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EXECUTIVE SUMMARY

Two scenarios were examined for small-scale electricity production from biomass using a gasifier/fuel cell system. In one case, a stand-alone Battelle Columbus Laboratory/Future Energy Resources gasifier is used to produce synthesis gas that is reformed and distributed though a pipeline network to individual phosphoric acid fuel cells. In the second design, the gasifier is integrated with a molten carbonate fuel cell stack and a steam bottoming cycle. In both cases, the gasifiers are fed the same amount of material, with the integrated system producing 4.0 MW of electricity, and the stand-alone design generating 2.0 MW of electricity.

The current capital cost of the stand-alone system was estimated to be $15 million, including $4.8 million for the phosphoric acid fuel cells. The electricity selling price, including depreciation and a 15% after-tax internal rate of return, was $0.47/kWh. The integrated gasifier had a total capital investment of $22 million and an electricity selling price of $0.31/kWh. Even the lowest-cost case, with zero profit, wood residue feed prices and a future fuel cell cost of $1,000/kW, the cost for the integrated design was still $0.11/kWh.

These power conversion efficiencies were lower than expected because less than 100% of the fuel was utilized in the fuel cells, oxidant and fuel streams were diluted with inert gases, the fuel cells had high excess air requirements, and considerable heat was lost to the flue gas. The integrated plant design had an overall electric conversion efficiency of 43%. The stand-alone design had an efficiency of 22%, partly because some of the raw synthesis gas must be burned to supply heat to the gas processing operations. The stand-alone design does, however, provide a total of 10.7 GJ/h (10.3 MM Btu/h) of heat at the fuel cell sites to bring the systems total efficiency up to 54% on a higher heating value basis.

Future work in the area of integrated biomass gasification and fuel cell systems should concentrate on eliminating drying or improving the energy efficiency of drying operations, developing low-cost separation processes to recovery and reuse the unreacted fuel leaving the fuel cell, and determining more accurate fuel cell costs.

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ABBREVIATIONS AND ACRONYMS

acfh	Actual cubic feet per hour
acfm	Actual cubic feet per minute
AFC	Alkaline fuel cell
BCL	Battelle Columbus Laboratory (gasifier)
BD	Bone dry (0% moisture)
Btu	British thermal unit
C	Degrees Celsius
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
ESP	Electrostatic precipitator
F	Degrees Fahrenheit
FCI	Fixed capital investment
FERCO	Future Energy Resources Company
ft	Feet
gpm	Gallons per minute
H_2	Hydrogen
hp	Horsepower
h	Hour
IRR	Internal rate of return
kg	Kilogram
kJ	Kilojoule
kPa	Kilopascal
kW	Kilowatt
kWh	Kilowatt-hour
lb	Pound
MCFC	Molten carbonate fuel cell
MM Btu	Million British thermal units
MM$	Million dollars
MW	Megawatt
PAFC	Phosphoric acid fuel cell
PEM	Polyelectrolyte membrane (fuel cell)
PEMFC	Polyelectrolyte membrane fuel cell
ppm	Parts per million
psig	pounds (force) per square inch gauge pressure
SOFC	Solid oxide fuel cell
TDC	Total direct cost
TIC	Total indirect cost
ton	English ton (2,000 pounds)
tonne	Metric tonne (1,000 kilograms)
tpd	Tons per day
yr	Year

1.0 INTRODUCTION

The purpose of this report was to evaluate the feasibility of producing electricity on a small scale using a Battelle Columbus Laboratory/Future Energy Resources Company (BCL/FERCO) gasifier linked to a fuel cell system. Two scenarios were examined: one where a stand-alone or centralized gasifier is supplying synthesis gas to a pipeline network with a number of phosphoric acid fuel cells (PAFCs), and a second case with a higher-temperature molten carbonate fuel cell (MCFC) and a gasifier on the same site to allow heat integration.

The biomass feed rate to each gasifier was set equal at 1,855 bone-dry kg/h (4,080 lb/h) to allow a comparison of the two configurations. The integrated gasifier-MCFC design had a net power output of 4.0 MW, compared to the stand-alone plant, which produced only 2.0 MW of power, accounting for parasitic loads. The stand-alone plant supplying several individual PAFC units had a low electrical power conversion efficiency of 22% and had a thermal efficiency (combined electricity and heat utilization) of 54%. The integrated plant had a higher electrical conversion efficiency of 43% because of tighter heat integration and the addition of a steam cycle to produce extra power from the waste heat.

The estimated capital cost of the stand-alone gasifier was $15 million, including $4.8 million for the fuel cells. For the integrated gasifier/fuel cell design, the total capital cost was estimated at $22 million. The electricity selling prices, including depreciation and a 15% internal rate of return (IRR), were $0.47/kWh and $0.31/kWh for the stand-alone and integrated cases, respectively.

2.0 FUEL CELL CHOICES

Several alternative fuel cell designs are under development, each with its own specific benefits and disadvantages. Fuel cells operate by feeding a fuel, usually a hydrogen (H_2)-rich stream, into the anode side of a gas-impermeable membrane while feeding an oxidant into the other cathode side of the membrane. On the cathode side, the oxidant breaks down into an ionic form that passes through the membrane by taking up electrons supplied through an external circuit. On the anode side, the fuel reacts with the ions coming through the membrane and gives up electrons to the external circuit. Because of the energy difference between the anode and cathode, there is a voltage difference and electrons flow from the anode to the cathode through the external circuit, producing electricity. The possible fuels vary depending on the fuel cell type, and each fuel cell has a specific range of operating temperatures (Hirschenhofer et al. 1994).

NASA has used alkaline fuel cells (AFCs) extensively in the space program for producing electricity from pure hydrogen and pure oxygen at a temperature of 200°C (392°F). Air cannot be used in AFCs because the carbon dioxide (CO_2) reacts with the electrolyte in the fuel cell. Pure hydrogen is required as the fuel because any CO_2 or carbon monoxide (CO) from fossil fuels would poison the fuel cell (Hirschenhofer et al. 1994). Therefore, AFCs cannot be used in biomass applications without an oxygen generation plant and extensive gas purification.

Polyelectrolyte membrane fuel cells (PEMs or PEMFCs) use a solid polymer membrane as the charge carrier in the fuel cell and are being developed mainly for transportation applications. The PEM fuel cells have the lowest operating temperature of any fuel cell, operating at 80°C (176°F). They can use air as an oxidant, but CO_2 concentrations higher than 10 ppm can poison PEM fuel cells (Hirschenhofer et al. 1994). In order to use synthesis gas, further purification using pressure swing adsorption or H_2-permeable membranes would be required. A PEM fuel cell system would be very similar to the design used in a previous report (Mann 1995) to produce hydrogen using the BCL/FERCO gasifier.

Solid oxide fuel cells (SOFCs) have the advantage that they operate at high temperatures (650 - 1,000°C [1,202 -1,832°F]) providing greater heat integration opportunities, but the high temperatures also create some construction- and material-related problems that still need to be solved. They can, however, be operated on air and CO-containing streams and could be an option in the future for biomass applications, (Hirschenhofer et al. 1994).

Phosphoric acid fuel cells are commercially available and typically operate on natural gas and air. PAFCs can be poisoned by high levels of CO, but can operate effectively with 1%-2% CO in the fuel feed. Because the units are currently available, they were used in the design for the stand-alone gasifier supplying synthesis gas to individual fuel cells. The only difference between the design included here and the commercial design is that the steam-reforming and water-gas-shift reactions are done at the gasifier site in the stand-alone design, instead of as a part of the fuel cell package. PAFCs operate at 200°C (400°F) and can provide heat for hot water and household heating, if needed (Hirschenhofer et al. 1994).

For the integrated case, MCFCs were used. MCFCs operate at 650°C (1,202°F), which is high enough to produce steam from the waste heat. This steam can then be run through a steam cycle to produce electricity. MCFCs, like SOFCs, can use fuels containing CO and can use air as an oxidant. One unique requirement of MCFCs is that CO_2 must be present in the cathode oxidant gas because the CO_2 is used as a charge carrier in the fuel cell. In pure H_2 hydrogen applications this can be a problem because an outside CO_2 source is needed. In biomass or natural gas reforming applications, the spent fuel from the fuel cell, containing CO_2 from fuel reforming and shift reactions, can be fed into the cathode.

For detailed information on each type of fuel cell, refer to Fuel Cell Handbook (Hirschenhofer et al. 1994).

3.0 STAND-ALONE DESIGN

The stand-alone gasifier design uses the same BCL/FERCO design used in prior studies (Craig and Mann 1996; Mann and Spath, 1997; Mann 1995). A recirculating sand bed acts as a heat carrier, taking heat from a char furnace and supplying it to the endothermic gasification reaction. The synthesis gas created by this process has a higher energy content than gas produced by air blown gasifiers because the gas is not diluted by nitrogen.

The stand-alone design can be broken down into three sections: the gasifier, gas processing, and the PAFC unit. The gasifier section in the stand-alone design has been simplified with minimal heat integration to allow for operation in remote areas. Some of the raw synthesis gas is burned to heat the reformer reactor with the exhaust gases going to the gasifier wood dryer. The gas discharged from the gas processing section is under pressure, so no fuel compressor is needed for the fuel cell unit.

A detailed description of each section of the stand-alone gasifier design follows.

3.1 Gasifier Section

Figure 1 shows the flowsheet for the gasifier section of the stand-alone plant. Dry wood, hot sand, and low-pressure superheated steam are fed into a fluidized bed gasifier. The heat from the recirculating sand is the only heat source for the endothermic gasification reaction that converts the wood into a mixture of CO_2, CO, H_2, CH_4 and a variety of other hydrocarbons. A significant amount of char is also formed during the reaction.

The char, sand, and gas mixture leaves the gasifier and the synthesis gas is separated from the sand and char in a cyclone. The char and sand enter a char furnace, along with preheated combustion air where the char is burned to heat the sand. The combustion gas is then separated from the sand, which is returned to the gasifier. Some sand is continuously purged from the system to remove the small amount of ash that results. Fresh sand is added to the stream returning to the gasifier.

The combustion gas from the char furnace passes through an air heater to preheat the char furnace combustion air. This preheating allows higher gasification temperatures, increasing the gasifier yield. The hot combustion gases are directed to the wood dryer. The flue gases from the reformer burner in the gas processing section are also sent to the dryer. Because of the high temperature of the combustion gases, dilution air is added to reduce the gas temperature to 232°C (450°F) before it enters the dryer. The outlet temperature of the dryer is kept above 104°C (220°F) to prevent condensation of the water vapor. This moisture-laden air is released to the atmosphere after passing through a cyclone to capture fines and an electrostatic precipitator (ESP) to remove smaller particulate matter.

The hot synthesis gas passes through a superheater and boiler to produce the low-pressure steam for the gasifier. The synthesis gas then goes through a hot filtration system to remove any particulate matter and continues on to the gas processing section of the plant.

3.2 Gas Processing

Gas processing is required to convert the CH_4 and higher hydrocarbons into H_2 and to reduce the CO concentration to 1%-2% so it can be fed into a PAFC without poisoning the catalyst. Figure 2 shows the gas processing section of the stand-alone design.

The gas is first compressed to provide the pressure needed to overcome the reformer and shift reactor pressure drops and to provide pressure to the gas distribution network. Some (15%) of the raw gas is also sent to a small burner that provides heat to the endothermic steam-reforming reaction. The exhaust gas from the burner also heats the gas entering the reformer, produces the steam for the reforming reaction, preheats the combustion air for the burner, and provides some heat for drying the wood feed to the gasifier.

The synthesis gas that doesn't go to the burner is mixed with low-pressure steam and passes through a preheater to recover heat from the gas leaving the reformer. The gas then passes through the reformer heater to bring the gas up to the reformer reactor temperature of 850°C (1,562°F). The gas enters the reformer where the primary reaction is the conversion of CH_4 into H_2 and CO. The gas passes back through the hot side of the reformer preheater before entering the high-temperature shift reactor.

The high-temperature shift reaction takes advantage of the faster kinetics at a high temperature to convert 70% of the CO into H_2 through a water-gas-shift reaction. Conversion is, however, limited by the reaction equilibrium, so the gas is cooled and passed through a second, low-temperature shift reactor to convert most of the remaining CO to H_2. The cooling between the high- and low-temperature shift reactors can be done using cooling water, or low-pressure steam can be generated.

After passing through the low-temperature shift reactor the gas passes through a condenser and a knock-out drum to remove excess water before going out to the distribution network and fuel cells.

3.3 Phosphoric Acid Fuel Cells

Phosphoric acid fuel cells that run off natural gas and air are currently available commercially. The typical size for such a unit is 200 kW. For the purposes of this evaluation, the system was modeled as a single fuel cell stack, but output from each fuel cell stack can be chosen by varying the membrane surface area and number of fuel cells in the fuel cell stack. Figure 3 shows the flows for a PAFC.

The synthesis gas coming from the gas distribution network is already at a high enough pressure that no additional gas compression is needed. A compressor is required for the fuel cell air fed to the cathode of the PAFC. Also, the fuel cell stack must be cooled. This can be accomplished with cooling water, or low-pressure steam can be generated.

Because the gas leaving the PAFC cannot be completely used, it is mixed with the cathode gas, containing excess oxygen, and is sent through a catalytic oxidation unit to consume the remaining gas. The cathode gas is preheated using the oxidizer exhaust gas to increase the reaction temperature in the oxidizer. The exhaust passes through a heat exchanger to produce more hot water or steam before being released to the atmosphere.

Figure 1- Stand-Alone Design Gasifier Flowsheet

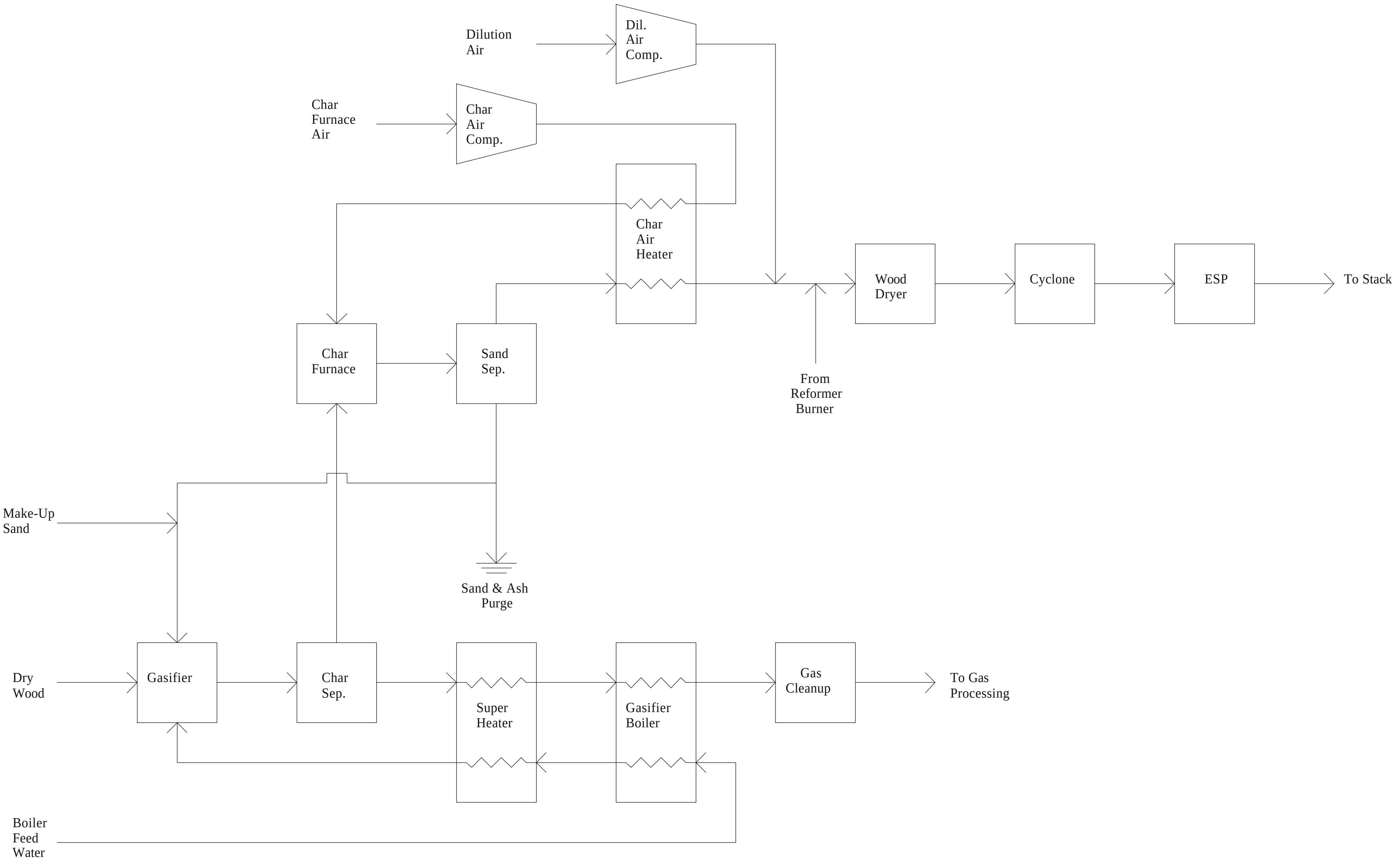


Figure 2 - Stand-Alone Design Gas Processing Section

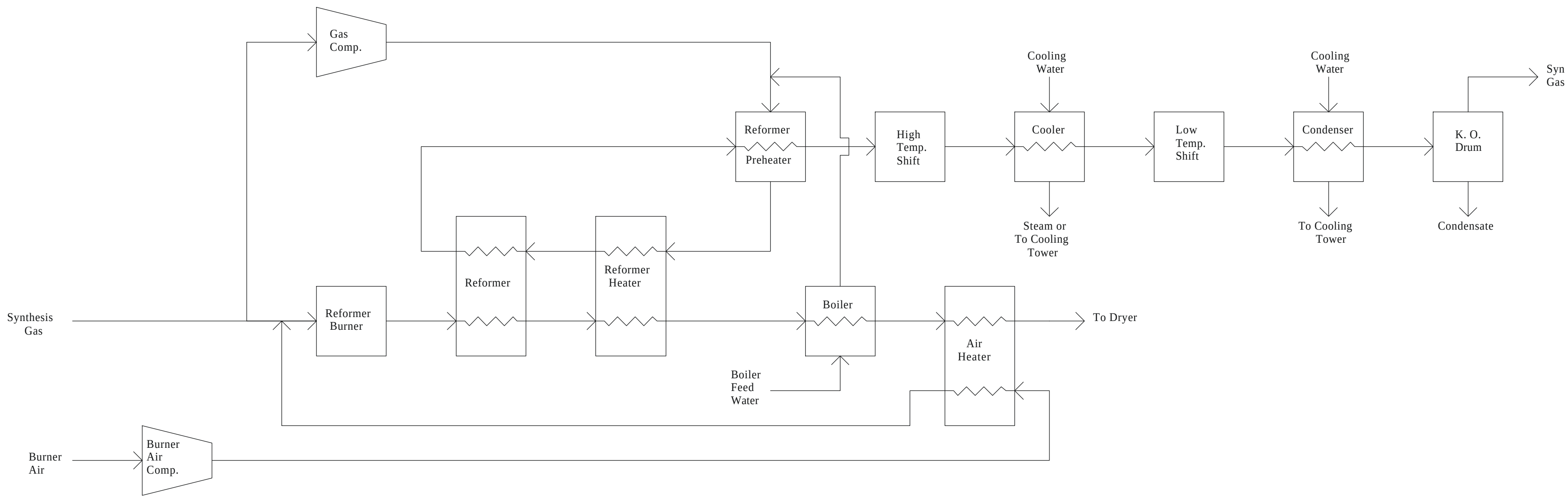
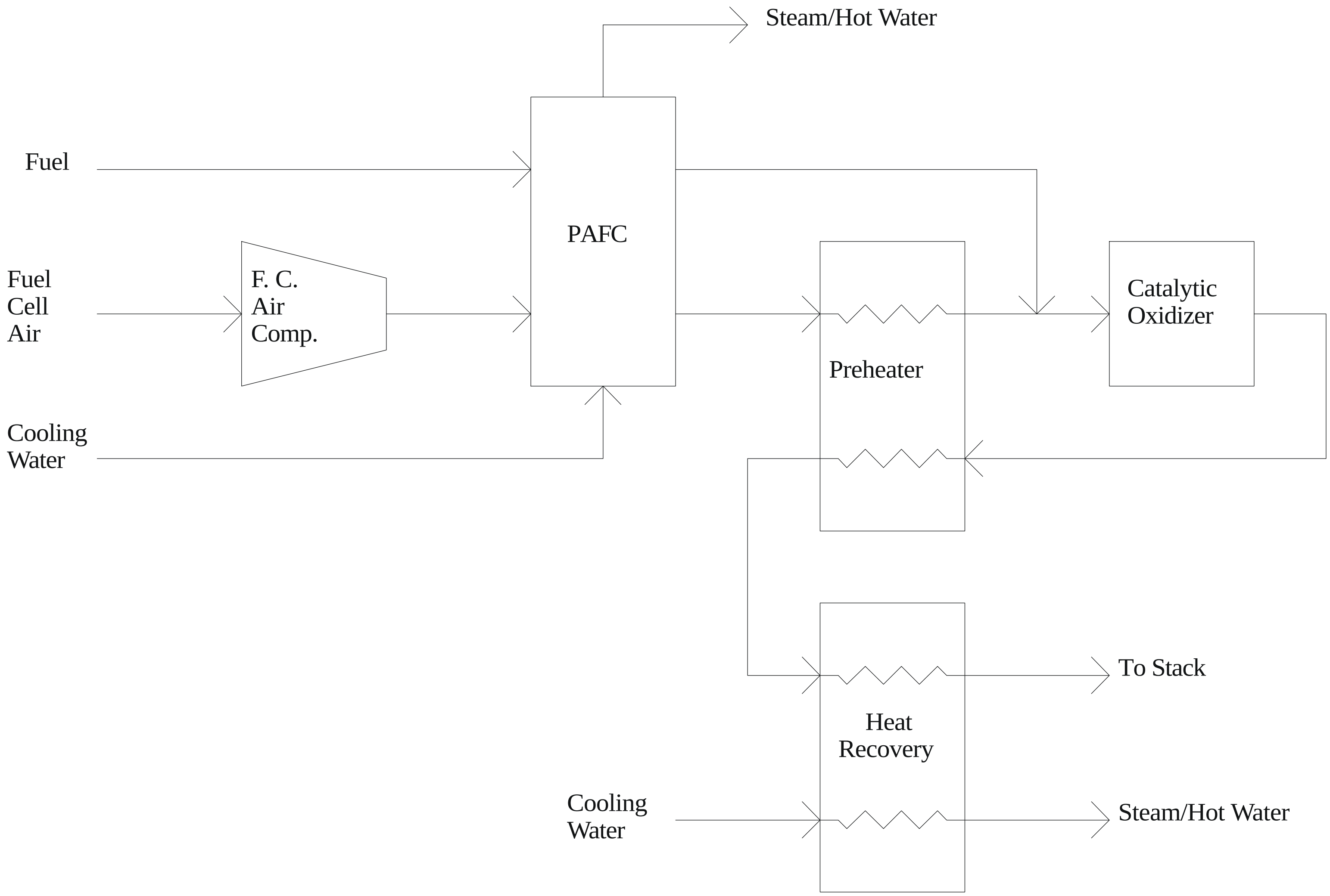


Figure 3 - Stand-Alone Design PAFC Flowsheet



Information on the flowrates and stream compositions for the stand-alone gasifier can be found in Appendix B.

4.0 INTEGRATED GASIFIER/FUEL CELL DESIGN

The integrated gasifier/fuel cell design represents a more advanced system than the stand-alone case, taking advantage of more heat integration and using a steam cycle to produce additional electricity from the gasifier and fuel cell waste heat. The design has three distinct sections: the gasifier, the fuel cell section, and the steam cycle.

4.1 The Integrated Gasifier

The only difference between the integrated and stand-alone gasifier sections is the additional heat recovery from the char furnace gases. The flowsheet around the gasifier, char furnace and gas filtration remain the same. Figure 4 shows the integrated gasifier flowsheet.

The char furnace gases leaving the sand and ash separation step first pass through a steam superheater for the steam cycle before passing through the char furnace air heater. The combustion gases then enter a steam generator that produces 30% of the steam for the steam power cycle. The char furnace gases then are directed to the wood dryer, along with the exhaust gas from the MCFC and some dilution air, which is again used to keep the temperature of the incoming gases below the combustion temperature of the wood.

4.2 Molten Carbonate Fuel Cell Section

Figure 5 shows the MFCF section of the integrated plant. The synthesis gas passes through a preheater before entering a MCFC with internal reforming. In the simulation, the reformer and high-temperature shift reaction were modeled separately, but the heat required for reforming and the small amount of heat released during the shift reaction were combined with the heat from the fuel cell as if the reforming and shift reactions were occurring within the fuel cell. Medium-pressure steam is generated from the excess heat produced by the fuel cell.

The spent anode gas, containing some remaining fuel, is combined with air and sent through a catalytic oxidizer to consume the fuel. The exhaust gas from the oxidizer is used to preheat the incoming synthesis gas and is then combined with additional air and fed into the cathode side of the fuel cell. The exhaust gas from the catalytic oxidizer supplies the required CO_2 for the MCFC reactions. The spent cathode oxidant stream is used to preheat the air to the fuel cell, then heat is recovered for the reheat step and economizer in the steam cycle. After heat recovery, the flue gas is sent to the wood dryer to take advantage of the remainder of the heat in the gas.

4.3 Steam Cycle

Figure 6 shows the steam power cycle used to produce additional power from the waste heat in the integrated design. The steam cycle consists of an economizer, a medium pressure boiler (500 psig, [3,500 kPa]), a superheater, a medium-pressure turbine, steam extraction for the reformer, a reheat step, a low-pressure turbine, and a condenser.

The heat for the economizer comes from the fuel cell exhaust gas. Two sections generate steam for the steam cycle: the exhaust from the char furnace, and the MCFC. The superheating comes from the char furnace combustion gas, and the heat for the reheat step comes from the fuel cell exhaust gas. The condenser has an operating pressure and temperature of 20 kPa (3 psia) and 6C (14F) based on the cooling water outlet temperature of 5C (12F).

Flowrate data and stream compositions for the integrated power plant design can be found in Appendix B.

5.0 STAND-ALONE PERFORMANCE AND COST

The stand-alone gasifier has minimal heat integration, but includes the gas processing section to use the CH_4 in the synthesis gas and to limit CO fed to the PAFC. Some power conversion efficiency is lost because the gasifier doesn't capture all the waste heat released. Some of the synthesis gas produced is diverted to the reformer burner, but much of this heat goes into increasing the heating value of the reformed gas and is not lost.

5.1 Stand-Alone Gasifier Cost

The total capital cost of the stand-alone gasifier was estimated to be $15 million. The operating costs for the stand-alone plant are $3.2 million/yr. Including depreciation and a 15% discounted cash flow factor, the electricity price is $0.47/kWh. The depreciation period for the gasifier was 5 years with a 15 year depreciation period for the fuel cells.

The details of the economic calculations can be found in Appendix A.

5.2 Stand-Alone Gasifier Efficiency and Heat Availability

As mentioned before, the electric generating efficiency for the stand-alone case is 22%, based on a biomass feed rate of 1,855 bone-dry kg/h (4,080 lb/h) and net power production of 2.0 MW. However, significant energy can be recovered from the PAFC, plus some steam can be generated in the gas processing section at the gasification site. The amount of heat available for steam or water heating from the PAFC is 10.7 GJ/h (10.3 MM Btu/h), which combined with the electricity production increases the overall thermal efficiency of the process to 54%.

Figure 4 - Integrated System Gasifier Flowsheet

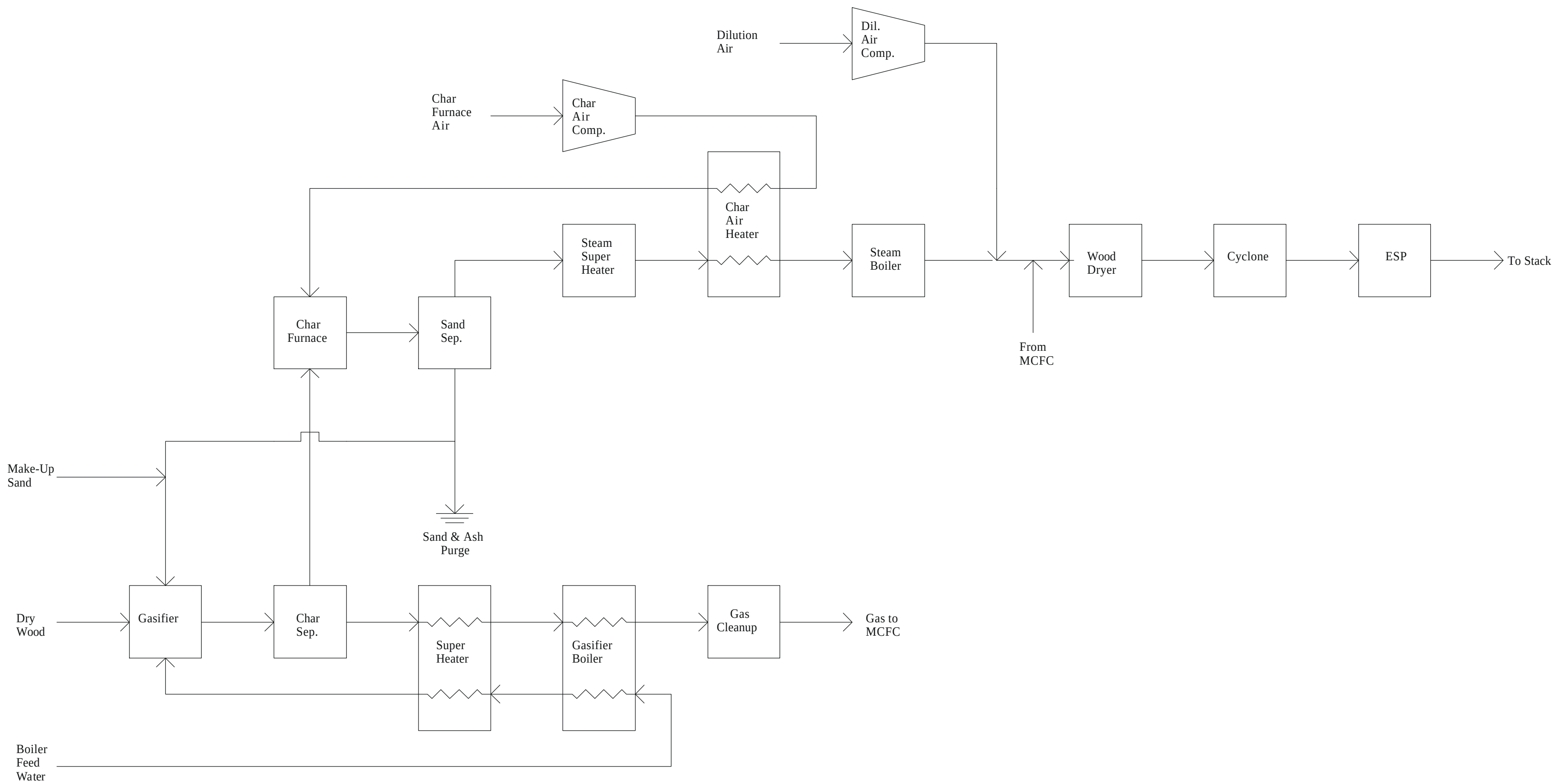


Figure 5 - Integrated System MCFC Flowsheet

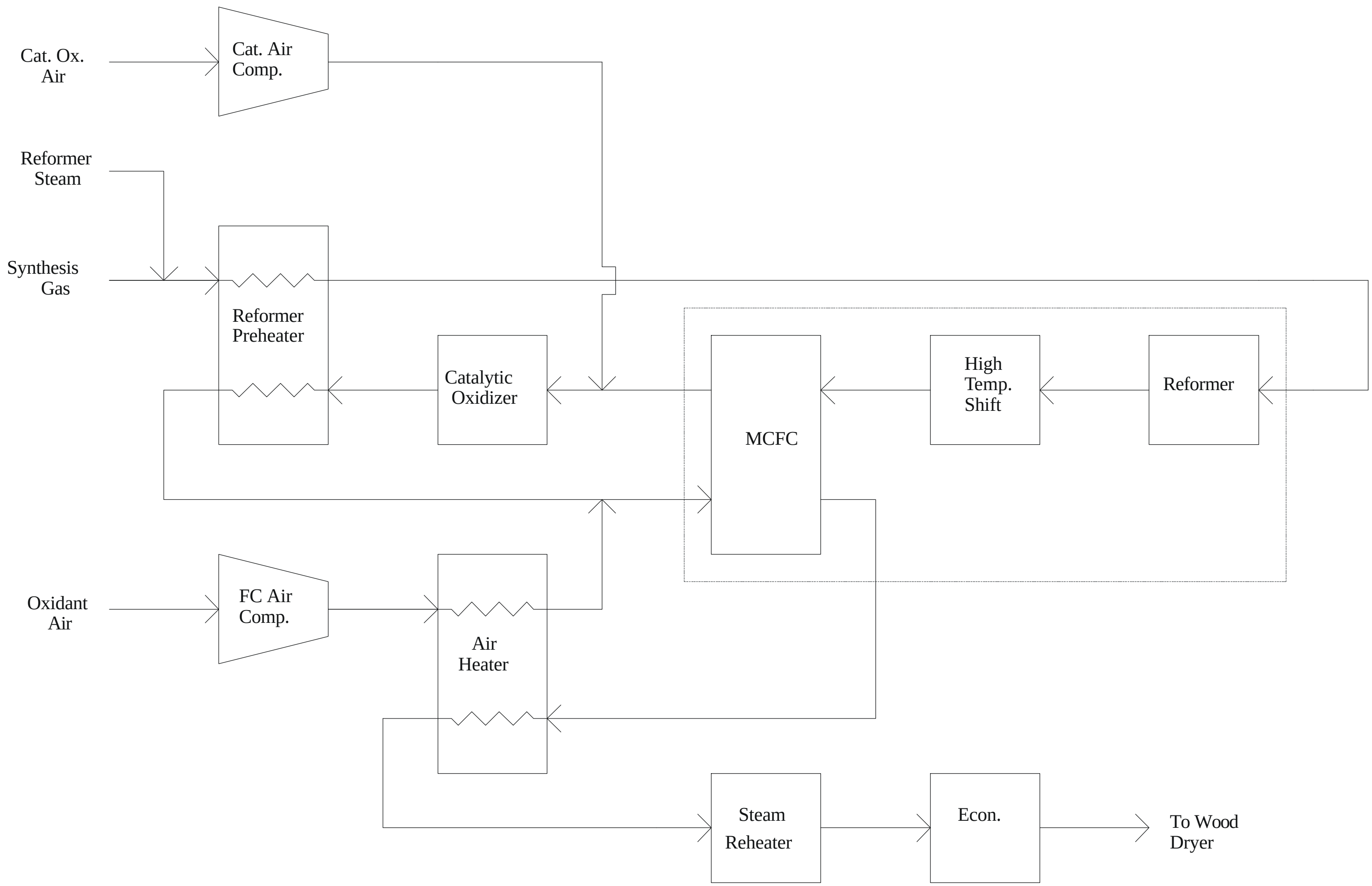
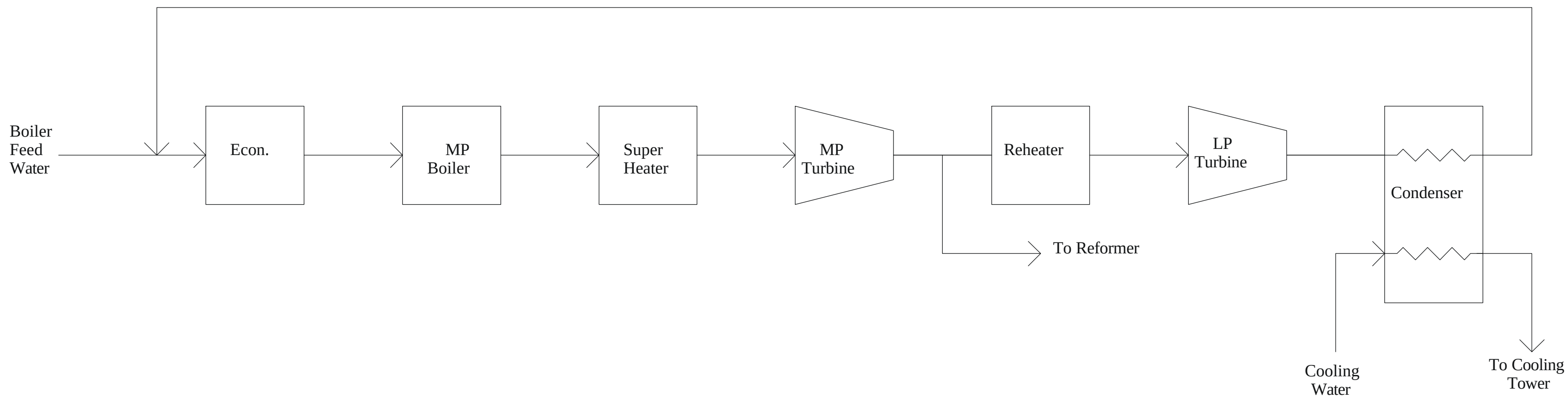


Figure 6 - Integrated System Steam Cycle



6.0 INTEGRATED PERFORMANCE AND COST

The integrated plant has more heat integration and therefore higher capital costs, but the electric conversion efficiency of the plant is much higher. No hot water or steam was made available in the integrated design; all available waste heat is instead used in a steam bottoming cycle.

6.1 Integrated System Cost

The total capital cost of the integrated gasifier was estimated to be $22 million. The operating costs for the integrated plant are $3.9 million/yr. Including depreciation and a 15% discounted cash flow factor, the price of electricity is $0.31/kWh. A depreciation period of 20 years was used for the steam section of the power plant. Details of the economic calculations for the integrated system can be found in Appendix A.

6.2 Integrated System Efficiency

As expected, the integrated system efficiency was higher than that of the stand-alone case. Net electric production efficiency was 43%. This is based on the same wood feed rate as the stand-alone case of 1,855 bone-dry kg/h (4,080 lb/h). The net power from the integrated system was 4.0 MW. Of this output, 0.7 MW comes from the steam cycle.

The integrated system efficiency is still considerably lower than the predicted fuel cell efficiency of 50%-60% for the MCFC, but there are several reasons for this. First, fuel utilization, or the amount of fuel converted to energy in the fuel cell, is not 100%--some fuel passes through unreacted. Second, the reactant and oxidant concentrations to the fuel cell are diluted by nitrogen and other non-reacting gases, lowering the fuel cell voltage and efficiency. More complex gas purification and fuel recycling would improve the overall fuel utilization and increase the efficiency, but would also increase the capital costs.

7.0 DESIGN CONSIDERATIONS

Like most power plants, much of the heat lost from the system is heat associated with the flue gas and condenser. In both designs some of the flue gas waste heat is used to dry the wood feed, but this still represents a great deal of lost energy, which could be used elsewhere in the process if drying were not required.

Another flue gas issue unique to the fuel cells is the large amount of excess air that is heated in the fuel cell. A power boiler might use 30%-50% excess air, but fuel cells typically have only 50% oxidant utilization, which means there is 100% excess air. In high temperature fuel cells such as the MCFC, even with heat recovery, a large amount of heat can leave the system with the spent oxidant.

Fuel utilization is a double-edged sword in the design of integrated systems. In order to take advantage of the high energy efficiency of fuel cells, it is desirable to have as much fuel as possible reacted using the fuel cell. However, if the single-pass utilization is high, the outlet concentration in the fuel will be low, causing the cell voltage to be low, reducing the efficiency. Also, if the spent fuel is to be burned to supply heat to other processes, such as reforming, high fuel utilization means less fuel to burn, and a lower gas temperature leaving the burner or catalytic oxidizer. One way to improve the overall system efficiency is to have low single-pass fuel utilization, but good recovery and separation of the unreacted fuel to recycle it back to the fuel cell inlet. This, however, increases the complexity and cost of the system.

Heat integration was also difficult in the designs because several areas needed high temperature heat sources, but only low-temperature waste heat was available. The high heat duty and high temperature requirements of the steam reformer is one example. In the stand-alone design, some of the raw synthesis gas must be burned to meet the reformer heat requirement.

8.0 FUEL CELL COSTS

For the stand-alone PAFC design, the assumed price of a fuel cell stack was $2,000/kW. The current price of International Fuel Cells 200 kW PC-25 fuel cell system is $600,000 or $3,000/kW (Appleby 1996). This unit includes an onboard reformer. Because a reformer is included in the stand-alone gasifier gas processing section, the fuel cell stack cost would be about one-third less, or $2000/kW.

For the MCFC integrated fuel cell case, a fuel cell cost of $3,000/kW was used. It was assumed that the MCFC stack was configured for internal reforming, so no additional costs were included for a reformer or shift reactor in the integrated plant design.

Projected fuel cell costs and cost goals vary, but to help assess the future outlook of an integrated gasifier/fuel cell facility, a fuel cell cost of $1,000/kW was assumed. This brought the capital cost of the stand-alone design down to $12 million and gave a electricity price of $0.42/kWh. For the integrated design, the estimated capital cost dropped to $15 million with a electricity price of $0.24/kWh.

One issue with using a per-kilowatt fuel cell cost is that changing fuel cell operating conditions to minimize the number of individual fuel cells will not have the proper effect on the fuel cell cost. For fuel cells, the production costs are directly related to the number of fuel cell assemblies required, and by operating under different conditions, such as higher current densities, the number of fuel cell assemblies can be reduced, usually at the expense of higher operating costs, (Hirschenhofer et al. 1994). However, with a fixed per-kilowatt cost, the proper break-even analysis between decreased capital costs and increased operating expenses cannot be done. A membrane assembly cost, which would allow more accurate cost estimates and optimization of fuel cell designs, is needed

9.0 WOOD COSTS

The assumed cost for the wood for both process designs was $46/bone dry tonne ($42/ton). The fuel cost for forest residue is closer to $19/bone dry tonne ($17/ton). Using the forest residue cost reduces the stand-alone and integrated electricity prices to $0.45/kWh and $0.30/kWh using current fuel cell costs. With the expected reductions in fuel cell costs, the electricity price drops to $0.40/kWh and $0.22/kWh for the stand-alone and integrated cases, respectively. These savings are small because the fuel cost is low compared to the capital related costs.

10.0 CONCLUSIONS

The 43% efficiency of producing power using an integrated gasifier/fuel cell system is much higher than the efficiency of a combustion boiler using the same fuel. In the case of the stand-alone plant, the electric conversion efficiency was only 22%, but the PAFC provided 10.7 GJ/h (10.3 MM Btu/h) for home heating. This heat brings the thermal efficiency of the process to 54%.

The electricity price for the stand-alone and integrated systems were $0.47/kWh and $0.31/kWh, respectively. This includes depreciation and a 15% rate of return. With a 0% pre-tax rate of return, representing the situation where the primary concern is providing power, and not profiting from its sale, the prices for the stand-alone and integrated systems would be $0.24/kWh and $0.15/kWh. Using the future fuel cell cost of $1,000/kW and wood residue, the stand-alone electricity price drops to $0.40/kWh, and $0.19/kWh with 0% pre-tax IRR. For the integrated case, the electricity price is $0.22/kWh with a 15% after-tax IRR and a price of $0.11/kWh for a 0% after-tax rate of return. These results are summarized in Table 1.

Table 1 - Summary of Biomass Gasification/Fuel Cell Costs

	Stand-Alone, Current Costs	Stand-Alone, Future Costs	Integrated, Current Costs	Integrated, Future Costs
Total Fixed Costs for Gasifier	$9.9 million	$9.9 million	$8.4 million	$8.4 million
Total Fixed Costs for Fuel Cells	$4.8 million	$2.4 million	$11.2 million	$3.7 million
Total Fixed Costs for Turbine	No Turbine	No Turbine	$2.5 million	$2.5 million
Total Fixed Capital Investment	$14.7 million	$12.3 million	$22.1 million	$14.6 million
Annual Operating Costs Using Wood	$3.2 million	$3.0 million	$3.9 million	$3.2 million
Annual Operating Costs Using Residues	$2.8 million	$2.4 million	$3.5 million	$2.8 million
Electricity Price Using Wood	$0.47/kWh	$0.42/kWh	$0.31/kWh	$0.24/kWh
Electricity Price Using Residues	$0.45/kWh	$0.40/kWh	$0.30/kWh	$0.22/kWh
Price with 0% Return and Wood	$0.24/kWh	$0.22/kWh	$0.15/kWh	$0.12/kWh
Price with 0% Return and Residues	$0.21/kWh	$0.19/kWh	$0.14/kWh	$0.11/kWh

11.0 FUTURE WORK

Although the integrated case uses much of the waste heat available, sensitivity analysis of various fuel and oxidant utilization rates and adjustment of operating temperatures for some equipment should be investigated for both system designs. These studies would require careful checks of the different heat integration sections whenever a change is made because a small change in something like fuel utilization can have a large effect on the waste heat available in the process.

One problem with the economic analysis was the uncertainty of some of the equipment estimates. Much work has been done in determining fuel cell efficiencies, but the current and projected costs of both the gasifier and fuel cells are uncertain. Even in the case of the PAFC, where a market price is available, it was not possible to estimate the effect fuel cell operational changes would have on capital costs since most cost estimates are given on a per kW basis and not per membrane basis.

Capital costs for the gasifier were also not reliable since it is not commercially available, but hopefully with the results from the U. S. Department of Energy BCL/FERCO gasifier demonstration in Burlington, Vermont, better cost data will become available.

REFERENCES AND PERTINENT LITERATURE

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APPENDIX A - ECONOMIC CALCULATIONS

Appendix A contains spreadsheets that detail the capital and operating cost estimates. The eight cases examined are summarized in Table A0. For each case, a calculation was also performed for a zero pre-tax rate of return for cases where power is generated at cost.

Table A0 - Summary of the eight cases examined.

	Wood	Residue	Current FC Cost	Future FC Cost	Stand-Alone	Integrated
Case 1	X		X		X	
Case 2	X		X			X
Case 3	X			X	X	
Case 4	X			X		X
Case 5		X	X		X	
Case 6		X	X			X
Case 7		X		X	X	
Case 8		X		X		X

Below is list of the tables in Appendix A, with a brief description of each one.

Table A1 - Capital costs for cases 1 and 5.
Table A2 - Capital costs for cases 2 and 6.
Table A3 - Capital costs for cases 3 and 7.
Table A4 - Capital costs for cases 4 and 8.
Table A5 - Variable operating costs for cases 1, 3, 5, and 7.
Table A6 - Variable operating costs for cases 2, 4, 6, and 8.
Table A7 - Internal rate of return calculation for case 1.
Table A8 - Internal rate of return calculation for case 2.
Table A9 - Internal rate of return calculation for case 3.
Table A10 - Internal rate of return calculation for case 4.
Table A11 - Internal rate of return calculation for case 5.
Table A12 - Internal rate of return calculation for case 6.
Table A13 - Internal rate of return calculation for case 7.
Table A14 - Internal rate of return calculation for case 8.

Table A1 - Stand-Alone Gasifier w/PAFCs - Current Fuel Cell Costs (Cases 1 & 5)																
Heat Exchangers	Hot In	Hot Out	Cold In	Cold Out	Heat Duty	Hot h	Cold h	U	dT1	dT2	LMTD	A		**Purchased**		
	(F)	(F)	(F)	(F)	MM Btu/h	(Btu/ft^2 h F)	(Btu/ft^2 h F)	(Btu/ft^2 h F)	(F)	(F)	(F)	(ft^2)		**Price (1995-$)**		
Gasifier Super Heater	1,482	1,240	242	1,000	0.7	10	10	5	482	998	709	197		$16,524	Garrett 1989	
Gasifier Boiler	1,240	380	242	242	2.2	10	1,000	10	998	138	435	511		$33,049	Garrett 1989	
Char Air Heater	1,800	1,693	182	325	0.5	10	10	5	1,475	1,511	1,493	67		$5,717	Garrett 1989	
Reformer Preheater	1,409	1,010	380	1,335	2.4	10	10	5	74	630	260	1,849		$35,728	Garrett 1989	
Reformer Heater	2,585	1,409	1,335	1,562	0.6	10	10	5	1,023	74	361	332		$9,528	Garrett 1989	
Cooler	920	392	110	125	1.4	10	100	9	795	282	495	311		$13,100	Garrett 1989	
Condenser	469	210	110	125	0.7	10	100	9	344	100	197	390		$14,291	Garrett 1989	
Reformer Boiler	1,010	422	242	242	0.8	10	1,000	10	768	180	405	199		$16,524	Garrett 1989	
Reformer Air Heater	442	300	107	300	0.2	10	10	5	142	193	166	241		$10,718	Garrett 1989	
Cat. Ox. Preheater	1,181	800	400	983	3.7	10	10	5	198	400	287	2,576		$53,592	Garrett 1989	
Heat Recovery HX	800	300	250	250	4.5	10	1,000	10	550	50	209	2,180		$47,638	Garrett 1989	
Pumps	Flow	Flow	Power													
	(lb/h)	(gpm)	(hp)													
Cooler Cooling Pump	88,038	176	7											$2,977	Garrett 1989	
Condenser Cooling Pump	42,097	84	4											$2,382	Garrett 1989	
Compressors/Fans	Flow	Flow	Power													
	(acfh)	(acfm)	(hp)													
Char Furnace FD Fan	178,951	2,983	160	(Priced as Comp.)										$32,232	Garrett 1989	
Dilution Air FD Fan	697,769	11,629	62	(Priced as Fan)										$26,446	Garrett 1989	
Gas Compressor	90,987	1,516	18	(Priced as Comp.)										$9,178	Garrett 1989	
Burner Air FD Fan	55,720	929	19	(Priced as Fan)										$5,460	Garrett 1989	
Fuel Cell Air Compressor	353,500	5,892	79	(Priced as Fan)										$14,306	Garrett 1989	
Boilers	Steam	Heat	Gas Flow	Gas Flow												
	(lb/h)	(MM Btu/h)	(acfh)	(acfm)												
Gasifier Steam Boiler	1,825	2.2	208,106	3,468												
Reformer Steam Boiler	706	0.8	172,907	2,882												
Stacks	Gas Flow	Gas Flow	Bldg. Ht.	Height												
	(acfh)	(acfm)	(ft)	(ft)												
Dryer Stack	1,458,950	24,316	50	125										$32,155	Garrett 1989	
Conveyors	Length															
	(ft)															
To Hog from Truck Dump	75													$21,437	Garrett 1989	
To Chip Pile from Hog	250													$52,401	Garrett 1989	
To Dryer from Chip Pile	250													$52,401	Garrett 1989	
To Day Pile from Dryer	50													$15,482	Garrett 1989	
To Gasifier from Day Pile	50													$15,482	Garrett 1989	
Return Conveyor to Day Pile	50													$15,482	Garrett 1989	
Hog	Capacity															
	(ton/h)															
Shredder	4.1	(Sized for 10 ton/h)												$22,628	Garrett 1989	
Cooling Tower	Total Flow															
	(gpm)															
Cooling Tower	260													$65,502	Garrett 1989	

Table A1 - Stand-Alone Gasifier w/PAFCs - Current Fuel Cell Costs (Cases 1 & 5) - Continued								
Furnaces	Heat					**Purchased**		
	(MM Btu/h)					**Price (1995-$)**		
Reformer Furnace	2.0					$83,831	Garrett 1989	
Char Furnace	25.0					$178,641	Garrett 1989	
Gasifier	10.0					$178,641	Garrett 1989	
Catalytic Oxidizer	6.0					$119,094	Garrett 1989	
Dryer Air Dilution	Gas Flow	Gas Flow						
	(acfh)	(acfm)						
Dilution Air System	673,022	11,217				$3,811	Garrett 1989	
Reactors	Heat							
	(MM Btu/h)							
Reformer	2.0	(Priced as Cat. Ox.)				$52,245	Garrett 1989	
High-Temperature Shift Reactor	0.6	(Priced as Cat. Ox.)				$21,178	Garrett 1989	
Low-Temperature Shift Reactor	0.2	(Priced as Cat. Ox.)				$9,291	Garrett 1989	
Fuel Cell	Power							
	(kW)							
PAFC Stack	2,271					$4,542,000		
Dryer	Heat	Flow						
	(MM Btu/h)	(ton/h)						
Wood Dryer	4.3	4.1	(Priced as Rotary Kiln)			$952,750	Garrett 1989	
Cyclones	Gas Flow	Gas Flow						
	(acfh)	(acfm)						
Char Separator	227,354	3,789				$5,335	Garrett 1989	
Sand Separator	479,674	7,995				$8,575	Garrett 1989	
ESP	Gas Flow	Gas Flow						
	(acfh)	(acfm)						
Char Furnace ESP	477,621	7,960				$71,456	Garrett 1989	
Flare	Gas Flow							
	(lb/h)							
Emergency Flare	5,129					$59,547	Garrett 1989	
Capital Cost Factors (Gasifier)						Gasifier	Fuel Cells	Total
	Factor	Dep.	Non-Dep.		Purchased Cost	2,386,756		2,386,756
Purchased Cost	100%	100%		% of purchased cost	Installed Cost	6,993,195	4,542,000	11,535,195
Installation	39%		39%	% of purchased cost	Depreciable	5,919,154	4,542,000	10,461,154
Instrumentation & Controls	13%	13%		% of purchased cost	Non-Depreciable	1,074,040		1,074,040
Piping	31%	31%		% of purchased cost	Total Direct Plant Cost	6,993,195	4,542,000	11,535,195
Electrical	10%	10%		% of purchased cost	Total Indirect Plant Cost	1,575,259		1,575,259
Buildings	29%	29%		% of purchased cost	Total Direct & indirect Plant Cost	8,568,453	4,542,000	13,110,453
Yard Improvements	10%	10%		% of purchased cost	Contractor Fee	428,423	227,100	655,523
Service Facilities	55%	55%		% of purchased cost	Contingency (10% TIC & TDC)	856,845		856,845
Land	6%		6%	% of purchased cost	Fixed Capital Investment	9,853,721	4,769,100	14,622,821
Total	293%	248%	45%	% of purchased cost	Total Non-Dep			4,161,667
Engineering & Supervision	32%	% of purchased cost						
Construction	34%	% of purchased cost						
Total	66%	% of purchased cost						
Contractor Fees	5%	% of TDC & TIC						
Contingency	10%	% of TDC & TIC						

Table A2 - Integrated Gasifier & MCFC - Current Fuel Cell Costs (Cases 2 & 6)																	
Heat Exchangers	Hot In	Hot Out	Cold In	Cold Out	Heat Duty	Hot h	Cold h	U	dT1	dT2	LMTD	A		**Purchased**		Gasifier	Turbine
	(F)	(F)	(F)	(F)	(MM Btu/h)	(Btu/ft^2 h F)	(Btu/ft^2 h F)	(Btu/ft^2 h F)	(F)	(F)	(F)	(ft^2)		**Price (1995-$)**			
Gasifier Super Heater	1,500	1,262	242	1,000	0.7	10	10	5	500	1,020	729	192		$16,524	Garrett 1989	$16,524	
Gasifier Boiler	1,262	413	242	242	2.2	10	1,000	10	1,020	171	475	467		$30,845	Garrett 1989	$30,845	
Char Air Heater	1,639	1,472	182	400	0.7	10	10	5	1,239	1,290	1,264	111		$5,955	Garrett 1989	$5,955	
Steam Super Heater	1,800	1,639	470	619	0.7	10	10	5	1,181	1,169	1,175	119		$11,457	Garrett 1989		$11,457
Steam Boiler	1,472	861	470	470	2.5	10	1,000	10	1,002	391	649	389		$26,439	Garrett 1989		$26,439
Reformer Pre-Heater	1,568	1,287	398	1,202	2.4	10	10	5	366	889	589	814		$27,392	Garrett 1989	$27,392	
Air Heater	1,202	762	103	1,054	4.3	10	10	5	148	659	342	2,514		$40,492	Garrett 1989	$40,492	
Steam Reheater	762	672	362	589	0.8	10	100	9	173	310	235	375		$26,439	Garrett 1989		$26,439
Economizer	672	507	139	300	1.5	10	100	9	372	368	370	446		$28,642	Garrett 1989		$28,642
Condenser	145	145	110	125	7.9	10	1,000	10	20	35	27	29,768		$275,063	Garrett 1989		$275,063
Pumps	Flow	Flow	Power														
	(lb/h)	(gpm)	(hp)														
Boiler Feed Water Pump	8,487	17	20											$7,717	Garrett 1989		$7,717
Hot Well Pump	7,561	15	1											$595	Garrett 1989		$595
Condenser Cooling Pump	520,628	1,040	33											$6,193	Garrett 1989		$6,193
Compressors/Fans	Flow	Flow	Power														
	(acfh)	(acfm)	(hp)														
Char Furnace FD Fan	172,709	2,878	154	(Priced as Comp.)										$34,918	Garrett 1989	$34,918	
Dilution Air FD Fan	290,897	4,848	26	(Priced as Fan)										$9,237	Garrett 1989	$9,237	
Fuel Cell Air Compressor	231,652	3,861	74	(Priced as Fan)										$12,183	Garrett 1989	$12,183	
Cat. Ox. Air Compressor	97,375	1,623	34	(Priced as Fan)										$7,269	Garrett 1989	$7,269	
Turbines	Power																
	(hp)																
MP Turbine	335	(Priced as Turbine & Elec. Motor)												$95,275	Garrett 1989		$95,275
LP Turbine	622	(Priced as Turbine & Elec. Motor)												$131,003	Garrett 1989		$131,003
Boilers																	
Gasifier Steam Boiler																	
Steam Cycle Boiler																	
Fuel Cell Boiler																	
Stacks	Gas Flow	Gas Flow	Bldg. Ht.	Height													
	(acfh)	(acfm)	(ft)	(ft)													
Dryer Stack	1,282,580	21,376	50	125										$32,155	Garrett 1989	$32,155	
Conveyors	Length																
	(ft)																
To Hog from Truck Dump	75													$21,437	Garrett 1989	$21,437	
To Chip Pile from Hog	250													$52,401	Garrett 1989	$52,401	
To Dryer from Chip Pile	250													$52,401	Garrett 1989	$52,401	
To Day Pile from Dryer	50													$15,482	Garrett 1989	$15,482	
To Gasifier from Day Pile	50													$15,482	Garrett 1989	$15,482	
Return Conveyor to Day Pile	50													$15,482	Garrett 1989	$15,482	
Hog	Capacity																
	(ton/h)																
Shredder	4.1	(Sized for 10 ton/h)												$22,628	Garrett 1989	$22,628	
Cooling Tower	Total Flow																
	(gpm)																
Cooling Tower	1,040													$71,456	Garrett 1989	$71,456	

Table A2 - Integrated Gasifier & MCFC - Current Fuel Cell Costs (Cases 2 & 6) - Continued									
								Gasifier	Turbine
Furnaces	Heat					**Purchased**			
	(MM Btu/h)					**Price (1995-$)**			
Char Furnace	25.0					$178,641	Garrett 1989	$178,641	
Gasifier	10.0					$178,641	Garrett 1989	$178,641	
Catalytic Oxidizer	6.0					$119,094	Garrett 1989	$119,094	
Dryer Air Dilution	Gas Flow	Gas Flow							
	(acfm)	(acfm)							
Dilution Air System	280,580	4,676				$3,335	Garrett 1989	$3,335	
Reactors									
Reformer									
High-Temperature Shift Reactor									
Fuel Cells	Power								
	(kW)								
MCFC	3,544					#########			
Dryer	Heat	Flow							
	(MM Btu/h)	(ton/h)							
Wood Dryer	4.3	4.1	(Priced as Rotary Kiln)			$952,750	Garrett 1989	$952,750	
Cyclones	Gas Flow	Gas Flow							
	(acfh)	(acfm)							
Char Separator	231,037	3,851				$5,335	Garrett 1989	$5,335	
Sand Separator	462,345	7,706				$8,765	Garrett 1989	$8,765	
ESP	Gas Flow	Gas Flow							
	(acfh)	(acfm)							
Char Furnace ESP	295,908	4,932				$55,974	Garrett 1989	$55,974	
Flare	Gas Flow								
	(lb/h)								
Emergency Flare	5,192					$59,547	Garrett 1989	$59,547	
Capital Cost Factors (Gasifier)						Gasifier	Fuel Cells	Turbine	Total
	Factor	Dep.	Non-Dep.		Purchased Cost	2,045,821		$608,823	2,654,644
Purchased Cost	100%	100%		% of purchased cost	Installed Cost	5,994,257	10,632,000	##########	18,410,107
Installation	39%		39%	% of purchased cost	Depreciable	5,073,637	10,632,000	1,509,880	17,215,518
Instrumentation & Controls	13%	13%		% of purchased cost	Non-Depreciable	920,620		273,970	1,194,590
Piping	31%	31%		% of purchased cost	Total Direct Plant Cost	5,994,257	10,632,000	1,783,851	18,410,107
Electrical	10%	10%		% of purchased cost	Total Indirect Plant Cost	1,350,242		401,823	1,752,065
Buildings	29%	29%		% of purchased cost	Total Direct & indirect Plant Cost	7,344,499	10,632,000	2,185,674	20,162,173
Yard Improvements	10%	10%		% of purchased cost	Contractor Fee	367,225	531,600	109,284	1,008,109
Service Facilities	55%	55%		% of purchased cost	Contingency (10% TIC & TDC)	734,450		218,567	953,017
Land	6%		6%	% of purchased cost	Fixed Capital Investment	8,446,174	11,163,600	2,513,525	22,123,298
Total	293%	248%	45%	% of purchased cost	Total Non-Dep				4,907,781
Engineering & Supervision	32%	% of purchased cost							
Construction	34%	% of purchased cost							
Total	66%	% of purchased cost							
Contractor Fees	5%	% of TDC & TIC							
Contingency	10%	% of TDC & TIC							

Table A3 - Stand-Alone Gasifier w/PAFCs - Future Fuel Cell Costs (Cases 3 & 7)															
Heat Exchangers	Hot In	Hot Out	Cold In	Cold Out	Heat Duty	Hot h	Cold h	U	dT1	dT2	LMTD	A		**Purchased**	
	(F)	(F)	(F)	(F)	MM Btu/h	(Btu/ft^2 h F)	(Btu/ft^2 h F)	(Btu/ft^2 h F)	(F)	(F)	(F)	(ft^2)		**Price (1995-$)**	
Gasifier Super Heater	1,482	1,240	242	1,000	0.7	10	10	5	482	998	709	197		$16,524	Garrett 1989
Gasifier Boiler	1,240	380	242	242	2.2	10	1,000	10	998	138	435	511		$33,049	Garrett 1989
Char Air Heater	1,800	1,693	182	325	0.5	10	10	5	1,475	1,511	1,493	67		$5,717	Garrett 1989
Reformer Pre-Heater	1,409	1,010	380	1,335	2.4	10	10	5	74	630	260	1,849		$35,728	Garrett 1989
Reformer Heater	2,585	1,409	1,335	1,562	0.6	10	10	5	1,023	74	361	332		$9,528	Garrett 1989
Cooler	920	392	110	125	1.4	10	100	9	795	282	495	311		$13,100	Garrett 1989
Condenser	469	210	110	125	0.7	10	100	9	344	100	197	390		$14,291	Garrett 1989
Reformer Boiler	1,010	422	242	242	0.8	10	1,000	10	768	180	405	199		$16,524	Garrett 1989
Reformer Air Heater	442	300	107	300	0.2	10	10	5	142	193	166	241		$10,718	Garrett 1989
Cat. Ox. Pre-Heater	1,181	800	400	983	3.7	10	10	5	198	400	287	2,576		$53,592	Garrett 1989
Heat Recovery HX	800	300	250	250	4.5	10	1,000	10	550	50	209	2,180		$47,638	Garrett 1989
Pumps	Flow	Flow	Power												
	(lb/h)	(gpm)	(hp)												
Cooler Cooling Pump	88,038	176	7											$2,977	Garrett 1989
Condenser Cooling Pump	42,097	84	4											$2,382	Garrett 1989
Compressors/Fans	Flow	Flow	Power												
	(acfh)	(acfm)	(hp)												
Char Furnace FD Fan	178,951	2,983	160	(Priced as Comp.)										$32,232	Garrett 1989
Dilution Air FD Fan	697,769	11,629	62	(Priced as Fan)										$26,446	Garrett 1989
Gas Compressor	90,987	1,516	18	(Priced as Comp.)										$9,178	Garrett 1989
Burner Air FD Fan	55,720	929	19	(Priced as Fan)										$5,460	Garrett 1989
Fuel Cell Air Compressor	353,500	5,892	79	(Priced as Fan)										$14,306	Garrett 1989
Boilers	Steam	Heat	Gas Flow	Gas Flow											
	(lb/h)	(MM Btu/h)	(acfh)	(acfm)											
Gasifier Steam Boiler	1,825	2.2	208,106	3,468											
Reformer Steam Boiler	706	0.8	172,907	2,882											
Stacks	Gas Flow	Gas Flow	Bldg. Ht.	Height											
	(acfh)	(acfm)	(ft)	(ft)											
Dryer Stack	1,458,950	24,316	50	125										$32,155	Garrett 1989
Conveyors	Length														
	(ft)														
To Hog from Truck Dump	75													$21,437	Garrett 1989
To Chip Pile from Hog	250													$52,401	Garrett 1989
To Dryer from Chip Pile	250													$52,401	Garrett 1989
To Day Pile from Dryer	50													$15,482	Garrett 1989
To Gasifier from Day Pile	50													$15,482	Garrett 1989
Return Conveyor to Day Pile	50													$15,482	Garrett 1989
Hog	Capacity														
	(ton/h)														
Shredder	4.1	(Sized for 10 ton/h)												$22,628	Garrett 1989
Cooling Tower	Total Flow														
	(gpm)														
Cooling Tower	260													$65,502	Garrett 1989

Table A3 - Stand-Alone Gasifier w/PAFCs - Future Fuel Cell Costs (Cases 3 & 7) - Continued																
Furnaces	Heat													**Purchased**		
	(MM Btu/h)													**Price (1995-$)**		
Reformer Furnace	2.0													$83,831	Garrett 1989	
Char Furnace	25.0													$178,641	Garrett 1989	
Gasifier	10.0													$178,641	Garrett 1989	
Catalytic Oxidizer	6.0													$119,094	Garrett 1989	
Dryer Air Dilution	Gas Flow	Gas Flow														
	(acfh)	(acfm)														
Dilution Air System	673,022	11,217												$3,811	Garrett 1989	
Reactors	Heat															
	(MM Btu/h)															
Reformer	2.0	(Priced as Cat. Ox.)												$52,245	Garrett 1989	
High-Temperature Shift Reacto	0.6	(Priced as Cat. Ox.)												$21,178	Garrett 1989	
Low-Temperature Shift Reactor	0.2	(Priced as Cat. Ox.)												$9,291	Garrett 1989	
Fuel Cell	Power															
	(kW)															
PAFC Stack	2,271													$2,271,000		
Dryer	Heat	Flow														
	(MM Btu/h)	(ton/h)														
Wood Dryer	4.3	4.1	(Priced as Rotary Kiln)											$952,750	Garrett 1989	
Cyclones	Gas Flow	Gas Flow														
	(acfh)	(acfm)														
Char Separator	227,354	3,789												$5,335	Garrett 1989	
Sand Separator	479,674	7,995												$8,575	Garrett 1989	
ESP	Gas Flow	Gas Flow														
	(acfh)	(acfm)														
Char Furnace ESP	477,621	7,960												$71,456	Garrett 1989	
Flare	Gas Flow															
	(lb/h)															
Emergency Flare	5,129													$59,547	Garrett 1989	
Capital Cost Factors (Gasifier)														Gasifier	Fuel Cells	Total
	Factor	Dep.	Non-Dep.						Purchased Cost					2,386,756		2,386,756
Purchased Cost	100%	100%		% of purchased cost					Installed Cost					6,993,195	2,271,000	9,264,195
Installation	39%		39%	% of purchased cost					Depreciable					5,919,154	2,271,000	8,190,154
Instrumentation & Controls	13%	13%		% of purchased cost					Non-Depreciable					1,074,040		1,074,040
Piping	31%	31%		% of purchased cost					Total Direct Plant Cost					6,993,195	2,271,000	9,264,195
Electrical	10%	10%		% of purchased cost					Total Indirect Plant Cost					1,575,259		1,575,259
Buildings	29%	29%		% of purchased cost					Total Direct & indirect Plant Cost					8,568,453	2,271,000	10,839,453
Yard Improvements	10%	10%		% of purchased cost					Contractor Fee					428,423	113,550	541,973
Service Facilities	55%	55%		% of purchased cost					Contingency (10% TIC & TDC)					856,845		856,845
Land	6%		6%	% of purchased cost					Fixed Capital Investment					9,853,721	2,384,550	12,238,271
Total	293%	248%	45%	% of purchased cost					Total Non-Dep							4,048,117
Engineering & Supervision	32%	% of purchased cost														
Construction	34%	% of purchased cost														
Total	66%	% of purchased cost														
Contractor Fees	5%	% of TDC & TIC														
Contingency	10%	% of TDC & TIC														

Table A4 - Integrated Gasifier & MCFC - Future Fuel Cell Costs (Cases 4 & 8)																	
Heat Exchangers	Hot In	Hot Out	Cold In	Cold Out	Heat Duty	Hot h	Cold h	U	dT1	dT2	LMTD	A		**Purchased**		Gasifier	Turbine
	(F)	(F)	(F)	(F)	(MM Btu/h)	(Btu/ft^2 h F)	(Btu/ft^2 h F)	(Btu/ft^2 h F)	(F)	(F)	(F)	(ft^2)		**Price (1995-$)**			
Gasifier Super Heater	1,500	1,262	242	1,000	0.7	10	10	5	500	1,020	729	192		$16,524	Garrett 1989	$16,524	
Gasifier Boiler	1,262	413	242	242	2.2	10	1,000	10	1,020	171	475	467		$30,845	Garrett 1989	$30,845	
Char Air Heater	1,639	1,472	182	400	0.7	10	10	5	1,239	1,290	1,264	111		$5,955	Garrett 1989	$5,955	
Steam Super Heater	1,800	1,639	470	619	0.7	10	10	5	1,181	1,169	1,175	119		$11,457	Garrett 1989		$11,457
Steam Boiler	1,472	861	470	470	2.5	10	1,000	10	1,002	391	649	389		$26,439	Garrett 1989		$26,439
Reformer Pre-Heater	1,568	1,287	398	1,202	2.4	10	10	5	366	889	589	814		$27,392	Garrett 1989	$27,392	
Air Heater	1,202	762	103	1,054	4.3	10	10	5	148	659	342	2,514		$40,492	Garrett 1989	$40,492	
Steam Reheater	762	672	362	589	0.8	10	100	9	173	310	235	375		$26,439	Garrett 1989		$26,439
Economizer	672	507	139	300	1.5	10	100	9	372	368	370	446		$28,642	Garrett 1989		$28,642
Condenser	145	145	110	125	7.9	10	1,000	10	20	35	27	29,768		$275,063	Garrett 1989		$275,063
Pumps	Flow	Flow	Power														
	(lb/h)	(gpm)	(hp)														
Boiler Feed Water Pump	8,487	17	20											$7,717	Garrett 1989		$7,717
Hot Well Pump	7,561	15	1											$595	Garrett 1989		$595
Condenser Cooling Pump	520,628	1,040	33											$6,193	Garrett 1989		$6,193
Compressors/Fans	Flow	Flow	Power														
	(acfh)	(acfm)	(hp)														
Char Furnace FD Fan	172,709	2,878	154											$34,918	Garrett 1989	$34,918	
Dilution Air FD Fan	290,897	4,848	26											$9,237	Garrett 1989	$9,237	
Fuel Cell Air Compressor	231,652	3,861	74											$12,183	Garrett 1989	$12,183	
Cat. Ox. Air Compressor	97,375	1,623	34											$7,269	Garrett 1989	$7,269	
Turbines	Power																
	(hp)																
MP Turbine	335	(Priced as Turbine & Elec. Motor)												$95,275	Garrett 1989		$95,275
LP Turbine	622	(Priced as Turbine & Elec. Motor)												$131,003	Garrett 1989		$131,003
Boilers																	
Gasifier Steam Boiler																	
Steam Cycle Boiler																	
Fuel Cell Boiler																	
Stacks	Gas Flow	Gas Flow	Bldg. Ht.	Height													
	(acfh)	(acfm)	(ft)	(ft)													
Dryer Stack	1,282,580	21,376	50	125										$32,155	Garrett 1989	$32,155	
Conveyors	Length																
	(ft)																
To Hog from Truck Dump	75													$21,437	Garrett 1989	$21,437	
To Chip Pile from Hog	250													$52,401	Garrett 1989	$52,401	
To Dryer from Chip Pile	250													$52,401	Garrett 1989	$52,401	
To Day Pile from Dryer	50													$15,482	Garrett 1989	$15,482	
To Gasifier from Day Pile	50													$15,482	Garrett 1989	$15,482	
Return Conveyor to Day Pile	50													$15,482	Garrett 1989	$15,482	
Hog	Capacity																
	(ton/h)																
Shredder	4.1	(Sized for 10 ton/h)												$22,628	Garrett 1989	$22,628	
Cooling Tower	Total Flow																
	(gpm)																
Cooling Tower	1,040													$71,456	Garrett 1989	$71,456	

Table A4 - Integrated Gasifier & MCFC - Future Fuel Cell Costs (Cases 4 & 8) - Continued								Gasifier	Turbine
Furnaces	Heat					**Purchased**			
	(MM Btu/h)					**Price (1995-$)**			
Char Furnace	36.0					$178,641	Garrett 1989	$178,641	
Gasifier	9.0					$178,641	Garrett 1989	$178,641	
Catalytic Oxidizer	8.0					$119,094	Garrett 1989	$119,094	
Dryer Air Dilution	Gas Flow	Gas Flow							
	(acfm)	(acfm)							
Dilution Air System	280,580	4,676				$3,335	Garrett 1989	$3,335	
Reactors									
Reformer									
High-Temperature Shift Reactor									
Fuel Cells	Power								
	(kW)								
MCFC	3,544					$3,544,000			
Dryer	Heat	Flow							
	(MM Btu/h)	(ton/h)							
Wood Dryer	4.3	4.1	(Priced as Rotary Kiln)			$952,750	Garrett 1989	$952,750	
Cyclones	Gas Flow	Gas Flow							
	(acfh)	(acfm)							
Char Separator	231,037	3,851				$5,335	Garrett 1989	$5,335	
Sand Separator	462,345	7,706				$8,765	Garrett 1989	$8,765	
ESP	Gas Flow	Gas Flow							
	(acfh)	(acfm)							
Char Furnace ESP	295,908	4,932				$55,974	Garrett 1989	$55,974	
Flare	Gas Flow								
	(lb/h)								
Emergency Flare	5,192					$59,547	Garrett 1989	$59,547	
Capital Cost Factors (Gasifier)						Gasifier	Fuel Cells	Turbine	Total
	Factor	Dep.	Non-Dep.		Purchased Cost	2,045,821		$608,823	2,654,644
Purchased Cost	100%	100%		% of purchased cost	Installed Cost	5,994,257	3,544,000	$1,783,850.68	11,322,107
Installation	39%		39%	% of purchased cost	Depreciable	5,073,637	3,544,000	1,509,880	10,127,518
Instrumentation & Controls	13%	13%		% of purchased cost	Non-Depreciable	920,620		273,970	1,194,590
Piping	31%	31%		% of purchased cost	Total Direct Plant Cost	5,994,257	3,544,000	1,783,851	11,322,107
Electrical	10%	10%		% of purchased cost	Total Indirect Plant Cost	1,350,242		401,823	1,752,065
Buildings	29%	29%		% of purchased cost	Total Direct & indirect Plant Cost	7,344,499	3,544,000	2,185,674	13,074,173
Yard Improvements	10%	10%		% of purchased cost	Contractor Fee	367,225	177,200	109,284	653,709
Service Facilities	55%	55%		% of purchased cost	Contingency (10% TIC & TDC)	734,450		218,567	953,017
Land	6%		6%	% of purchased cost	Fixed Capital Investment	8,446,174	3,721,200	2,513,525	14,680,898
Total	293%	248%	45%	% of purchased cost	Total Non-Dep				4,553,381
Engineering & Supervision	32%	% of purchased cost							
Construction	34%	% of purchased cost							
Total	66%	% of purchased cost							
Contractor Fees	5%	% of TDC & TIC							
Contingency	10%	% of TDC & TIC							

Table A5 - Stand-Alone Gasifier w/PAFCs - Variable Operating Costs (Cases 1, 3, 5, & 7)							
Operating Days/Year	350	days					
Fuel	Flow-Wet	Flow-BD	Flow-Wet	Flow-BD	Cost		Cost
	(lb/h)	(lb/h)	(tpd)	(tpd)	($/BD ton)		($/yr)
Wood	4,585	4,081	55.02	48.9678	$42.00		$719,827
Wood Residue	4,585	4,081	55.02	48.9678	$17.00		$291,358
Water Use	Flow	Flow	Cost				Cost
	(lb/h)	(gpm)	($/1000 gal)				($/yr)
Process Water	0	0	$0.20				$0
Boiler Feed Water	2,531	5	$5.00				$2,549
Cooling Water	130,135	260	$0.20				$131,071
						Total	$133,620
Power Production	Electricity	Electricity					
	(kW)	(kWh/yr)					
Net Output	2,011	16,892,400					
Power Demand	Electricity						
	(kW)						
Char Furnace FD Fan	119						
Dilution Air FD Fan	46						
Gas Compressor	13						
Burner Air FD Fan	15						
Fuel Cell Air Compressor	59						
Cooler Cooling Pump	5						
Condenser Cooling Pump	3						
Total	260						

Table A6 - Integrated Gasifier & MCFC - Variable Operating Costs (Cases 2, 4, 6 & 8)							
Operating Days/Year	350	days					
Fuel	Flow-Wet	Flow-BD	Flow-Wet	Flow-BD	Cost		Cost
	(lb/h)	(lb/h)	(tpd)	(tpd)	($/BD ton)		($/yr)
Wood	8,162	4,081	97.944	48.9678	42		$719,827
Wood Residue	8,162	4,081	97.944	48.9678	17		$291,358
Water Use	Flow	Flow	Cost				Cost
	(lb/h)	(gpm)	($/1000 gal)				($/yr)
Boiler Feed Water	2,750	5	$5.00				$13,849
Cooling Water	520,628	1,040	$0.20				$104,875
						Total	$118,724
Power Production	Electricity	Electricity					
	(kW)	(kWh/yr)					
Net Output	4,003	33,625,200					
Power Demand	Electricity						
	(kW)						
Char Furnace FD Fan	115						
Dilution Air FD Fan	19						
Fuel Cell Air Compressor	55						
Cat. Ox. Air Compressor	26						
Boiler Feed Water Pump	15						
Hot Well Pump	1						
Condenser Cooling Pump	24						
Total	255						

Table A7 - Stand-Alone/PAFC, Current FC Costs, Wood (Case 1)

Discounted cash flow - rate of return				
After Tax IRR =		15.00%		
Pre Tax IRR =		22.92%		
Construction Period = 2 years				
Assumed Sale Price		($/kWh) =		$0.472
Electricity produced (kWh/yr)=				16,892,400
Gross Income (MM$/yr)				7.98
Royalties (0.5% of sales) (MM$/yr) =				0.04
Working Capital (30% of annual sales) (MM$) =				2.39
Operating Costs (MM$/yr) =				3.18
	Labor	3	Operators	
		$28.75	per hour worked	0.76
			supervisor cost (15% of op. labor)	0.11
	Maintenance and general expenses (10% of FCI)			1.46
	Utilities			0.13
	Byproduct Credit			-
	Feed			0.72
Non-depreciable Capital ($MM)				4.16
Depreciable Capital Costs (MM$) =				10.46
Tax Rate =				37.00%
Gasifier Dep.	5.92	(5 yrs)		
Fuel Cell Dep.	4.54	(15 yrs)		
Turbine Dep.		(20 yrs)		
Total	10.46			
Salvage	10%			
Salvage Value	1.05			

Table A8 - Integrated/MCFC, Current FC Costs, Wood (Case 2)				
Discounted cash flow - rate of return				
After Tax IRR =		15.00%		
Pre Tax IRR =		21.15%		
Construction Period = 2 years				
Assumed Sale Price		($/kWh) =		$0.311
Electricity produced (kWh/yr)=				33,625,200
Gross Income (MM$/yr)				10.45
Royalties (0.5% of sales) (MM$/yr) =				0.05
Working Capital (30% of annual sales) (MM$) =				3.13
Operating Costs (MM$/yr) =				3.92
	Labor	3	Operators	
		$28.75	per hour worked	0.76
			supervisor cost (15% of op. labor)	0.11
	Maintenance and general expenses (10% of FCI)			2.21
	Utilities			0.12
	Byproduct Credit			-
	Feed			0.72
Non-depreciable Capital ($MM)				4.91
Depreciable Capital Costs (MM$) =				17.22
Tax Rate =				37.00%
Gasifier Dep.	5.07	(5 yrs)		
Fuel Cell Dep.	10.63	(15 yrs)		
Turbine Dep.	1.51	(20 yrs)		
Total	17.22			
Salvage	10%			
Salvage Value	1.72			

Table A9 - Stand-Alone/PAFC, Future FC Costs, Wood (Case 3)				
Discounted cash flow - rate of return				
After Tax IRR =		15.00%		
Pre Tax IRR =		23.77%		
Construction Period = 2 years				
Assumed Sale Price		($/kWh) =		$0.424
Electricity produced (kWh/yr)=				16,892,400
Gross Income (MM$/yr)				7.17
Royalties (0.5% of sales) (MM$/yr) =				0.04
Working Capital (30% of annual sales) (MM$) =				2.15
Operating Costs (MM$/yr) =				2.95
	Labor	3	Operators	
		$28.75	per hour worked	0.76
			supervisor cost (15% of op. labor)	0.11
	Maintenance and general expenses (10% of FCI)			1.22
	Utilities			0.13
	Byproduct Credit			-
	Feed			0.72
Non-depreciable Capital ($MM)				4.05
Depreciable Capital Costs (MM$) =				8.19
Tax Rate =				37.00%
Gasifier Dep.	5.92	(5 yrs)		
Fuel Cell Dep.	2.27	(15 yrs)		
Turbine Dep.		(20 yrs)		
Total	8.19			
Salvage	10%			
Salvage Value	0.82			

Table A10 - Integrated/MCFC, Future FC Costs, Wood (Case 4)				
Discounted cash flow - rate of return				
After Tax IRR =		15.00%		
Pre Tax IRR =		22.58%		
Construction Period = 2 years				
Assumed Sale Price		($/kWh) =		$0.235
Electricity produced (kWh/yr)=				33,625,200
Gross Income (MM$/yr)				7.91
Royalties (0.5% of sales) (MM$/yr) =				0.04
Working Capital (30% of annual sales) (MM$) =				2.37
Operating Costs (MM$/yr) =				3.18
	Labor	3	Operators	
		$28.75	per hour worked	0.76
			supervisor cost (15% of op. labor)	0.11
	Maintenance and general expenses (10% of FCI)			1.47
	Utilities			0.12
	Byproduct Credit			-
	Feed			0.72
Non-depreciable Capital ($MM)				4.55
Depreciable Capital Costs (MM$) =				10.13
Tax Rate =				37.00%
Gasifier Dep.	5.07	(5 yrs)		
Fuel Cell Dep.	3.54	(15 yrs)		
Turbine Dep.	1.51	(20 yrs)		
Total	10.13			
Salvage	10%			
Salvage Value	1.01			

Table A11 - Stand-Alone/PAFC, Current FC Costs, Residues (Case 5)				
Discounted cash flow - rate of return				
After Tax IRR =		15.00%		
Pre Tax IRR =		22.96%		
Construction Period = 2 years				
Assumed Sale Price		($/kWh) =		$0.446
Electricity produced (kWh/yr)=				16,892,400
Gross Income (MM$/yr)				7.53
Royalties (0.5% of sales) (MM$/yr) =				0.04
Working Capital (30% of annual sales) (MM$) =				2.26
Operating Costs (MM$/yr) =				2.76
	Labor	3	Operators	
		$28.75	per hour worked	0.76
			supervisor cost (15% of op. labor)	0.11
	Maintenance and general expenses (10% of FCI)			1.46
	Utilities			0.13
	Byproduct Credit			-
	Feed			0.29
Non-depreciable Capital ($MM)				4.16
Depreciable Capital Costs (MM$) =				10.46
Tax Rate =				37.00%
Gasifier Dep.	5.92	(5 yrs)		
Fuel Cell Dep.	4.54	(15 yrs)		
Turbine Dep.		(20 yrs)		
Total	10.46			
Salvage	10%			
Salvage Value	1.05			

Table A12 - Integrated/MCFC, Current FC Costs, Residues (Case 6)				
Discounted cash flow - rate of return				
After Tax IRR =		15.00%		
Pre Tax IRR =		21.17%		
Construction Period = 2 years				
Assumed Sale Price		($/kWh) =		$0.297
Electricity produced (kWh/yr)=				33,625,200
Gross Income (MM$/yr)				10.00
Royalties (0.5% of sales) (MM$/yr) =				0.05
Working Capital (30% of annual sales) (MM$) =				3.00
Operating Costs (MM$/yr) =				3.49
	Labor	3	Operators	
		$28.75	per hour worked	0.76
			supervisor cost (15% of op. labor)	0.11
	Maintenance and general expenses (10% of FCI)			2.21
	Utilities			0.12
	Byproduct Credit			-
	Feed			0.29
Non-depreciable Capital ($MM)				4.91
Depreciable Capital Costs (MM$) =				17.22
Tax Rate =				37.00%
Gasifier Dep.	5.07	(5 yrs)		
Fuel Cell Dep.	10.63	(15 yrs)		
Turbine Dep.	1.51	(20 yrs)		
Total	17.22			
Salvage	10%			
Salvage Value	1.72			

Table A13 - Stand-Alone/PAFC, Future FC Costs, Residues (Case 7)				
Discounted cash flow - rate of return				
After Tax IRR =		15.00%		
Pre Tax IRR =		23.83%		
Construction Period = 2 years				
Assumed Sale Price		($/kWh) =		$0.398
Electricity produced (kWh/yr)=				16,892,400
Gross Income (MM$/yr)				6.72
Royalties (0.5% of sales) (MM$/yr) =				0.03
Working Capital (30% of annual sales) (MM$) =				2.01
Operating Costs (MM$/yr) =				2.52
	Labor	3	Operators	
		$28.75	per hour worked	0.76
			Supervisor cost (15% of op. labor)	0.11
	Maintenance and general expenses (10% of FCI)			1.22
	Utilities			0.13
	Byproduct Credit			-
	Feed			0.29
Non-depreciable Capital ($MM)				4.05
Depreciable Capital Costs (MM$) =				8.19
Tax Rate =				37.00%
Gasifier Dep.	5.92	(5 yrs)		
Fuel Cell Dep.	2.27	(15 yrs)		
Turbine Dep.		(20 yrs)		
Total	8.19			
Salvage	10%			
Salvage Value	0.82			

Table A14 - Integrated/MCFC, Future FC Costs, Residues (Case 8)				
Discounted cash flow - rate of return				
After Tax IRR =		15.00%		
Pre Tax IRR =		22.62%		
Construction Period = 2 years				
Assumed Sale Price		($/kWh) =		$0.222
Electricity produced (kWh/yr)=				33,625,200
Gross Income (MM$/yr)				7.46
Royalties (0.5% of sales) (MM$/yr) =				0.04
Working Capital (30% of annual sales) (MM$) =				2.24
Operating Costs (MM$/yr) =				2.75
	Labor	3	Operators	
		$28.75	per hour worked	0.76
			supervisor cost (15% of op. labor)	0.11
	Maintenance and general expenses (10% of FCI)			1.47
	Utilities			0.12
	Byproduct Credit			-
	Feed			0.29
Non-depreciable Capital ($MM)				4.55
Depreciable Capital Costs (MM$) =				10.13
Tax Rate =				37.00%
Gasifier Dep.	5.07	(5 yrs)		
Fuel Cell Dep.	3.54	(15 yrs)		
Turbine Dep.	1.51	(20 yrs)		
Total	10.13			
Salvage	10%			
Salvage Value	1.01			

APPENDIX B - STREAM TABLES

Appendix B contains the stream tables for both the stand-alone and integrated biomass gasification/fuel cell designs. Flowrates are provided in both English and SI units, and the molar compositions are also given for all gas streams.

Figures B1, B2 and B3 are for the stand-alone plant design. The stream data for these flowsheets can be found in Tables B1 and B2. Figures B4, B5 and B6 are for the integrated case. The corresponding stream data can be found in Tables B3 and B4.

Below is a list of the figures and tables in Appendix B, with a brief description of each one.

Figure B1 - Gasifier flowsheet for stand-alone design.
Figure B2 - Gas processing section for stand-alone design.
Figure B3 - PAFC flowsheet for stand-alone design.
Figure B4 - Gasifier flowsheet for integrated design.
Figure B5 - MCFC flowsheet for integrated design.
Figure B6 - Steam cycle for integrated design.

Table B1 - Stream compositions and mass flowrates in lb/h.
Table B2 - Mass flowrates in kg/h.
Table B3 - Stream compositions and mass flowrates in lb/h.
Table B4 - Mass flowrates in kg/h.

Figure B1 - Stand-Alone Gasifier Flowsheet

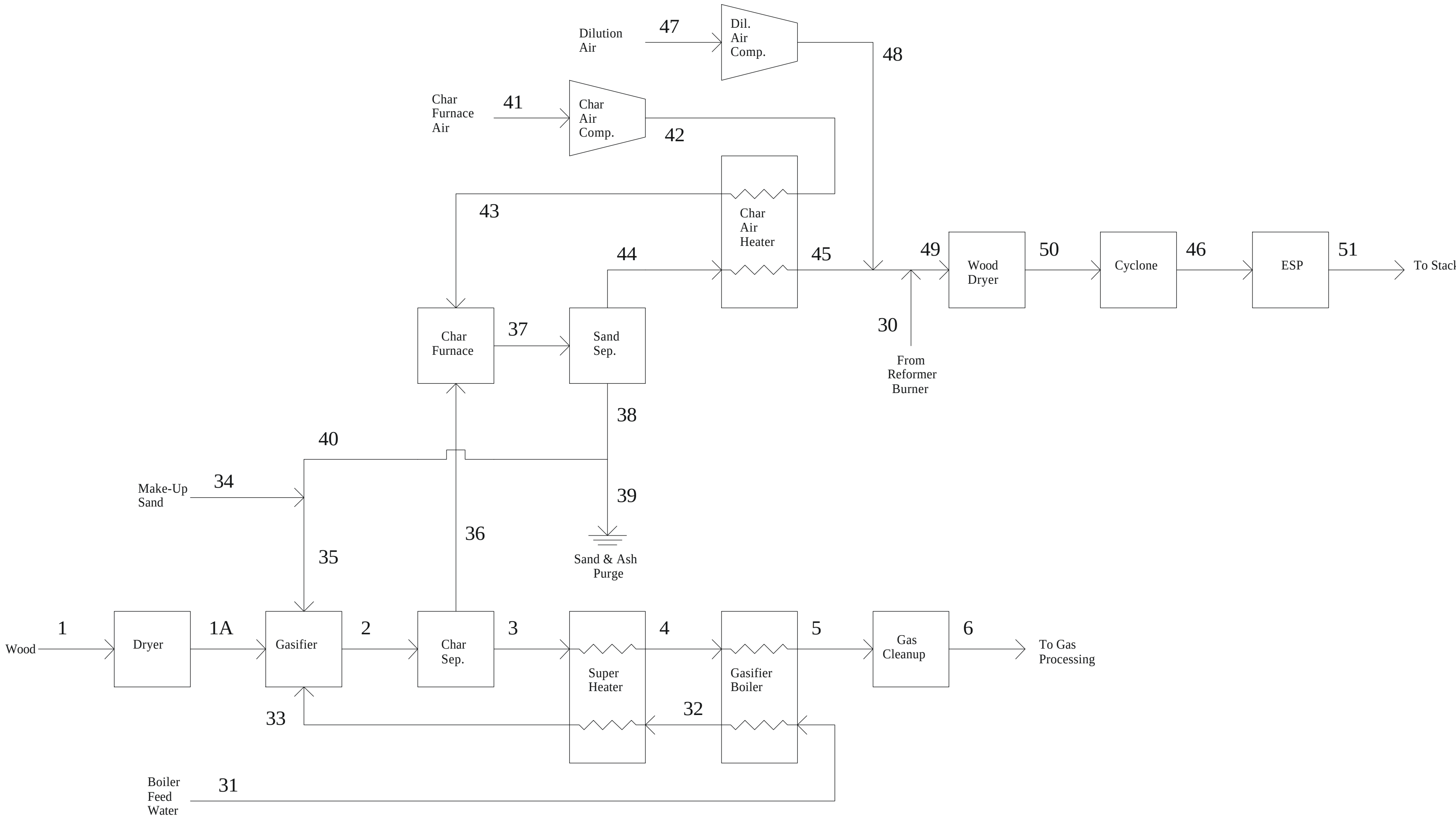

Figure B2 - Stand-Alone Gas Processing Flowsheet

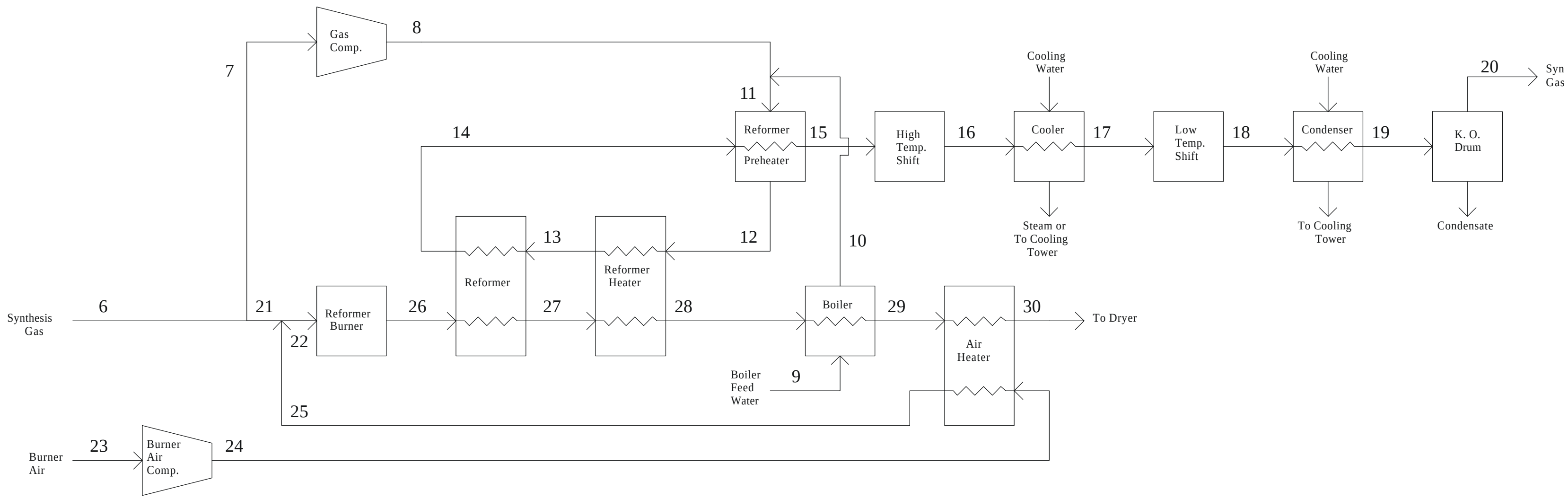

Figure B3 - Stand-Alone PAFC Flowsheet

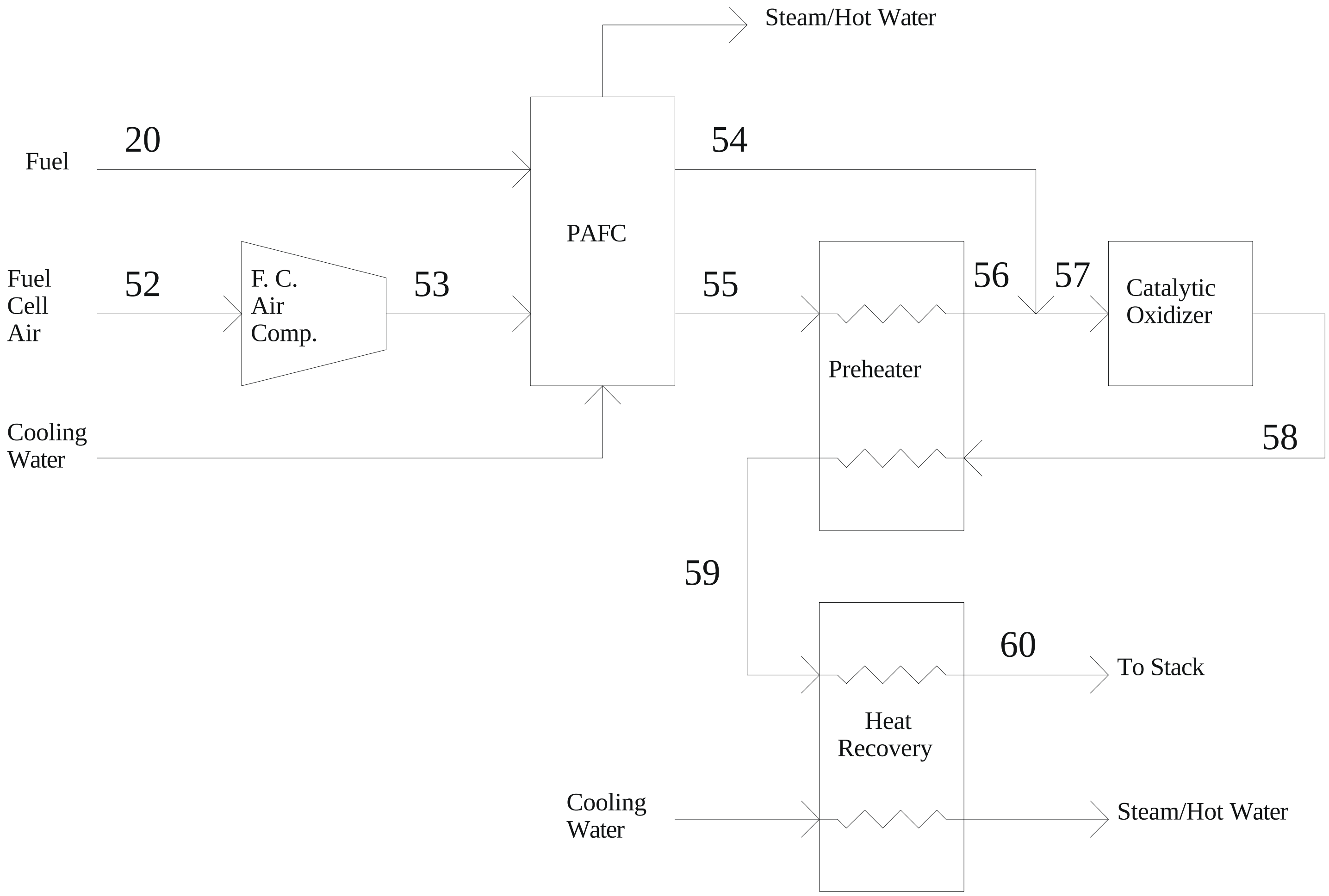

Table B1 - Stream Table for Stand-Alone Gasifier/PAFC Design Units)										
Steam #	1	1A	2	3	4	5	6	7	8	9
Temp. (°F)	59	80	1482	1482	1240	380	380	404	404	59
Pressure (psia)	14.7	14.7	25	24.5	23.9	23.4	22.7	24.6	24.6	25
O2 (lb/h)										
N2 (lb/h)										
H2 (lb/h)			100	100	100	100	100	100	100	
CO (lb/h)			1,428	1,428	1,428	1,428	1,428	1,428	1,428	
CO2 (lb/h)			702	702	702	702	702	702	702	
H2O (lb/h)	4,080	504	2,339	2,339	2,339	2,339	2,339	2,339	2,339	706
CH4 (lb/h)			299	299	299	299	299	299	299	
H2S (lb/h)			3.58	3.58	3.58	3.58	3.58	3.58	3.58	
SO2 (lb/h)										
NH3 (lb/h)			7.88	7.88	7.88	7.88	7.88	7.88	7.88	
COS (lb/h)										
Tar - C10H8 (lb/h)			66.2	66.2	66.2	66.2	66.2	66.2	66.2	
C2H2 (lb/h)			10.1	10.1	10.1	10.1	10.1	10.1	10.1	
C2H4 (lb/h)			152	152	152	152	152	152	152	
C2H6 (lb/h)			19.2	19.2	19.2	19.2	19.2	19.2	19.2	
Sand (lb/h)			82,807							
Char (lb/h)			3,123							
Wood (lb/h)	4,080	4,080								
Ash (lb/h)										
Total (lb/h)	8,160	4,584	91,057	5,127	5,127	5,127	5,127	5,127	5,127	706
O2 (mol. frac.)										
N2 (mol. frac.)										
H2 (mol. frac.)			0.183	0.183	0.183	0.183	0.183	0.183	0.183	
CO (mol. frac.)			0.187	0.187	0.187	0.187	0.187	0.187	0.187	
CO2 (mol. frac.)			0.059	0.059	0.059	0.059	0.059	0.059	0.059	
H2O (mol. frac.)			0.476	0.476	0.476	0.476	0.476	0.476	0.476	
CH4 (mol. frac.)			0.068	0.068	0.068	0.068	0.068	0.068	0.068	
H2S (mol. frac.)			3.85E-4	3.85E-4	3.85E-4	3.85E-4	3.85E-4	3.85E-4	3.85E-4	
SO2 (mol. frac.)										
NH3 (mol. frac.)			0.002	0.002	0.002	0.002	0.002	0.002	0.002	
COS (mol. frac.)										
Tar - C10H8 (mol. frac.)			0.002	0.002	0.002	0.002	0.002	0.002	0.002	
C2H2 (mol. frac.)			0.001	0.001	0.001	0.001	0.001	0.001	0.001	
C2H4 (mol. frac.)			0.020	0.020	0.020	0.020	0.020	0.020	0.020	
C2H6 (mol. frac.)			0.002	0.002	0.002	0.002	0.002	0.002	0.002	

Table B1 - Stream Table for Stand-Alone Gasifier/PAFC Design (English Units)										
Steam #	10	11	12	13	14	15	16	17	18	19
	242	380	1235	1562	1562	698	920	392	496	210
Pressure (psia)	25	24.6	24.1	23.5	21.7	21.2	19.8	19.4	17	16.5
O2 (lb/h)										
N2 (lb/h)					5.43	5.43	5.43	5.43	5.43	5.43
H2 (lb/h)		84.4	84.4	84.4	279	279	353	353	377	377
CO (lb/h)		1,200	1,200	1,200	1,467	1,467	440	440	110	110
CO2 (lb/h)		591	591	591	1,525	1,525	3,139	3,139	3,657	3,657
H2O (lb/h)	706	2,672	2,672	2,672	1,735	1,735	1,074	1,074	862	862
CH4 (lb/h)		251	251	251	1.23	1.23	1.23	1.23	1.23	1.23
H2S (lb/h)		3.01	3.01	3.01	2.96	2.96	2.96	2.96	2.96	2.96
SO2 (lb/h)										
NH3 (lb/h)		6.62	6.62	6.62	.02	.02	.02	.02	.02	.02
COS (lb/h)					.09	.09	.09	.09	.09	.09
Tar - C10H8 (lb/h)		55.6	55.6	55.6						
C2H2 (lb/h)		8.49	8.49	8.49						
C2H4 (lb/h)		128	128	128						
C2H6 (lb/h)		16.1	16.1	16.1						
Sand (lb/h)										
Char (lb/h)										
Wood (lb/h)										
Ash (lb/h)										
Total (lb/h)	706	5,016	5,016	5,016	5,016	5,016	5,016	5,016	5,016	5,016
O2 (mol. frac.)										
N2 (mol. frac.)					6.02E-4	6.02E-4	6.02E-4	6.02E-4	6.02E-4	6.02E-4
H2 (mol. frac.)		0.156	0.156	0.156	0.430	0.430	0.544	0.544	0.580	0.580
CO (mol. frac.)		0.160	0.160	0.160	0.163	0.163	0.049	0.049	0.012	0.012
CO2 (mol. frac.)		0.045	0.045	0.045	0.108	0.108	0.221	0.221	0.258	0.258
H2O (mol. frac.)		0.553	0.553	0.553	0.299	0.299	0.185	0.185	0.149	0.149
CH4 (mol. frac.)		0.058	0.058	0.058	2.37E-4	2.37E-4	2.37E-4	2.37E-4	2.37E-4	2.37E-4
H2S (mol. frac.)		3.29E-4	3.29E-4	3.29E-4	2.69E-4	2.69E-4	2.69E-4	2.69E-4	2.69E-4	2.69E-4
SO2 (mol. frac.)										
NH3 (mol. frac.)		0.001	0.001	0.001	3.10E-6	3.10E-6	3.10E-6	3.10E-6	3.10E-6	3.10E-6
COS (mol. frac.)					4.75E-6	4.75E-6	4.75E-6	4.75E-6	4.75E-6	4.75E-6
Tar - C10H8 (mol. frac.)										
C2H2 (mol. frac.)		0.001	0.001	0.001						
C2H4 (mol. frac.)		0.017	0.017	0.017						
C2H6 (mol. frac.)		0.002	0.002	0.002						

Table B1 - Stream Table for Stand-Alone Gasifier/PAFC Design (English Units) - Continued										
Steam #	20	21	22	23	24	25	26	27	28	29
Temp. (°F)	210	380	321	59	107	300	2584	1409	1010	442
Pressure (psia)	16.5	22.7	17.9	14.7	18.5	17.9	17.8	17.2	16.7	16.1
O2 (lb/h)			977	977	977	977	395	395	395	395
N2 (lb/h)	5.43		3,225	3,225	3,225	3,225	3,226	3,226	3,226	3,226
H2 (lb/h)	377	16.	16.							
CO (lb/h)	110	228	228							
CO2 (lb/h)	3,657	112	114	2.14	2.14	2.14	731	731	731	731
H2O (lb/h)	862	374	400	26.9	26.9	26.9	697	697	697	697
CH4 (lb/h)	1.23	47.7	47.7							
H2S (lb/h)	2.96	.57	.57							
SO2 (lb/h)							1.07	1.07	1.07	1.07
NH3 (lb/h)	.02	1.26	1.26							
COS (lb/h)	.09									
Tar - C10H8 (lb/h)		10.6	10.6							
C2H2 (lb/h)		1.61	1.61							
C2H4 (lb/h)		24.3	24.3							
C2H6 (lb/h)		3.07	3.07							
Sand (lb/h)										
Char (lb/h)										
Wood (lb/h)										
Ash (lb/h)										
Total (lb/h)	5,016	819	5,049	4,231	4,231	4,231	5,050	5,050	5,050	5,050
O2 (mol. frac.)			0.160	0.207	0.207	0.207	0.068	0.068	0.068	0.068
N2 (mol. frac.)	6.02E-4		0.604	0.782	0.782	0.782	0.630	0.630	0.630	0.630
H2 (mol. frac.)	0.580	0.183	0.042							
CO (mol. frac.)	0.012	0.187	0.043							
CO2 (mol. frac.)	0.258	0.059	0.014	3.30E-4	3.30E-4	3.30E-4	0.091	0.091	0.091	0.091
H2O (mol. frac.)	0.149	0.476	0.117	0.010	0.010	0.010	0.212	0.212	0.212	0.212
CH4 (mol. frac.)	2.37E-4	0.068	0.016							
H2S (mol. frac.)	2.69E-4	3.85E-4	8.79E-5							
SO2 (mol. frac.)							9.17E-5	9.17E-5	9.17E-5	9.17E-5
NH3 (mol. frac.)	3.10E-6	0.002	3.87E-4							
COS (mol. frac.)	4.75E-6									
Tar - C10H8 (mol. frac.)		0.002	4.32E-4							
C2H2 (mol. frac.)		0.001	3.25E-4							
C2H4 (mol. frac.)		0.020	4.54E-4							
C2H6 (mol. frac.)		0.002	5.35E-4							

Table B1 - Stream Table for Stand-Alone Gasifier/PAFC Design (English Units) - Continued										
Steam #	30	31	32	33	34	35	36	37	38	39
Temp. (°F)	300	59	242	1000	59	1770	1482	1800	1800	1800
Pressure (psia)	15.6	25	25	25	14.7	25	25	25	24.5	14.7
O2 (lb/h)	395							998		
N2 (lb/h)	3,226							10,359		
H2 (lb/h)										
CO (lb/h)										
CO2 (lb/h)	731							3,052		
H2O (lb/h)	697	1,825	1,825	1,825	10.	10.		432		
CH4 (lb/h)										
H2S (lb/h)										
SO2 (lb/h)	1.07							.61		
NH3 (lb/h)										
COS (lb/h)										
Tar - C10H8 (lb/h)										
C2H2 (lb/h)										
C2H4 (lb/h)										
C2H6 (lb/h)										
Sand (lb/h)					1,656	82,807	82,807	82,807	82,807	1,656
Char (lb/h)							3,123			
Wood (lb/h)										
Ash (lb/h)						1,832		1,869	1,869	37.
Total (lb/h)	5,050	1,825	1,825	1,825	1,666	84,649	85,930	99,518	84,676	1,693
O2 (mol. frac.)	0.068							0.063		
N2 (mol. frac.)	0.630							0.748		
H2 (mol. frac.)										
CO (mol. frac.)										
CO2 (mol. frac.)	0.091							0.140		
H2O (mol. frac.)	0.212							0.049		
CH4 (mol. frac.)										
H2S (mol. frac.)										
SO2 (mol. frac.)	9.17E-5							1.92E-5		
NH3 (mol. frac.)										
COS (mol. frac.)										
Tar - C10H8 (mol. frac.)										
C2H2 (mol. frac.)										
C2H4 (mol. Frac.)										
C2H6 (mol. Frac.)										

Table B1 - Stream Table for Stand-Alone Gasifier/PAFC Design (English Units) - Continued										
Steam #	40	41	42	43	44	45	46	47	48	49
Temp. (°F)	1800	59	182	325	1800	1693	220	59	71	450
Pressure (psia)	24.5	14.7	25.6	25	24.5	23.9	14.7	14.7	15.6	15.6
O2 (lb/h)		3,137	3,137	3,137	998	998	13,623	12,230	12,230	13,623
N2 (lb/h)		10,359	10,359	10,359	10,359	10,359	53,978	40,392	40,392	53,978
H2 (lb/h)										
CO (lb/h)										
CO2 (lb/h)		6.87	6.87	6.87	3,052	3,052	3,810	26.8	26.8	3,810
H2O (lb/h)		86.4	86.4	86.4	432	432	5,042	337	337	1,466
CH4 (lb/h)										
H2S (lb/h)										
SO2 (lb/h)					.61	.61	1.68			1.68
NH3 (lb/h)										
COS (lb/h)										
Tar - C10H8 (lb/h)										
C2H2 (lb/h)										
C2H4 (lb/h)										
C2H6 (lb/h)										
Sand (lb/h)	81,151									
Char (lb/h)										
Wood (lb/h)										
Ash (lb/h)	1,832									
Total (lb/h)	82,983	13,589	13,589	13,589	14,842	14,842	76,455	52,986	52,986	72,879
O2 (mol. frac.)		0.207	0.207	0.207	0.063	0.063	0.157	0.207	0.207	0.169
N2 (mol. frac.)		0.782	0.782	0.782	0.748	0.748	0.709	0.782	0.782	0.764
H2 (mol. frac.)										
CO (mol. frac.)										
CO2 (mol. frac.)		3.30E-4	3.30E-4	3.30E-4	0.140	0.140	0.032	3.30E-4	3.30E-4	0.034
H2O (mol. frac.)		0.010	0.010	0.010	0.049	0.049	0.103	0.010	0.010	0.032
CH4 (mol. frac.)										
H2S (mol. frac.)										
SO2 (mol. frac.)					1.92E-5	1.92E-5	9.67E-6			1.04E-5
NH3 (mol. frac.)										
COS (mol. frac.)										
Tar - C10H8 (mol. frac.)										
C2H2 (mol. frac.)										
C2H4 (mol. frac.)										
C2H6 (mol. frac.)										

Table B1 - Stream Table for Stand-Alone Gasifier/PAFC Design (English Units) - Continued											
Steam #	50	51	52	53	54	55	56	57	58	59	60
Temp. (°F)	220	223	59	90	400	400	983	800	1181	800	300
Pressure (psia)	15.2	14.7	14.7	17	16.7	16.7	16.1	16.1	15.8	15.2	14.7
O2 (lb/h)	13,623	13,623	6,198	6,198		3,756	3,756	3,756	3,198	3,198	3,198
N2 (lb/h)	53,978	53,978	20,469	20,469	5.43	20,469	20,469	20,474	20,474	20,474	20,474
H2 (lb/h)					76.9			76.9	7.69	7.69	7.69
CO (lb/h)											
CO2 (lb/h)	3,810	3,810	13.6	13.6	3,830	13.6	13.6	3,844	3,847	3,847	3,847
H2O (lb/h)	5,042	5,042	171	171	3,541	171	171	3,711	4,334	4,334	4,334
CH4 (lb/h)					1.23			1.23	.01	.01	.01
H2S (lb/h)					2.96			2.96			
SO2 (lb/h)	1.68	1.68							5.56	5.56	5.56
NH3 (lb/h)					.02			.02			
COS (lb/h)					.09			.09	.09	.09	.09
Tar - C10H8 (lb/h)											
C2H2 (lb/h)											
C2H4 (lb/h)											
C2H6 (lb/h)											
Sand (lb/h)											
Char (lb/h)											
Wood (lb/h)											
Ash (lb/h)											
Total (lb/h)	76,455	76,455	26,852	26,852	7,458	24,410	24,410	31,866	31,866	31,866	31,866
O2 (mol. frac.)	0.157	0.157	0.207	0.207		0.137	0.137	0.100	0.086	0.086	0.086
N2 (mol. frac.)	0.709	0.709	0.782	0.782	6.02E-4	0.852	0.852	0.619	0.629	0.629	0.629
H2 (mol. frac.)					0.118			0.032	0.003	0.003	0.003
CO (mol. frac.)											
CO2 (mol. frac.)	0.032	0.032	3.30E-4	3.30E-4	0.270	3.59E-4	3.59E-4	0.074	0.075	0.075	0.075
H2O (mol. frac.)	0.010	0.010	0.010	0.010	0.610	0.011	0.011	0.175	0.207	0.207	0.207
CH4 (mol. frac.)					2.37E-4			6.47E-5	6.57E-6	6.57E-6	6.57E-6
H2S (mol. frac.)					2.69E-4			7.35E-5			
SO2 (mol. frac.)	9.67E-5	9.67E-5							7.46E-5	7.46E-5	7.46E-5
NH3 (mol. frac.)					3.10E-6			8.47E-7			
COS (mol. frac.)					4.75E-6			1.30E-6	1.32E-6	1.32E-6	1.32E-6
Tar - C10H8 (mol. frac.)											
C2H2 (mol. frac.)											
C2H4 (mol. frac.)											
C2H6 (mol. frac.)											

Table B2 - Stream Table for Stand-Alone Gasifier/PAFC Design (SI Units)										
Steam #	1	1A	2	3	4	5	6	7	8	9
Temp. (K)	288	300	1,079	1,079	944	467	467	480	480	288
Pressure (kPa)	101	101	172	169	165	161	157	170	170	172
O2 (kg/h)										
N2 (kg/h)										
H2 (kg/h)			45.4	45.4	45.4	45.4	45.4	45.4	45.4	
CO (kg/h)			648	648	648	648	648	648	648	
CO2 (kg/h)			318	318	318	318	318	318	318	
H2O (kg/h)	1,851	229	1,061	1,061	1,061	1,061	1,061	1,061	1,061	320
CH4 (kg/h)			136	136	136	136	136	136	136	
H2S (kg/h)			1.62	1.62	1.62	1.62	1.62	1.62	1.62	
SO2 (kg/h)										
NH3 (kg/h)			3.57	3.57	3.57	3.57	3.57	3.57	3.57	
COS (kg/h)										
Tar - C10H8 (kg/h)			30.	30.	30.	30.	30.	30.	30.	
C2H2 (kg/h)			4.58	4.58	4.58	4.58	4.58	4.58	4.58	
C2H4 (kg/h)			68.9	68.9	68.9	68.9	68.9	68.9	68.9	
C2H6 (kg/h)			8.71	8.71	8.71	8.71	8.71	8.71	8.71	
Sand (kg/h)			37,561							
Char (kg/h)			1,417							
Wood (kg/h)	1,851	1,851								
Ash (kg/h)										
Total (kg/h)	3,701	2,079	41,303	2,326	2,326	2,326	2,326	2,326	2,326	320

Table B2 - Stream Table for Stand-Alone Gasifier/PAFC Design (SI Units) - Continued										
Steam #	10	11	12	13	14	15	16	17	18	19
Temp. (K)	390	467	942	1,123	1,123	643	767	473	531	372
Pressure (kPa)	172	170	166	162	150	146	137	134	117	114
O2 (kg/h)										
N2 (kg/h)					2.46	2.46	2.46	2.46	2.46	2.46
H2 (kg/h)		38.3	38.3	38.3	127	127	160	160	171	171
CO (kg/h)		544	544	544	665	665	200	200	49.9	49.9
CO2 (kg/h)		268	268	268	692	692	1,424	1,424	1,659	1,659
H2O (kg/h)	320	1,212	1,212	1,212	787	787	487	487	391	391
CH4 (kg/h)		114	114	114	.56	.56	.56	.56	.56	.56
H2S (kg/h)		1.37	1.37	1.37	1.34	1.34	1.34	1.34	1.34	1.34
SO2 (kg/h)										
NH3 (kg/h)		3.	3.	3.	.01	.01	.01	.01	.01	.01
COS (kg/h)					.04	.04	.04	.04	.04	.04
Tar - C10H8 (kg/h)		25.2	25.2	25.2						
C2H2 (kg/h)		3.85	3.85	3.85						
C2H4 (kg/h)		58.1	58.1	58.1						
C2H6 (kg/h)		7.3	7.3	7.3						
Sand (kg/h)										
Char (kg/h)										
Wood (kg/h)										
Ash (kg/h)										
Total (kg/h)	320	2,275	2,275	2,275	2,275	2,275	2,275	2,275	2,275	2,275

Table B2 - Stream Table for Stand-Alone Gasifier/PAFC Design (SI Units) - Continued										
Steam #	20	21	22	23	24	25	26	27	28	29
Temp. (K)	372	467	434	288	315	422	1,691	1,038	817	501
Pressure (kPa)	114	157	123	101	128	123	123	119	115	111
O2 (kg/h)			443	443	443	443	179	179	179	179
N2 (kg/h)	2.46		1,463	1,463	1,463	1,463	1,463	1,463	1,463	1,463
H2 (kg/h)	171	7.26	7.26							
CO (kg/h)	49.9	103	103							
CO2 (kg/h)	1,659	50.8	51.7	.97	.97	.97	332	332	332	332
H2O (kg/h)	391	170	181	12.2	12.2	12.2	316	316	316	316
CH4 (kg/h)	.56	21.6	21.6							
H2S (kg/h)	1.34	.26	.26							
SO2 (kg/h)							.49	.49	.49	.49
NH3 (kg/h)	.01	.57	.57							
COS (kg/h)	.04									
Tar - C10H8 (kg/h)		4.81	4.81							
C2H2 (kg/h)		.73	.73							
C2H4 (kg/h)		11.	11.							
C2H6 (kg/h)		1.39	1.39							
Sand (kg/h)										
Char (kg/h)										
Wood (kg/h)										
Ash (kg/h)										
Total (kg/h)	2,275	372	2,290	1,919	1,919	1,919	2,291	2,291	2,291	2,291

Table B2 - Stream Table for Stand-Alone Gasifier/PAFC Design (SI Units) - Continued										
Steam #	30	31	32	33	34	35	36	37	38	39
Temp. (K)	422	288	390	811	288	1,239	1,079	1,256	1,256	1,256
Pressure (kPa)	108	172	172	172	101	172	172	172	169	101
O2 (kg/h)	179							453		
N2 (kg/h)	1,463							4,699		
H2 (kg/h)										
CO (kg/h)										
CO2 (kg/h)	332							1,384		
H2O (kg/h)	316	828	828	828	4.54	4.54		196		
CH4 (kg/h)										
H2S (kg/h)										
SO2 (kg/h)	.49							.28		
NH3 (kg/h)										
COS (kg/h)										
Tar - C10H8 (kg/h)										
C2H2 (kg/h)										
C2H4 (kg/h)										
C2H6 (kg/h)										
Sand (kg/h)					751	37,561	37,561	37,561	37,561	751
Char (kg/h)							1,417			
Wood (kg/h)										
Ash (kg/h)						831		848	848	16.8
Total (kg/h)	2,291	828	828	828	756	38,396	38,977	45,140	38,408	768

Table B2 - Stream Table for Stand-Alone Gasifier/PAFC Design (SI Units) - Continued										
Steam #	40	41	14	43	44	45	46	47	48	49
Temp. (K)	1,256	288	357	436	1,256	1,196	378	288	295	506
Pressure (kPa)	169	101	177	172	169	165	101	101	108	108
O2 (kg/h)		1,423	1,423	1,423	453	453	6,179	5,547	5,547	6,179
N2 (kg/h)		4,699	4,699	4,699	4,699	4,699	24,484	18,321	18,321	24,484
H2 (kg/h)										
CO (kg/h)										
CO2 (kg/h)		3.12	3.12	3.12	1,384	1,384	1,728	12.2	12.2	1,728
H2O (kg/h)		39.2	39.2	39.2	196	196	2,287	153	153	665
CH4 (kg/h)										
H2S (kg/h)										
SO2 (kg/h)					.28	.28	.76			.76
NH3 (kg/h)										
COS (kg/h)										
Tar - C10H8 (kg/h)										
C2H2 (kg/h)										
C2H4 (kg/h)										
C2H6 (kg/h)										
Sand (kg/h)	36,809									
Char (kg/h)										
Wood (kg/h)										
Ash (kg/h)	831									
Total (kg/h)	37,640	6,164	6,164	6,164	6,732	6,732	34,679	24,034	24,034	33,057

Table B2 - Stream Table for Stand-Alone Gasifier/PAFC Design (SI Units) - Continued											
Steam #	50	51	52	53	54	55	56	57	58	59	60
Temp. (K)	378	379	288	306	478	478	802	700	912	700	422
Pressure (kPa)	105	101	101	117	115	115	111	111	109	105	101
O2 (kg/h)	6,179	6,179	2,811	2,811		1,704	1,704	1,704	1,451	1,451	1,451
N2 (kg/h)	24,484	24,484	9,285	9,285	2.46	9,285	9,285	9,287	9,287	9,287	9,287
H2 (kg/h)					34.9			34.9	3.49	3.49	3.49
CO (kg/h)											
CO2 (kg/h)	1,728	1,728	6.17	6.17	1,737	6.17	6.17	1,744	1,745	1,745	1,745
H2O (kg/h)	2,287	2,287	77.6	77.6	1,606	77.6	77.6	1,683	1,966	1,966	1,966
CH4 (kg/h)					.56			.56	.01	.01	.01
H2S (kg/h)					1.34			1.34			
SO2 (kg/h)	.76	.76							2.52	2.52	2.52
NH3 (kg/h)					.01			.01			
COS (kg/h)					.04			.04	.04	.04	.04
Tar - C10H8 (kg/h)											
C2H2 (kg/h)											
C2H4 (kg/h)											
C2H6 (kg/h)											
Sand (kg/h)											
Char (kg/h)											
Wood (kg/h)											
Ash (kg/h)											
Total (kg/h)	34,679	34,679	12,180	12,180	3,383	11,072	11,072	14,454	14,454	14,454	14,454

Figure B4 - Integrated Gasifier Flowsheet

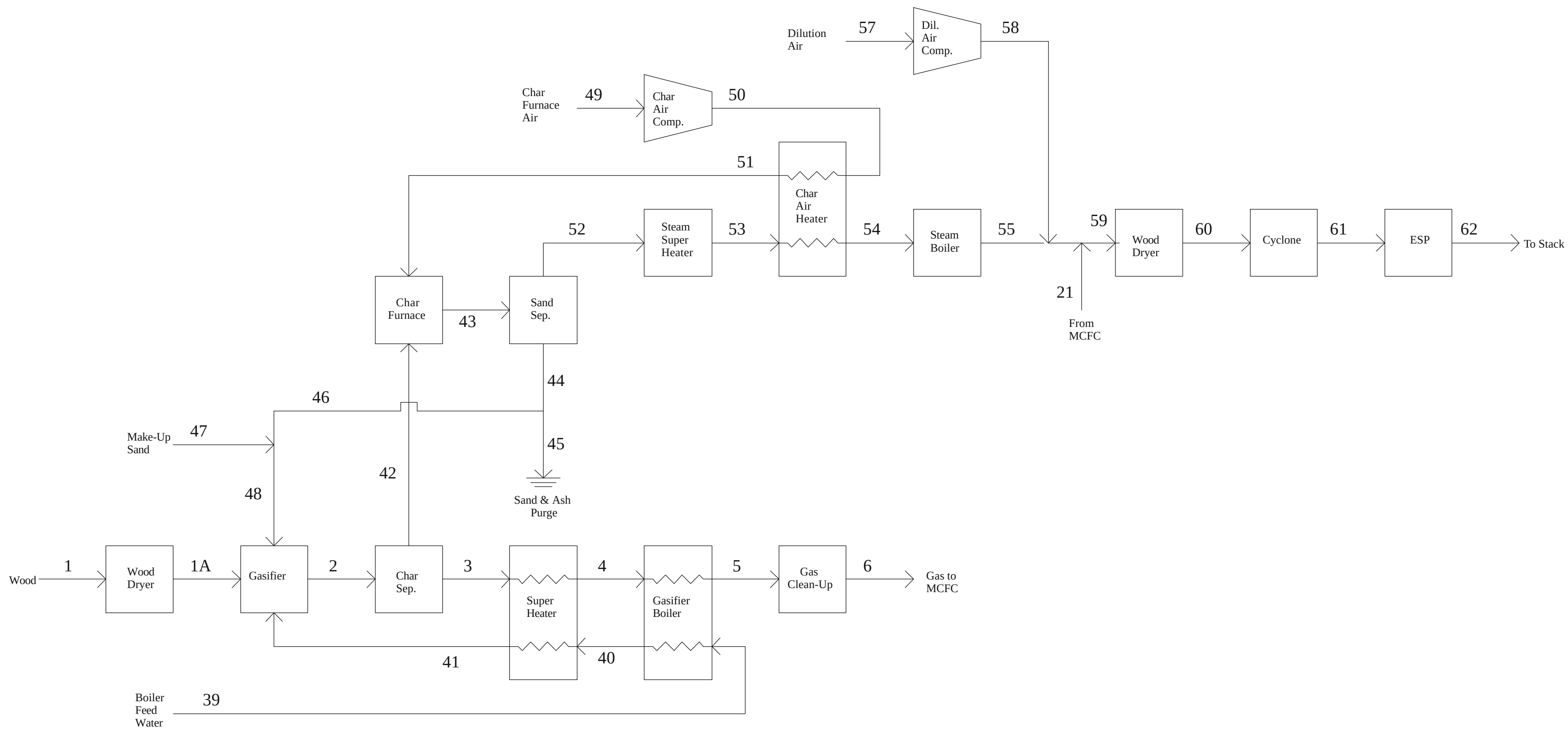

Figure B5 - Integrated MCFC Flowsheet

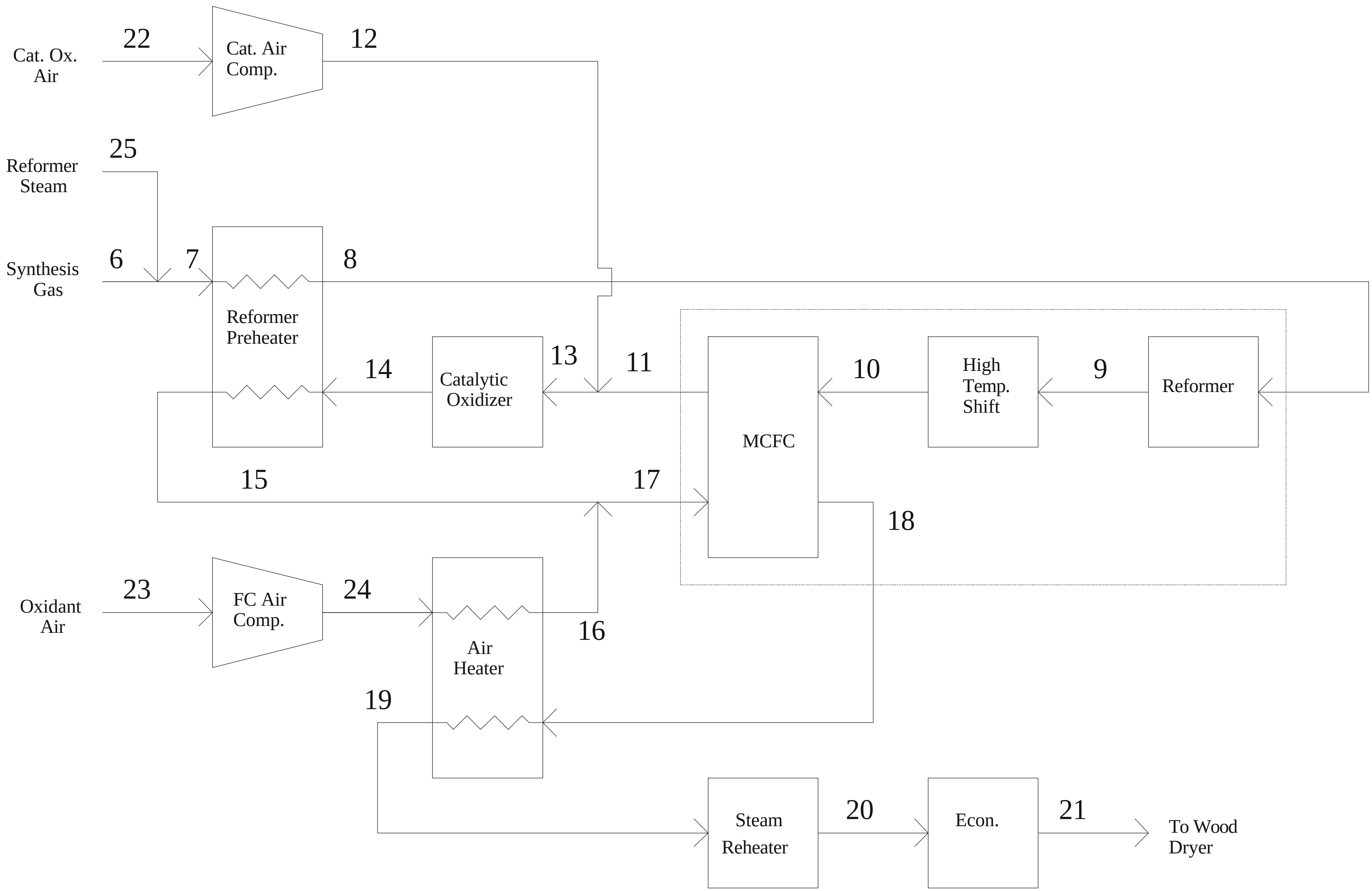

Figure B6 - Integrated Steam Cycle Flowsheet

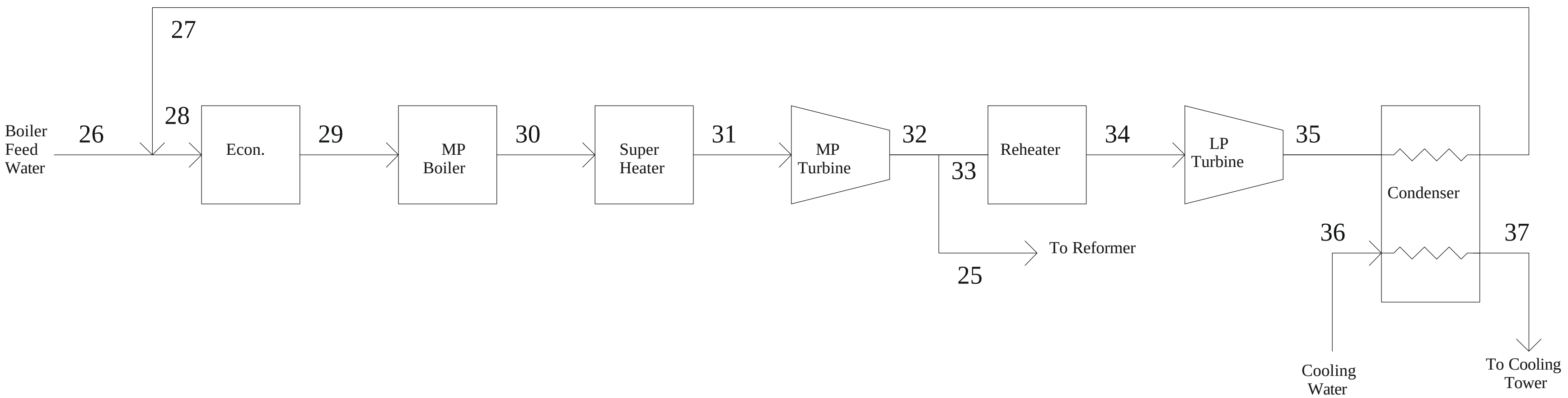

Table B3 - Stream Table for Integrated Gasifier/MCFC Design (English Units)										
Steam #	1	1A	2	3	4	5	6	7	8	9
Temp. (°F)	59	80	1500	1500	1262	413	413	398	1202	1202
Pressure (psia)	14.7	14.7	25	24.5	23.9	23.4	23.4	22.7	22.1	21.7
O2 (lb/h)										
N2 (lb/h)										6.42
H2 (lb/h)			99.2	99.2	99.2	99.2	99.2	99.2	99.2	309
CO (lb/h)			1,465	1,465	1,465	1,465	1,465	1,465	1,465	1,044
CO2 (lb/h)			720	720	720	720	720	720	720	2,586
H2O (lb/h)	4,080	504	2,339	2,339	2,339	2,339	2,339	3,265	3,265	2,007
CH4 (lb/h)			307	307	307	307	307	307	307	161
H2S (lb/h)			3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.54
SO2 (lb/h)										
NH3 (lb/h)			7.88	7.88	7.88	7.88	7.88	7.88	7.88	.07
COS (lb/h)										.08
Tar - C10H8 (lb/h)			64.7	64.7	64.7	64.7	64.7	64.7	64.7	
C2H2 (lb/h)			10.9	10.9	10.9	10.9	10.9	10.9	10.9	
C2H4 (lb/h)			157	157	157	157	157	157	157	
C2H6 (lb/h)			18.2	18.2	18.2	18.2	18.2	18.2	18.2	
Sand (lb/h)			87,926							
Char (lb/h)			3,060							
Wood (lb/h)	4,080	4,080								
Ash (lb/h)										
Total (lb/h)	8,160	4,584	96,178	5,192	5,192	5,192	5,192	6,118	6,118	6,117
O2 (mol. frac.)										
N2 (mol. frac.)										6.18E-4
H2 (mol. frac.)			0.179	0.179	0.179	0.179	0.179	0.151	0.151	0.413
CO (mol. frac.)			0.190	0.190	0.190	0.190	0.190	0.160	0.160	0.100
CO2 (mol. frac.)			0.060	0.060	0.060	0.060	0.060	0.050	0.050	0.158
H2O (mol. frac.)			0.473	0.473	0.473	0.473	0.473	0.556	0.556	0.300
CH4 (mol. frac.)			0.070	0.070	0.070	0.070	0.070	0.059	0.059	0.027
H2S (mol. frac.)			3.83E-4	3.83E-4	3.83E-4	3.83E-4	3.83E-4	3.22E-4	3.22E-4	2.79E-4
SO2 (mol. frac.)										
NH3 (mol. frac.)			0.002	0.002	0.002	0.002	0.002	0.001	0.001	1.09E-5
COS (mol. frac.)										3.47E-6
Tar - C10H8 (mol. frac.)			0.002	0.002	0.002	0.002	0.002	0.002	0.002	
C2H2 (mol. frac.)			0.002	0.002	0.002	0.002	0.002	0.001	0.001	
C2H4 (mol. frac.)			0.020	0.020	0.020	0.020	0.020	0.017	0.017	
C2H6 (mol. frac.)			0.002	0.002	0.002	0.002	0.002	0.002	0.002	

Table B3 - Stream Table for Integrated Gasifier/MCFC Design (English Units) - Continued										
Steam #	10	11	12	13	14	15	16	17	18	19
Temp. (°F)	1202	1202	108	947	1568	1287	1054	1202	1202	762
Pressure (psia)	21.4	18.5	18.5	18.5	18.1	17.6	17.6	17.6	17.2	16.7
O2 (lb/h)			1,707	1,707	963	963	4,061	5,025	2,070	2,070
N2 (lb/h)	6.42	6.48	5,637	5,463	5,643	5,643	13,413	19,057	19,057	19,057
H2 (lb/h)	362	60.9		60.9						
CO (lb/h)	313	446		446						
CO2 (lb/h)	3,734	12,094	3.74	12,097	12,798	12,798	8.89	12,807	4,681	4,681
H2O (lb/h)	1,537	4,587	47.	4,634	5,181	5,181	112	5,293	5,293	5,293
CH4 (lb/h)	161	.05		.05						
H2S (lb/h)	3.54	3.49		3.49						
SO2 (lb/h)					6.55	6.55		6.55	6.55	6.55
NH3 (lb/h)	.07									
COS (lb/h)	.08	.16		.16						
Tar - C10H8 (lb/h)										
C2H2 (lb/h)										
C2H4 (lb/h)										
C2H6 (lb/h)										
Sand (lb/h)										
Char (lb/h)										
Wood (lb/h)										
Ash (lb/h)										
Total (lb/h)	6,117	17,198	7,395	24,412	24,592	24,592	17,595	42,189	31,108	31,108
O2 (mol. frac.)			0.207	0.064	0.037	0.037	0.207	0.110	0.057	0.057
N2 (mol. frac.)	6.18E-4	4.01E-5	0.782	0.242	0.249	0.249	0.782	0.478	0.594	0.594
H2 (mol. frac.)	0.484	0.053		0.036						
CO (mol. frac.)	0.030	0.028		0.019						
CO2 (mol. frac.)	0.229	0.477	3.30E-4	0.330	0.359	0.359	3.30E-4	0.205	0.093	0.093
H2O (mol. frac.)	0.230	0.442	0.010	0.309	0.355	0.355	0.010	0.207	0.257	0.257
CH4 (mol. frac.)	0.027	5.25E-6		3.63E-6						
H2S (mol. frac.)	2.79E-4	1.78E-4		1.23E-4						
SO2 (mol. frac.)					1.26E-4	1.26E-4		7.19E-5	8.93E-5	8.93E-5
NH3 (mol. frac.)	1.09E-5									
COS (mol. frac.)	3.47E-6	4.74E-6		3.28E-6						
Tar - C10H8 (mol. frac.)										
C2H2 (mol. frac.)										
C2H4 (mol. frac.)										
C2H6 (mol. frac.)										

Table B3 - Stream Table for Integrated Gasifier/MCFC Design (English Units) - Continued										
Steam #	20	21	22	23	24	25	26	27	28	29
Temp. (°F)	672	507	59	59	108	339	59	144	139	300
Pressure (psia)	16.1	15.6	14.7	14.7	18.4	115	25	25	515	515
O2 (lb/h)	2,070	2,070	1,707	4,061	4,061					
N2 (lb/h)	19,057	19,057	5,637	13,413	13,413					
H2 (lb/h)										
CO (lb/h)										
CO2 (lb/h)	4,681	4,681	3.74	8.89	8.89					
H2O (lb/h)	5,293	5,293	47.	112	112	925	925	7,561	8,487	8,487
CH4 (lb/h)										
H2S (lb/h)										
SO2 (lb/h)	6.55	6.55								
NH3 (lb/h)										
COS (lb/h)										
Tar - C10H8 (lb/h)										
C2H2 (lb/h)										
C2H4 (lb/h)										
C2H6 (lb/h)										
Sand (lb/h)										
Char (lb/h)										
Wood (lb/h)										
Ash (lb/h)										
Total (lb/h)	31,108	31,108	7,395	17,595	17,595	925	925	7,561	8,487	8,487
O2 (mol. frac.)	0.057	0.057	0.207	0.207	0.207					
N2 (mol. frac.)	0.594	0.594	0.782	0.782	0.782					
H2 (mol. frac.)										
CO (mol. frac.)										
CO2 (mol. frac.)	0.093	0.093	3.30E-4	3.30E-4	3.30E-4					
H2O (mol. frac.)	0.257	0.257	0.010	0.010	0.010					
CH4 (mol. frac.)										
H2S (mol. frac.)										
SO2 (mol. frac.)	8.93E-5	8.93E-5								
NH3 (mol. frac.)										
COS (mol. frac.)										
Tar - C10H8 (mol. frac.)										
C2H2 (mol. frac.)										
C2H4 (mol. frac.)										
C2H6 (mol. frac.)										

Table B3 - Stream Table for Integrated Gasifier/MCFC Design (English Units) - Continued									
Steam #	30	31	32	33	34	35	36	37	39
Temp. (°F)	470	619	362	362	589	145	110	125	59
Pressure (psia)	515	515	115	115	115	3	50	50	25
O2 (lb/h)									
N2 (lb/h)									
H2 (lb/h)									
CO (lb/h)									
CO2 (lb/h)									
H2O (lb/h)	8,487	8,487	8,487	7,561	7,561	7,561	520,628	520,628	1,825
CH4 (lb/h)									
H2S (lb/h)									
SO2 (lb/h)									
NH3 (lb/h)									
COS (lb/h)									
Tar - C10H8 (lb/h)									
C2H2 (lb/h)									
C2H4 (lb/h)									
C2H6 (lb/h)									
Sand (lb/h)									
Char (lb/h)									
Wood (lb/h)									
Ash (lb/h)									
Total (lb/h)	8,487	8,487	8,487	7,561	7,561	7,561	520,628	520,628	1,825
O2 (mol. frac.)									
N2 (mol. frac.)									
H2 (mol. frac.)									
CO (mol. frac.)									
CO2 (mol. frac.)									
H2O (mol. frac.)									
CH4 (mol. frac.)									
H2S (mol. frac.)									
SO2 (mol. frac.)									
NH3 (mol. frac.)									
COS (mol. frac.)									
Tar - C10H8 (mol. frac.)									
C2H2 (mol. frac.)									
C2H4 (mol. frac.)									
C2H6 (mol. frac.)									

Table B3 - Stream Table for Integrated Gasifier/MCFC Design (English Units) - Continued

Steam #	40	41	42	43	44	45	46	47	48	49
Temp. (°F)	242	1000	1500	1800	1800	1800	1800	59	1770	59
Pressure (psia)	25	25	24.5	25	24.5	14.7	24.5	14.7	24.5	14.7
O2 (lb/h)				944						3,027
N2 (lb/h)				9,998						9,998
H2 (lb/h)										
CO (lb/h)										
CO2 (lb/h)				2,946						6.63
H2O (lb/h)	1,825	1,825		417				10.	10.	83.4
CH4 (lb/h)										
H2S (lb/h)										
SO2 (lb/h)				.61						
NH3 (lb/h)										
COS (lb/h)										
Tar - C10H8 (lb/h)										
C2H2 (lb/h)										
C2H4 (lb/h)										
C2H6 (lb/h)										
Sand (lb/h)			87,926	87,926	87,926	1,759	86,167	1,759	87,926	
Char (lb/h)			3,060							
Wood (lb/h)										
Ash (lb/h)				1,870	1,870	37.4	1,833		1,833	
Total (lb/h)	1,825	1,825	90,986	104,102	89,796	1,796	88,000	1,769	89,769	13,115
O2 (mol. frac.)				0.062						0.207
N2 (mol. frac.)				0.749						0.782
H2 (mol. frac.)										
CO (mol. frac.)										
CO2 (mol. frac.)				0.140						3.30E-4
H2O (mol. frac.)				0.049						0.010
CH4 (mol. frac.)										
H2S (mol. frac.)										
SO2 (mol. frac.)				2.00E-5						
NH3 (mol. frac.)										
COS (mol. frac.)										
Tar - C10H8 (mol. frac.)										
C2H2 (mol. frac.)										
C2H4 (mol. frac.)										
C2H6 (mol. frac.)										

Table B3 - Stream Table for Integrated Gasifier/MCFC Design (English Units) - Continued									
Steam #	50	51	52	53	54	55	57	58	59
Temp. (°F)	182	400	1800	1639	1472	861	59	71	450
Pressure (psia)	25.6	25	24.5	23.9	23.4	22.8	14.7	15.6	15.6
O2 (lb/h)	3,027	3,027	944	944	944	944	5,099	5,099	8,113
N2 (lb/h)	9,998	9,998	9,998	9,998	9,998	9,998	16,839	16,839	45,894
H2 (lb/h)									
CO (lb/h)									
CO2 (lb/h)	6.63	6.63	2,946	2,946	2,946	2,946	11.2	11.2	7,638
H2O (lb/h)	83.4	83.4	417	417	417	417	141	141	5,850
CH4 (lb/h)									
H2S (lb/h)									
SO2 (lb/h)			.61	.61	.61	.61			7.16
NH3 (lb/h)									
COS (lb/h)									
Tar - C10H8 (lb/h)									
C2H2 (lb/h)									
C2H4 (lb/h)									
C2H6 (lb/h)									
Sand (lb/h)									
Char (lb/h)									
Wood (lb/h)									
Ash (lb/h)									
Total (lb/h)	13,115	13,115	14,306	14,306	14,306	14,306	22,090	22,090	67,502
O2 (mol. frac.)	0.207	0.207	0.062	0.062	0.062	0.062	0.207	0.207	0.106
N2 (mol. frac.)	0.782	0.782	0.749	0.749	0.749	0.749	0.782	0.782	0.685
H2 (mol. frac.)									
CO (mol. frac.)									
CO2 (mol. frac.)	3.30E-4	3.30E-4	0.140	0.140	0.140	0.140	3.30E-4	3.30E-4	0.073
H2O (mol. frac.)	0.010	0.010	0.049	0.049	0.049	0.049	0.010	0.010	0.136
CH4 (mol. frac.)									
H2S (mol. frac.)									
SO2 (mol. frac.)			2.00E-5	2.00E-5	2.00E-5	2.00E-5			4.68E-5
NH3 (mol. frac.)									
COS (mol. frac.)									
Tar - C10H8 (mol. frac.)									
C2H2 (mol. frac.)									
C2H4 (mol. frac.)									
C2H6 (mol. frac.)									

Table B3 - Stream Table for Integrated Gasifier/MCFC Design (English Units) - Continued							
Steam #	60	61	62				
Temp. (°F)	220	220	220				
Pressure (psia)	15.2	14.7	14.7				
O2 (lb/h)	8,113	8,113	8,113				
N2 (lb/h)	45,894	45,894	45,894				
H2 (lb/h)							
CO (lb/h)							
CO2 (lb/h)	7,638	7,638	7,638				
H2O (lb/h)	9,427	9,427	9,427				
CH4 (lb/h)							
H2S (lb/h)							
SO2 (lb/h)	7.16	7.16	7.16				
NH3 (lb/h)							
COS (lb/h)							
Tar - C10H8 (lb/h)							
C2H2 (lb/h)							
C2H4 (lb/h)							
C2H6 (lb/h)							
Sand (lb/h)							
Char (lb/h)							
Wood (lb/h)							
Ash (lb/h)							
Total (lb/h)	71,079	71,079	71,079				
O2 (mol. frac.)	0.098	0.098	0.098				
N2 (mol. frac.)	0.633	0.633	0.633				
H2 (mol. frac.)							
CO (mol. frac.)							
CO2 (mol. frac.)	0.067	0.067					0.067
H2O (mol. frac.)	0.202	0.202					0.202
CH4 (mol. frac.)							
H2S (mol. frac.)							
SO2 (mol. frac.)	4.32E-5	4.32E-5					4.32E-5
NH3 (mol. frac.)							
COS (mol. frac.)							
Tar - C10H8 (mol. frac.)							
C2H2 (mol. frac.)							
C2H4 (mol. frac.)							
C2H6 (mol. frac.)							

Table B4 - Stream Table for Integrated Gasifier/MCFC Design (SI Units)										
Steam #	1	1A	2	3	4	5	6	7	8	9
Temp. (K)	288	300	1,089	1,089	957	485	485	477	923	923
Pressure (kPa)	101	101	172	169	165	161	161	157	152	150
O2 (kg/h)										
N2 (kg/h)										2.91
H2 (kg/h)			45.	45.	45.	45.	45.	45.	45.	140
CO (kg/h)			665	665	665	665	665	665	665	474
CO2 (kg/h)			327	327	327	327	327	327	327	1,173
H2O (kg/h)	1,851	229	1,061	1,061	1,061	1,061	1,061	1,481	1,481	910
CH4 (kg/h)			139	139	139	139	139	139	139	73.
H2S (kg/h)			1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.61
SO2 (kg/h)										
NH3 (kg/h)			3.57	3.57	3.57	3.57	3.57	3.57	3.57	.03
COS (kg/h)										.04
Tar - C10H8 (kg/h)			29.3	29.3	29.3	29.3	29.3	29.3	29.3	
C2H2 (kg/h)			4.94	4.94	4.94	4.94	4.94	4.94	4.94	
C2H4 (kg/h)			71.2	71.2	71.2	71.2	71.2	71.2	71.2	
C2H6 (kg/h)			8.26	8.26	8.26	8.26	8.26	8.26	8.26	
Sand (kg/h)			39,883							
Char (kg/h)			1,388							
Wood (kg/h)	1,851	1,851								
Ash (kg/h)										
Total (kg/h)	3,701	2,079	43,626	2,355	2,355	2,355	2,355	2,775	2,775	2,775

Table B4 - Stream Table for Integrated Gasifier/MCFC Design (SI Units) - Continued										
Steam #	10	11	12	13	14	15	16	17	18	19
Temp. (K)	923	923	316	782	1,127	971	841	923	923	679
Pressure (kPa)	148	128	128	128	125	121	121	121	119	115
O2 (kg/h)			774	774	437	437	1,842	2,279	939	939
N2 (kg/h)	2.91	2.94	2,557	2,478	2,560	2,560	6,084	8,644	8,644	8,644
H2 (kg/h)	164	27.6		27.6						
CO (kg/h)	142	202		202						
CO2 (kg/h)	1,694	5,486	1.7	5,487	5,805	5,805	4.03	5,809	2,123	2,123
H2O (kg/h)	697	2,081	21.3	2,102	2,350	2,350	50.8	2,401	2,401	2,401
CH4 (kg/h)	73.	.02		.02						
H2S (kg/h)	1.61	1.58		1.58						
SO2 (kg/h)					2.97	2.97		2.97	2.97	2.97
NH3 (kg/h)	.03									
COS (kg/h)	.04	.07		.07						
Tar - C10H8 (kg/h)										
C2H2 (kg/h)										
C2H4 (kg/h)										
C2H6 (kg/h)										
Sand (kg/h)										
Char (kg/h)										
Wood (kg/h)										
Ash (kg/h)										
Total (kg/h)	2,775	7,801	3,354	11,073	11,155	11,155	7,981	19,136	14,110	14,110

Table B4 - Stream Table for Integrated Gasifier/MCFC Design (SI Units) - Continued

Steam #	20	21	22	23	24	25	26	27	28	29
Temp. (K)	629	537	288	288	316	444	288	336	333	422
Pressure (kPa)	111	108	101	101	127	793	172	172	3,551	3,551
O2 (kg/h)	939	939	774	1,842	1,842					
N2 (kg/h)	8,644	8,644	2,557	6,084	6,084					
H2 (kg/h)										
CO (kg/h)										
CO2 (kg/h)	2,123	2,123	1.7	4.03	4.03					
H2O (kg/h)	2,401	2,401	21.3	50.8	50.8	420	420	3,430	3,850	3,850
CH4 (kg/h)										
H2S (kg/h)										
SO2 (kg/h)	2.97	2.97								
NH3 (kg/h)										
COS (kg/h)										
Tar - C10H8 (kg/h)										
C2H2 (kg/h)										
C2H4 (kg/h)										
C2H6 (kg/h)										
Sand (kg/h)										
Char (kg/h)										
Wood (kg/h)										
Ash (kg/h)										
Total (kg/h)	14,110	14,110	3,354	7,981	7,981	420	420	3,430	3,850	3,850

Table B4 - Stream Table for Integrated Gasifier/MCFC Design (SI Units) - Continued									
Steam #	30	31	32	33	34	35	36	37	39
Temp. (K)	517	599	457	457	583	336	317	325	288
Pressure (kPa)	3,551	3,551	793	793	793	21	345	345	172
O2 (kg/h)									
N2 (kg/h)									
H2 (kg/h)									
CO (kg/h)									
CO2 (kg/h)									
H2O (kg/h)	3,850	3,850	3,850	3,430	3,430	3,430	236,153	236,153	828
CH4 (kg/h)									
H2S (kg/h)									
SO2 (kg/h)									
NH3 (kg/h)									
COS (kg/h)									
Tar - C10H8 (kg/h)									
C2H2 (kg/h)									
C2H4 (kg/h)									
C2H6 (kg/h)									
Sand (kg/h)									
Char (kg/h)									
Wood (kg/h)									
Ash (kg/h)									
Total (kg/h)	3,850	3,850	3,850	3,430	3,430	3,430	236,153	236,153	828

Table B4 - Stream Table for Integrated Gasifier/MCFC Design (SI Units) - Continued										
Steam #	40	41	42	43	44	45	46	47	48	49
Temp. (K)	390	811	1,089	1,256	1,256	1,256	1,256	288	1,239	288
Pressure (kPa)	172	172	169	172	169	101	169	101	169	101
O2 (kg/h)				428						1,373
N2 (kg/h)				4,535						4,535
H2 (kg/h)										
CO (kg/h)										
CO2 (kg/h)				1,336						3.01
H2O (kg/h)	828	828		189				4.54	4.54	37.8
CH4 (kg/h)										
H2S (kg/h)										
SO2 (kg/h)				.28						
NH3 (kg/h)										
COS (kg/h)										
Tar - C10H8 (kg/h)										
C2H2 (kg/h)										
C2H4 (kg/h)										
C2H6 (kg/h)										
Sand (kg/h)			39,883	39,883	39,883	798	39,085	798	39,883	
Char (kg/h)			1,388							
Wood (kg/h)										
Ash (kg/h)				848	848	17.	831		831	
Total (kg/h)	828	828	41,271	47,220	40,731	815	39,916	802	40,719	5,949

Table B4 - Stream Table for Integrated Gasifier/MCFC Design (SI Units) - Continued									
Steam #	50	51	52	53	54	55	57	58	59
Temp. (K)	357	478	1,256	1,166	1,073	734	288	295	506
Pressure (kPa)	177	172	169	165	161	157	101	108	108
O2 (kg/h)	1,373	1,373	428	428	428	428	2,313	2,313	3,680
N2 (kg/h)	4,535	4,535	4,535	4,535	4,535	4,535	7,638	7,638	20,817
H2 (kg/h)									
CO (kg/h)									
CO2 (kg/h)	3.01	3.01	1,336	1,336	1,336	1,336	5.08	5.08	3,465
H2O (kg/h)	37.8	37.8	189	189	189	189	64.	64.	2,654
CH4 (kg/h)									
H2S (kg/h)									
SO2 (kg/h)			.28	.28	.28	.28			3.25
NH3 (kg/h)									
COS (kg/h)									
Tar - C10H8 (kg/h)									
C2H2 (kg/h)									
C2H4 (kg/h)									
C2H6 (kg/h)									
Sand (kg/h)									
Char (kg/h)									
Wood (kg/h)									
Ash (kg/h)									
Total (kg/h)	5,949	5,949	6,489	6,489	6,489	6,489	10,020	10,020	30,618

Table B4 - Stream Table for Integrated Gasifier/MCFC Design (SI Units) - Continued							
Steam #	60	61	62				
Temp. (K)	378	378	378				
Pressure (kPa)	105	101	101				
O2 (kg/h)	3,680	3,680	3,680				
N2 (kg/h)	20,817	20,817	20,817				
H2 (kg/h)							
CO (kg/h)							
CO2 (kg/h)	3,465	3,465	3,465				
H2O (kg/h)	4,276	4,276	4,276				
CH4 (kg/h)							
H2S (kg/h)							
SO2 (kg/h)	3.25	3.25	3.25				
NH3 (kg/h)							
COS (kg/h)							
Tar - C10H8 (kg/h)							
C2H2 (kg/h)							
C2H4 (kg/h)							
C2H6 (kg/h)							
Sand (kg/h)							
Char (kg/h)							
Wood (kg/h)							
Ash (kg/h)							
Total (kg/h)	32,241	32,241	32,241				

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13. ABSTRACT *(Maximum 200 words)* Two scenarios were examined for small-scale electricity production from biomass using a gasifier/fuel cell system. In one case, a stand-alone BCL/FERC gasifier is used to produce synthesis gas that is reformed and distributed through a pipeline network to individual phosphric acid fuel cells. In the second design, the gasifier is integrated with a molten carbonate fuel cell stack and a steam bottoming cycle. In both cases, the gasifiers are fed the same amount of material, with the integrated system producing 4 MW of electricity, and the stand-alone design generating 2 MW of electricity.

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