A TECHNO-ECONOMIC ANALYSIS OF HIGH AND MEDIUM TEMPERATURE SOLID OXIDE FUEL CELLS INTEGRATED WITH BIOMASS GASIFICATION

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Introduction

Solid oxide fuel cells (SOFCs) offer the possibility of efficient electricity generation for both domestic (<30kWe) and industrial (>200kWe) Combined Heat and Power (CHP) applications. In general natural gas is considered to be a suitable fuel, but concerns on its long-term availability and increase in cost make biomass a possible alternative [1].

In this paper the ECLIPSE process simulation package [2] is used to model and make a techno-economic analysis of both domestic and industrial scale systems that combine biomass gasification with SOFC stacks. Simulations have already been made for similar systems using Molten Carbonate and Phosphoric Acid fuel cells [3].

Two forms of the SOFC are considered; the intermediate temperature solid oxide fuel cell (ITSOFC) and the standard high temperature solid oxide fuel cell (HTSOFC). Nanocomposites offer the possibility of new pathways for charge carriers in solid oxide fuel cells, so that their operating temperatures could be reduced considerably, from 1000C (high temperature) to around 600-700C (intermediate temperature) [4] and even to less than 400C (low temperature) [5]. This would reduce start up times, help solve sealing problems associated with SOFCs [6], as well as allowing lower cost equipment to be used in the Balance of Plant. However, in this paper only high temperature and intermediate temperature operation are considered.

The biomass technology chosen for the two systems was an air-blown downdraught gasifier. This is one of the simplest and cheapest biomass conversion technologies at the scales chosen, It does however supply a producer gas rich in inert nitrogen, which reduces its calorific value. Willow and miscanthus were taken as the biomass fuels for the power plants.

Comparisons were made of the systems in terms of their electrical output, electrical efficiency, CO2 emissions, specific capital investment and break-even electricity selling price (BESP). In addition, the sensitivity of the BESP to variations in the fuel cost, the fuel cell cost, the fuel cell lifetime and the waste heat selling price were examined and compared.

Simulation Results

Technical Data

The technical results for the ECLIPSE simulations for the 25kW and 250kW CHP systems, with willow as the fuel, are summarised in table 1 and with miscanthus as the fuel in table 2. Simulations have been made for both the high and intermediate temperature versions of the SOFCs.

System Output (kWe)	250	250	25	25
SOFC Temperature, C	913 (HT)	616 (IT)	911 (HT)	607 (IT)
Fuel	Willow	Willow	Willow	Willow
Biomass Flow daf t/day	3.04	3.07	0.35	0.35
Thermal Input kWth, LHV	655.4	661	74.48	74.48
Electricity Usages	10.7	11.8	3.9	4.3
Heat Recovered	121	44	9	0
Gross Electricity Out	264	264.4	29.4	30
Net Electricity Out	253.3	252.2	24.9	25.1
Electrical Efficiency, LHV	38.65	38.33	33.4	33.7
CHP Efficiency, LHV	57.1	44.8	45.5	33.7
CO2 g/kWh	841	850	998	1118

Table 1. Summary of the technical simulation results for willow as the fuel.

With willow as the fuel, the 250 kWe systems were found to be about 5 percentage points more efficient than the 25 kWe systems. The systems with the HTSOFCs were found to recover more heat and emit less CO2 than those with the ITSOFCs.

With miscanthus as the fuel, the 250 kWe systems were found to be about 4 percentage points more efficient than the 25 kWe systems. The systems with the HTSOFCs were found to recover more heat and emit less CO2 than those with the ITSOFCs.

System Output (kWe)	250	250	25	25
SOFC Temperature	953C (HT)	647C (IT)	944C (HT)	614C (IT)
Fuel	Miscanthus	Miscanthus	Miscanthus	Miscanthus
Biomass Flow daf t/day	3.16	3.16	0.35	0.35
Thermal Input kWth, LHV	657.7	657.7	74.48	74.48
Electricity Usages	14.3	15.7	4.2	4.5
Heat Recovered	231	124	13	3
Gross Electricity Out	264	266	29.2	29.8
Net Electricity Out	249.5	250.5	24.9	25.1
Electrical Efficiency, LHV	37.94	38.09	33.8	34.07
CHP Efficiency, LHV	73.06	56.94	51.44	38.14
CO2 g/kWh	887	889	983	1133

Table 2. Summary of technical simulation results for miscanthus as the fuel.

There was little difference found between the capital costs of the systems when they used miscanthus or willow, so only the economics for the systems using willow are shown.

Economic Data

CHP Plant Size (kWe)	250	25	250	25
Fuel Cell Op. Temperature	HT	HT	IT	IT
Fuel Cell Lifetime (yrs)	5	5	5	5
Fuel Cell Output gross kWe	264	30	264	30
Fuel Cell Cost rate $/kWe	1300	1300	1300	1300
Costs ($ 2008)				
Total Fuel Cell Cost ($)	1,009,600	114,700	1,009,600	114,700
Downdraught Gasifier	187,000	45,300	187,000	45,300
Burner	83,500	17,000	83,500	17,000
Gas Cleaner	46,300	26,600	46,300	26,600
Biomass Conveyer	28,500	*24,500*	28,500	*24,500*
Dryer	18,200	10,700	18,200	10,700
Fans	22,800	9,000	22,800	9,000
Pumps	10,800	0	10,800	0
Heat Exchangers	197,000	86,000	*102,000*	*42,000*
Total balance of Plant (BOP)	594,100	219,100	499,100	175,100
Total System Costs ($)	1,603,700	333,800	1,508,700	289,800
Specific Investment ($/kWe)	6,415	13,352	6,035	11,592

Table 3. Example of typical economics for the CHP plant. Fuel Cell lifetime is 5 years and Fuel cell cost rate is $1300/kW. Discounted Cash Flow rate is 8%.

Result and discussion

The 250 kWe version of the system modeled here was found to have an LHV efficiency for electricity generation of about 39% and the 25 kWe version around 33% when using willow and around 38% and 34% when using miscanthus. The type of biomass did not cause the change in efficiency; this was solely due to the moisture content differences. There was little difference in efficiency between the plants using HTSOFCs and those using LTSOFCs.

These efficiency values are higher than any other power plant fuelled by biomass, and at least as good as fossil-fuel-fired plants, of this size. Some waste heat can also be recovered, but less that with some other biomass power plants. However, the financial returns from electricity generation are more lucrative than from the selling of waste heat.

The systems modelled here proved to be very efficient and retained their high efficiencies even as the operating temperatures were reduced from high to intermediate values, offering promise for low temperature operation as well. The specific investments are still very high, but these could fall significantly when low temperature materials are used for both the fuel cells and BOP.

References

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