concern. Methods for managing and reducing these emissions must be found and implemented, if irreversible climate change is to be avoided. The use of biomass, grown in a sustainable manner, as a replacement for fossil fuels in power generation systems is one method of reducing CO_2 emissions. Another method is to use more efficient power plant technology, such as the fuel cell. In this paper the possibility of combining these two methods is examined i.e. wood gasification integrated with fuel cell modules. The ECLIPSE suite of process simulation computer programmes (Williams and McMullan, 1996), which has successfully modelled a range of power generation systems (McMullan *et al.,* 1995), is used to make techno-economic simulations of two wood-fired fuel cell technologies for a range of small scale power plants with outputs from around 20 kWe to 500 kWe.

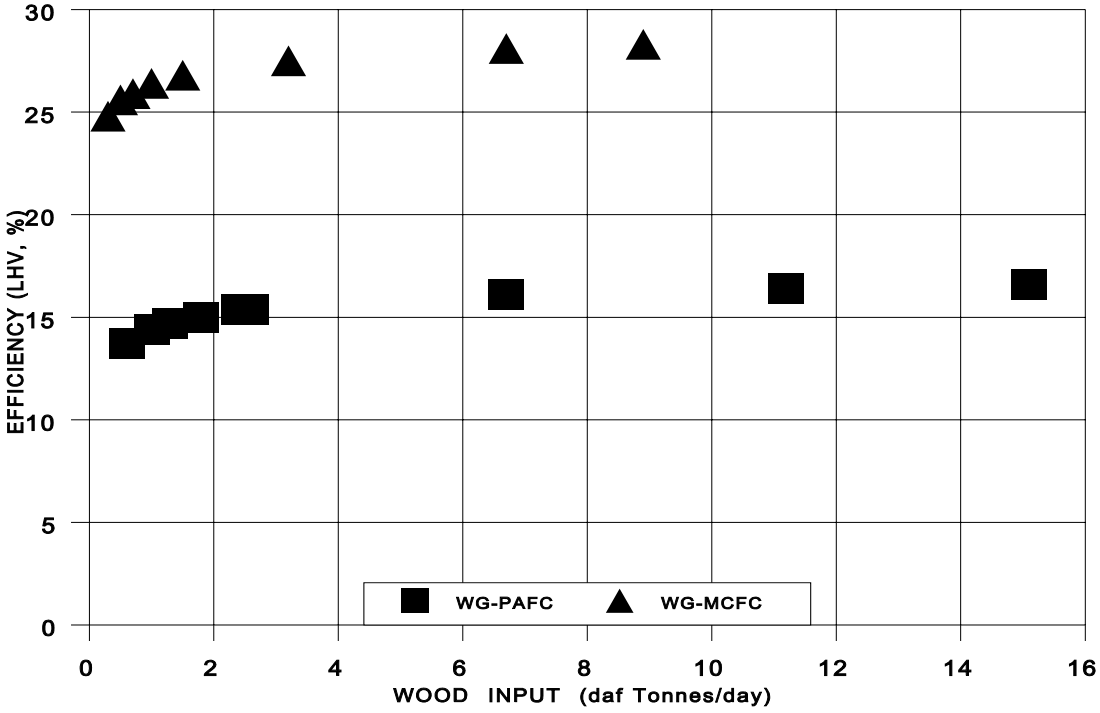
The most active common fuel for use in fuel cells is hydrogen, since it has an oxidation rate of about 4 orders of

magnitude greater than that of simple partially oxidised one-carbon compounds, which themselves have the same oxidation advantage over saturated hydrocarbons under the same conditions (Appelby, 1994). Hydrogen can be produced from the thermochemical gasification of many biomass feedstocks, such as municipal solid waste, agricultural or forest wastes or wood chips from short rotation forestry plantations. The synthesis gas (or syngas) coming from an oxygen-blown gasifier will contain methane and carbon monoxide in addition to the hydrogen. In general, the fuel cell electrolytes cannot use the syngas directly, it must receive the appropriate pretreatment. This pretreatment can involve adding steam at high temperature to the syngas to convert the methane to carbon monoxide and hydrogen in a process known as *steam reforming*. At a lower temperature steam can react with the carbon monoxide to form hydrogen (and carbon dioxide) in the *shift conversion* reaction. Carbon dioxide (and sulphur compounds, if present) can be removed at a later stage, if necessary.

The equipment for converting syngas to hydrogen (methane reformers, shift reactors, CO_2-removal systems and hydrogen purification "pressure-swing-adsorption" technology) are all well-established commercial technologies in the chemical process industries.

Biomass gasifiers in various forms have been available on the pilot scale, as demonstration systems and as commercial plants. Some of these which are being developed for methanol production are also suitable for hydrogen production, since the production of syngas is the first of two stages in methanol synthesis (Ogden and Nitsch, 1993); the second stage being the recombination of carbon monoxide and hydrogen at elevated temperature and pressure (~300°C and 70 bar), and in the presence of a Cu-Zn catalyst, to produce methanol.

The properties of the fuel cell electrolyte must be taken into account when considering what gas conditioning is necessary for the syngas. The PAFC is (a) CO_2-rejecting i.e. is insensitive to CO_2 and other acid components, (b) can tolerate 1-2% CO at the operating temperature of 200°C, and © can use the waste heat from the electrochemical cell stack efficiently for steam reforming and for providing space heating or hot water (Srinivasan, 1993). The MCFC (a) can tolerate CO_2, (b) can use both H_2 and CO as "fuel" to produce electricity, © has an operating temperature of 600-700°C, (d) has recoverable waste heat at high temperatures which could provide high grade steam, as well as low temperature waste heat for hot water. The MCFCs are not yet at the commercial stage, it is about five years behind the PAFC in development, but efficiencies of 50-60% are expected to be readily achievable (Mugerwa and Blomen, 1993).



Gasification Integrated with Fuel Cells

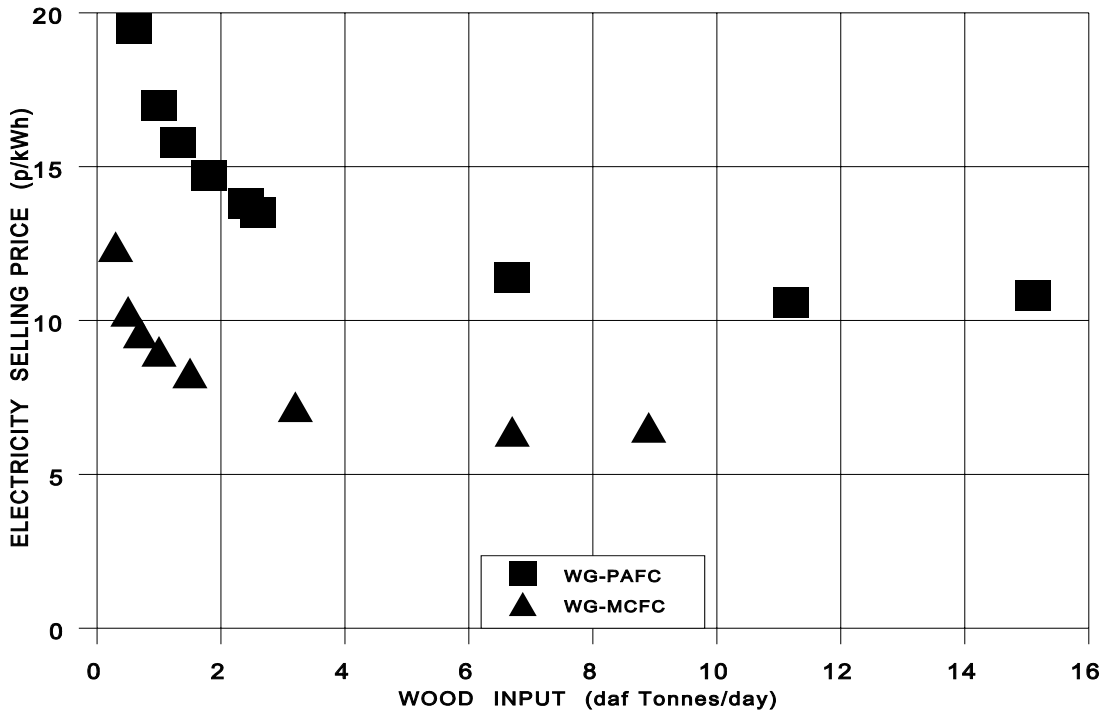
The system comprises a low pressure oxygen (LPO) wood gasifier, a wood drying stage, cold gas-cleaning, (shifter, where necessary) integrated with a fuel cell. The most appropriate gasifier is considered to be the Koppers-Totzek entrained-flow gasifier, which was originally developed for coal gasification and is taken to be representative of commercially available LPO technology (Wyman *et al.*, 1993). It has been assessed for biomass (Chem Systems, 1990). The LPO gasifier is chosen since it gives a gas which is low in methane (and is not diluted by nitrogen as would occur in an air-blown gasifier). This means that it is not necessary to "reform" the methane to hydrogen and carbon monoxide. Nine plants of different sizes were examined for a system composed of the LPO wood gasifier integrated with the PAFC (WG-PAFC), and eight with the MCFC (WG-MCFC).

Results for the LPO Gasifier Integrated with MCFC or PAFC Systems

Certain parameters have been chosen to assess these technologies. For the technical features of the systems the efficiency (Lower Heating Value) for electricity generation is used. This is shown in Fig. 1. BESP (see Fig. 2) and Specific Investment (SI, which is the capital cost per installed kilowatt of electricity output) are taken as the indicators of the system economics. Although sustainably grown wood is assumed to be used as the fuel, CO_2 is emitted and the amount of CO_2 emissions is used as a monitor of the environmental impact of the system.

The smallest WG-PAFC system would use 0.6 daf Tonnes/day, emit 2,720 g/kWh of CO_2, produce 15 kWe at an efficiency of 13.7%, with a BESP of 19.5 p/kWh and SI of 7,200 £/kW. The largest WG-PAFC system would use 15.1 daf Tonnes/day, emit 2,260 g/kWh of CO_2, produce 505 kWe at an efficiency of 16.6%, with a BESP of 10.8 p/kWh and SI of 3,300 £/kW. The latter system could also transfer around 1.5 MW_{th} of low grade waste heat for warm water heating to give an overall energy efficiency of 68% for such a CHP configuration. The smallest WG-MCFC system would use 0.3 daf Tonnes/day, emit 1,530 g/kWh of CO_2, produce 15 kWe at an efficiency of 24.8%, with a BESP of 12.4 p/kWh and SI of 4,700 £/kW. The largest WG-MCFC system would use 8.9 daf Tonnes/day, emit 1,350 g/kWh of CO_2, produce 505 kWe at an efficiency of 28.3%, with a BESP of 6.5 p/kWh and SI of 2,050 £/kW. The latter system could also transfer about 500 kW_{th} of high grade and around 200 kW_{th} of low grade waste heat for warm water heating to give an overall energy efficiency of 64% for such a CHP configuration (McIlveen-Wright, 1996).

Conclusions for LPO Gasifier/ Fuel Cell Systems



- The WG-MCFC system has the highest efficiency of all small biomass-fuelled systems (McIlveen-Wright *et al.,* 1998). The WG-PAFC has an efficiency similar to that of wood combustion plants of similar size (i.e. wood input), which is the least efficient type of small thermochemical system using biomass.
- BESP values for both these systems are better than for similarly sized wood combustion plants, but are expected to be higher than those of the gasifier-gas engine systems (McIlveen-Wright *et al.,* 1997).
- All of these systems use downdraft gasifiers integrated with fuel cells. The fuel cells are modular, so their capital cost increases linearly with the number of modules used. Gasifier costs are exponential, but they are capped by the limit of the technology i.e. downdraft gasifiers do not yet work at large scale (above about 2 MW thermal). If more electricity is required, then more than one gasifier must be used. BESP falls sharply with increased size for the smallest systems, then falls more gradually. In Fig. 2 it can be seen to rise for the largest size, due to the impact of transportation costs on feedstock costs. The optimum plant size for a single LPO downdraft gasifier integrated with PAFC or MCFC modules was found to be in the range 300-500 kWe.
- Specific Investment, SI, was found to be very high for both system types, ranging from £4,700/kWe to £2,050/kWe (with increasing size) for the WG-MCFCs and £7,200/kWe to £3,300/kWe for the WG-PAFCs. These figures should be considered as guidelines, since capital costs of novel technologies are notoriously difficult to estimate.
- CO_2 emissions are high for the WG-PAFCs, but are similar to those for wood combustion plants of the same size. The more efficient WG-MCFCs emit considerably less CO_2. However, if the wood comes from sustainably-managed plantations, then the systems can be considered CO_2 neutral.

References

Appelby, A.J. (1994), *Int. J. Hydrogen Energy,* 19(2), 175-180.

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

McIlveen-Wright, D. R. (1996). *Wood-Fired Fuel Cells*, MSc. Thesis, University of Ulster, Coleraine.

McIlveen-Wright, D.R., B. C. Williams and J. T. McMullan (1997), Electricity Generation from Wood-Fired Power Plants: The Principal Technologies Reviewed. In: *Developments in Thermochemical Biomass Conversion*, (A. V. Bridgwater and D. G. B. Boocock, eds.), Volume 2, pp. 1525-1538, Blackie Academic & Professional, London, UK .

McIlveen-Wright, D., B. C. Williams and J. T. McMullan (1998), Options for Small and Medium Scale Power Generation from Biomass. *Developments in Chemical Engineering and Mineral Processing* (to be published).

McMullan, J. T., B. C. Williams, P. Campbell, D. McIlveen-Wright, and J. M. Bemtgen (1995). Techno-economic assessment studies of fossil fuel and fuel wood power generation technologies. CEC Report on “R&D in Clean Coal Technology” for the JOULE II Programme, contract nr. JOUF-0017.

Mugerwa M.N. and Blomen, L.J. (1993), System Design and Optimisation. In *Fuel Cell Systems*, (L. J. Blomen and M. N. Mugerwa, eds.,), p. 211, Plenum Press, New York.

Ogden and Nitsch (1993), "Solar Hydrogen. In: Ch. 22 of *Renewable Energy, Sources for Fuels and Electricity,* Island Press, Washington DC.

Srinivasan, S. et al. (1993), Overview of Fuel Cell Technology. In: *Fuel Cell Systems*, (eds. Blomen L.J. and Mugerwa M.N.), Plenum Press, New York, 48.

Williams, B. C. and J. T. McMullan (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. *lnt. J. Energy Research,* 20, 125-142.

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