Economic Assessment of Combustion Technologies for Specified Risk Material Disposal in British Columbia

Stantec

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Funding for this study was provided in part by the Canada–British Columbia Specified Risk Material (SRM) Management Program. The SRM Program is designed to assist the province's beef processing sector in complying with the Canadian Food Inspection Agency's enhanced feed ban.

Agriculture and Agri-food Canada (AAFC) and the B.C. Ministry of Agriculture and Lands (BCMAL) are pleased to partner in the delivery of this program. Both bodies are committed to working with stakeholders to address issues of importance to the agriculture and agri-food industry of British Columbia.

Executive Summary

This report builds on the previous work completed by the B.C. Ministry of Agriculture and Lands in the study of disposal of specified risk material (SRM) and slaughterhouse waste.

The report confirms interest from the supplier community to participate in the development of the technology and processes required to combust this waste resource. Gasification and combustion technologies available are capable and proven for firing biomass. The gasification and combustion of SRM and slaughterhouse waste combined with biomass is, however, a new and relatively unproven process with the exception of European experience firing a processed SRM material in fluidized bed boilers. This material is known as Biomal. Biomal is a processed, non-rendered SRM and slaughterhouse waste material that has been ground to a pumpable consistency.

Information received from suppliers was used to confirm the technology was suitable for gasification and combustion of SRM and slaughterhouse waste material; however, adequate information was not received for a thorough economic analysis. Published economic information on the gasification and combustion of biomass was used for the economic analysis. This information was adequate to determine the relative economic ranking of these technologies. The comparison of the technologies has shown in general that as the unit size increases the cost per unit output decreases. This was found to be the case for each of the technologies studied.

The analysis of each fuel scenario was broken down into two classes. These are the combined production of power and heat and the production of heat only. The heat and power class primarily focuses on power output and handles the surplus heat remaining after power production as a beneficial byproduct of the process. The value of the produced electrical power was assumed to be equivalent to the rate paid by BC Hydro to power producers. The value of the heat for both of the classes was taken to be equivalent to the value of natural gas required to offset this heat. The use of the heat from the process can be used for thermal heating applications (greenhouse heating, drying kilns and space heating through the use of a heat exchanger), heat recovery steam generation or absorption chillers.

The technology with the lowest total cost per electrical and heat units of output is the fixed bed gasification system for all fuel scenarios and both the combined heat and power case and the heat only case. The main reason is that the fixed bed gasification equipment has the least expensive capital cost for a given output. This outweighs the efficiency advantage of the other technologies.

Fuel testing is required as one of the next steps as the project develops. This will enable the suppliers to confirm that their technologies are suitable for the specific fuels anticipated for this project as well as to allow a more accurate cost estimate. Pilot plant testing of the fuel in an existing test facility or boiler plant is required to verify the technology is a natural step following from the fuel testing program.

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1.0 Objectives

The objectives of this project are as defined in the Ministry of Agriculture and Lands Request for Proposals (Number 2034) as originally issued on April 1, 2008. The key objectives of this project are:

1. Define combustion technologies in addition to fixed bed gasification, fluidized bed gasification and fluidized bed combustion.

2. Review of the 2007 Golder Associates Innovative Applications (GAIA) report entitled "Desktop Study on Available Incineration Technologies".

3. Follow up on information received in response to the "Gasification Pilot Project Request for Expression of Interest" published by the British Columbia Ministry of Agriculture and Lands on November 26, 2007 and closed on Dec 7, 2007.

4. Identification of a minimum of three (3) suppliers of commercially available, fixed bed gasification, fluidized bed gasification and fluidized bed incinerators as a starting point to develop a detailed economic assessment for the combinations of fuel and feedstock scenarios as outlined below.

5. Develop indicative capital, operational and maintenance costs associated with receiving of the slaughterhouse and dead stock wastes and the operation of the incineration/gasification unit proper as well as the energy capturing equipment.

6. Develop a detailed economic assessment for each of the above three key technologies including a break-even tipping fee for the following four scenarios:

    6.1. Scenario 1
    Fuel: Specified Risk Material (ruminant-based slaughterhouse waste and dead stock)
    Volume: 25 tonnes/day
    Additional fuel for uniformity of feedstock: 25 tonnes/day of wood waste (estimated)

    6.2. Scenario 2
    Fuel: Specified Risk Material as in Scenario 1 plus a mix of non-SRM livestock waste tissues (mainly from pork and beef)
    Volume: 105 tonnes/day
    Additional fuel for uniformity of feedstock: 105 tonnes/day of wood waste (estimated)

    6.3. Scenario 3
    Fuel: As in Scenario 2 plus spent hens
    Volume: 120 tonnes/day
    Additional fuel for uniformity of feedstock: 120 tonnes/day of wood waste (estimated)

6.4. Scenario 4

Fuel: As in Scenario 3 plus broiler and turkey litter

Volume: 425 tonnes/day (of which 120 tonnes/day are animal waste tissues as in Scenario 3 and of which 305 tonnes/day are excess broiler and turkey litter requiring disposal)

Additional fuel for uniformity of feedstock: No wood waste; the dry turkey and poultry litter are assumed to create a mix adequate for uniform combustion.

2.0 Introduction

Stantec Consulting was engaged by the Resource Management Branch of the B.C. Ministry of Agriculture and Lands to study the economic assessment of combustion technologies for specified risk material disposal in British Columbia. This project included the confirmation of the technologies and the suggestion of new technologies that merit further consideration as well as the analysis of the economics of the technologies.

The technologies as identified by the client and studied are fixed bed gasification, fluidized bed gasification and fluidized bed combustion. Additional technologies also reviewed are plasma gasification (PlascoEnergy) and reductive thermal processing (Vertus).

Four fuel (SRM/biomass) scenarios were considered for each of the technologies. These fuels consist of a combination of SRM and slaughterhouse waste material and wood waste or poultry litter (scenario 4).

The characteristics of the fuels were derived based on the quantities provided in the Request for Proposals and published data available for the fuel properties. The fuel as fed to each of the gasifier/combustion systems was considered a blend of the various components as specified in the Request for Proposals. In each case a component (such as wood waste or boiler or turkey litter) of the fuel is used to reduce the average moisture level of the fuel. It should be noted that the reduced average moisture level is still not adequate for gasification without additional drying. The cost of the additional drying is included in the economic analysis.

Requests for information were issued to representative suppliers for each of the technologies. Responses were received from vendors for these cases. The information that was received by the vendors was adequate to confirm that the technology appears to be suitable for the combustion of SRM and slaughterhouse waste; however, it was not adequate to complete a representative economic comparison of the studied technologies. The economic analysis therefore was carried out using published data for firing biomass in fixed and fluidized bed gasification systems and fluidized bed combustion systems.

The analysis of each fuel scenario was broken down into two classes. These are the combined production of power and heat and the production of heat only. The heat and power class primarily focuses on power output and handles the surplus heat remaining after power production as a beneficial byproduct of the process. The value of the produced electrical power was assumed to be equivalent to the rate paid by BC Hydro to power producers. The value of the heat for both of the classes was taken to be equivalent to the value of natural gas required to offset this heat. The use of the heat from the process can be used for thermal heating applications (greenhouse heating, drying kilns and space heating through the use of a heat exchanger), heat recovery steam generation or absorption chillers.

The results of the investigation are discussed in Section 3.

3.0 Discussion

The following is a discussion of each of the Objectives as listed in Section 1.0 above.

1. Potential combustion technologies in addition to fixed bed gasification, fluidized bed gasification and fluidized bed combustion are plasma gasification (vendor: PlascoEnergy) and reductive thermal processing (vendor: Vertus Technologies). These technologies are both relatively new developments adapted for the destruction of SRM. The plasma gasification technology was developed for the destruction of municipal solid waste (MSW) and the reductive thermal processing technology was developed for the gasification of coal. Refer to Section 3.4 for a detailed description of these technologies.

2. The 2007 Golder Associates Innovative Applications (GAIA) report entitled “Desktop Study on Available Incineration Technologies” was reviewed. The objective of this study was to collect contact information of incinerator vendors suitable for the destruction of SRM materials. The purpose of collecting this information was to provide a guide to the provincial cattle industry for implementing an incinerator program.

   The information in this report was reviewed; however, the majority of the incinerator companies contact information was not used as the focus of the current study was on combustion techniques beyond the realm of pure incineration (including fixed and fluidized bed gasification and fluidized bed combustion). It should be noted that this study followed up with some of the gasifier vendors listed. The companies that were contacted for this study are listed in Table 2 (Technology Suitability Matrix).

3. Information received in response to the “Gasification Pilot Project Request for Expression of Interest” published by the British Columbia Ministry of Agriculture and Lands was used as a starting point for contacting the gasifier vendors for the current project. The basis of the request for the Expression of Interest was to gauge the interest in involvement in a pilot plant for the gasification of SRM. This solicitation drew positive responses from 14 respondents offering a variety of gasification systems. The majority of the products as offered by these respondents are small fixed bed gasification units applicable for fuel scenarios 1 and 2. These units may also be considered as multiple installations for fuel scenarios 3 and 4. This arrangement would be appropriate for a distributed application but, however, may not be appropriate for a central process station due to the duplication of common services and the inherently better performance of a single large fluidized bed gasification plant.

   Refer to Item 5 below for the listing of the respondents contacted for the current project.

4. The fuel parameters for this project are summarized on Table 1 (Fuel Summary Table). It should be noted that ultimate and proximate fuel analyses are not available for the SRM fuel.

The heating value and moisture content of the SRM fuel used for this analysis was as reported in a published document. The moisture content for the SRM and non-SRM fuel for this analysis is 62% with an as-fired heating value of 7513 kJ/kg (3230 Btu/lb). (Refer to Reference 1).

The moisture content for the spent hens was determined as 56% with an as-fired heating value of 8318 kJ/kg (3576 Btu/lb) (Refer to Reference 2).

The wood waste was assumed to be hogged fuel with a moisture level of 45% and an as-fired heating value of 9339 kJ/kg (4015 Btu/lb). The broiler and turkey litter is assumed to have a moisture content of 26% with an as-fired heating value of 10,430 kJ/kg (4484 Btu/lb). (Refer to Reference 3 for the source of the broiler and turkey litter analysis.)

The studied fuels are blended with wood waste for scenarios 1, 2 and 3 while the scenario 4 fuel is blended with broiler and turkey litter. The results are shown in Table 1 (Fuel Summary Table). The heating value and moisture content of each of the fuel blends was determined as the average of the components. The values used for the fuel analysis are appropriate for the current work; however, an actual fuel analysis is required as the project moves forward to the pilot plant phase.

Biomal has fuel properties as follows: as-fired heating content in the range of 7600 to 8300 kJ/kg (3270 to 3570 Btu/lb) with a moisture content estimated to be 65%. (Refer to Reference 1).

The fuel quantities as shown in Table 1 (Fuel Summary Table) are as presented in the RFP for this project.

The oxidant for both of the gasification systems was considered as air.

Table 1 (Fuel Summary)

Item	Units	Fuel Scenario 1	Fuel Scenario 2	Fuel Scenario 3	Fuel Scenario 4
SRM (note 1)					
Moisture	%	62%	62%	62%	62%
Heating value, as fired	kJ/kg (Btu/lb)	7513 (3230)	7513 (3230)	7513 (3230)	7513 (3230)
Fuel flow	kg/h (lb/h)	1041 (2296)	1041 (2296)	1041 (2296)	1041 (2296)
Heat input	kJ/h (Btu/h) (10^6)	7.82 (7.41)	7.82 (7.41)	7.82 (7.41)	7.82 (7.41)
Wood waste (note 2)					
Moisture	%	45%	45%	45%	n.a.
Heating value, as fired	kJ/kg (Btu/lb)	9339 (4015)	9339 (4015)	9339 (4015)	n.a.
Fuel flow	kg/h (lb/h)	1041 (2296)	4375 (9644)	5042 (11115)	0
Heat input	kJ/h (Btu/h) (10^6)	9.72 (9.22)	40.86 (38.72)	47.09 (44.62)	0
Non-SRM livestock waste tissues (note 3)					
Moisture	%	n.a.	62%	62%	62%
Heating value, as fired	kJ/kg (Btu/lb)	0	7513 (3230)	7513 (3230)	7513 (3230)
Fuel flow	kg/h (lb/h)	0	3334 (7349)	3334 (7349)	3334 (7349)
Heat input	kJ/h (Btu/h) (10^6)	0	25.05 (23.74)	25.05 (23.74)	25.05 (23.74)
Spent hens (note 4)					
Moisture	%	n.a.	n.a.	56%	56%
Heating value, as fired	kJ/kg (Btu/lb)	0	n.a.	8318 (3576)	8318 (3576)
Fuel flow	kg/h (lb/h)	0	0	600 (1323)	600 (1323)
Heat input	kJ/h (Btu/h) (10^6)	0	0	5.0 (4.73)	5.0 (4.73)
Broiler and turkey litter (note 5)					
Moisture	%	n.a.	n.a.	n.a.	26%
Heating value, as fired	kJ/kg (Btu/lb)	0	n.a.	n.a.	10430 (4484)
Fuel flow	kg/h (lb/h)	0	0	0	12730 (28065)
Heat input	kJ/h (Btu/h) (10^6)	0	0	0	132.8 (125.84)
Combined fuel					
Moisture (combined)	%	54%	54%	53%	36%
Heating value of fuel, combined, as fired	kJ/kg (Btu/lb)	8427 (3623)	8425 (3622)	8481 (3646)	9637 (4143)
Total fuel flow	kg/h (lb/h)	2083 (4593)	8750 (19290)	10017 (22083)	17705 (39032)
Total fuel flow	tonne/day	50	210	240	425
Total heat input in fuel	kJ/h (Btu/h) (10^6)	17.6 (16.6)	73.7 (69.9)	85.0 (80.5)	170.6 (161.7)

Note 1: SRM moisture content and energy content based on information in "Co-combustion of Animal Waste in Fluidized Bed Boilers - Operating Experiences and Emission Data" (See Reference 1)

Note 2: Wood waste considered as hogged fuel with a typical moisture content of 45%. Heat content: 11140 KJ/Kg (4795 B/lb) HHV, 9330 KJ/Kg (4015 B/lb) LHV based on in-house data base.

Note 3: Non-SRM livestock waste tissues: moisture content and energy content considered the same as SRM waste. (See Reference 1).

Note 4: Spent hens: assume moisture content of 56% based on information in paper "Humane On-farm Processing of Spent Hens" (Refer to Reference 2).

Note 5: Broiler and turkey litter moisture content and energy content based on information in "Demonstration of a Small Modular BioPower System Using Poultry Litter DOE SBIR Phase-1 Final Report". (See Reference 3).

5. Table 2 (Technology Suitability Matrix) summarizes project objectives 4, 5 and 6. This table is used to show the technical and economic assumptions, the steps followed and the summary of the analysis of each of the fuel scenarios for the specified combustion technologies as well as two additional potential technologies. Several suppliers are identified for each of the technologies; however, contact was made with what was judged to be the key suppliers of each technology classification. The feedback from these suppliers was adequate to confirm the technology selection.

   The key question received from the potential suppliers of the gasification and combustion equipment was the availability of an ultimate and proximate analysis and an ash analysis for the given fuel blends. This information is required so that vendors can accurately evaluate the potential of fouling and slagging in the combustor as well as to definitively confirm the technology.

   In general, fouling may occur in heat exchange surfaces of the boiler or reactor if the flue gas temperature is greater than the ash fusion temperature. This fouling may result in poor heat transfer characteristics and underperformance of the gasification or combustion system. This may result in lower unit efficiency and high gas temperatures as well as operational problems such as heat exchanger plugging.

   Slagging is also dependent on the characteristics of the ash and the temperature regime of the gas and may form on the boiler or reactor walls. Slagging may reduce the heat transfer to the heat absorbing walls of a boiler resulting in loss efficiency and output as well as cause operational upsets such as large pieces of slag falling into the ash handling system.

   This fuel information is required as the project moves forward. The fuel information (moisture, heating value, flow and heat input) presented to the suppliers was sufficient for confirmation that their equipment was appropriate for the combustion of the given material.

   The Technology Suitability Matrix summarizes the technical analysis of the three main technologies for each of the fuel scenarios. Two cases for each of the gasification / combustion technologies were considered. These are the combined heat and power case and the heat only case.

   Electrical output was developed for the combined heat and power case for each of the fuel scenarios studied. The electrical power was deemed generated by internal combustion engine-based gensets firing syngas for the gasification technologies and by a steam turbine generator for the fluidized bed combustion system. The surplus heat from the electrical generation process was treated as a byproduct with a value equivalent to the heat offset from natural gas. The sum of these two outputs is the total output for each of the combined heat and power cases. The total output was used as a basis for comparison between the various fuel scenarios as well as between the technology cases.

Heat output was developed for the heat production only case for each of the fuel scenarios for the technologies studied. The heat produced was also considered with a value equivalent to the heat offset from natural gas. This value was used to compare the various fuel scenarios.

The heat produced by the heat only case is in the form of hot gas which could be used with a heat recovery system for space heating (greenhouse using hot water) or steam production for process use or electrical generation. The heat could also be used for an absorption chiller system.

It should be noted that sufficient economic information has not been received from potential suppliers for either the gasification or the combustion options. Vendors have confirmed that both technologies are suitable for the application. The economic analysis for these cases was carried out using published data. Refer to Reference 4 for the source of the data used for the economic analysis.

Points to consider regarding the economic analysis include:

- Balance of plant equipment is included with the capital cost of the equipment for each of the studies cases. The balance of plant equipment is made of but not limited to the fuel drying equipment for the gasification technologies, gas clean-up equipment, electrical and structural work.

- Present worth based on assumed 20 year plant life and 7% interest rate.

The operational cost for the various plants is based on the total annual cost of capital, the cost of fuel and the cost of operations and maintenance.

The auxiliary fuel cost (wood waste) for scenario 1, 2 and 3 is based on \$1.90 / 10^6 kJ (\$2.00 / 10^6 Btu) which includes the cost of the fuel and delivery (Refer to Reference 4). The poultry litter cost was considered as no cost; however, an allowance of \$0.95 / 10^6 kJ (\$1.00 / 10^6 Btu) for delivery was included.

Operation and maintenance for each of the scenarios was estimated for the fuel preparation and gasification section of the plant and the power generation section of the plant (internal combustion engine-based genset for scenarios 1 and 2 and steam turbine generator for scenario 3).

The break-even tipping fee was based on the total annual cost for the plant (including operating and capital) divided by the total waste disposed (including SRM, non-SRM livestock waste tissues and spent hens and not including the broiler and turkey litter waste). The break-even tipping fee was calculated with and without the contribution of electrical and heat sales.

The plant capacity factor was considered as 90% for all fuel scenarios and all technology cases based on the expected operating period and the requirement for annual outages.

Table 2 (Technology Suitability Matrix)

Technology: Fixed Bed Gasification
Possible Suppliers:
Thermogenics, Inc
Nexterra (fixed bed updraft)
Repotec
Energos (fixed bed updraft)
Prime Energy (fixed bed updraft)
B&W Volund (fixed bed updraft)
Westwood Energy Systems (fixed bed updraft)
REL-Waterwide (fixed bed updraft)
Lurgi Dry Ash Gasifier
Chiptec (fixed bed updraft)
Emery Energy (fixed bed updraft)
Vidir Best (fixed rotating grate bed updraft)
Suppliers Contacted:
Thermogenics, Inc (fixed bed updraft)
Nexterra (fixed bed updraft)
Westwood Energy Systems Inc. (fixed bed updraft)
Vidir Best (fixed bed updraft)
Advantages of Technology:
Simpler design than fluidized bed gasification
Lower capital cost for small scale gasifiers (fuel scenario 1,2,3)
Lower annual cost for small scale gasifiers (fuel scenario 1,2,3)
Many suppliers – may be possible to source locally which should result in good after sales service
Shop fabricated and individual components tested which should maintain good quality
The modules are small size and therefore easy to transport and install
Small sizes are appropriate for distributed installation (multiple sites)
Commercially available for biomass
Hot clean-up of Syngas may be possible prior to the combustion stage of the process resulting in cleaner combustion
Disadvantages of Technology:
Requires <20% moisture content of the fuel; therefore fuel drying is required
Limited test experience with similar fuels
May produce a lower heat content syngas than fluidized bed gasifier depending on oxidant
There is no inert bed material which may allow the grate to be exposed to high temperatures thereby resulting in grate overheating and possible maintenance concerns.
Limited in capacity to an output of approximately 5 MW (17 (10^6) Btu/h)
Small number of installed units and no commercial units gasifying SRM.

Small units; therefore will require multiple units for higher fuel flow requirements resulting in more expense due to duplication of common services.
Tars produced in the reactor may lead to slagging and fouling in downstream heat exchange devices and associated operational problems.
Tar may be produced in the producer gas requiring clean-up prior to use.
Technology Assessment:
Commercial units firing SRM – none discovered
Pilot plant recommended – yes
Recommended technology - not without pilot plant project to confirm technology

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Comments
	Technology: Fixed Bed Gasification					
	Technical Analysis:					
1	Fuel moisture, %	54%	54%	53%	36%	From Table 1
2	Heating value of combined fuel, kJ/kg (Btu/lb)	8427 (3623)	8425 (3622)	8481 (3646)	9637 (4143)	From Table 1
3	Total fuel flow, kg/h (lb/h)	2083 (4593)	8750 (19290)	10017(22083)	17705(39032)	From Table 1
4	Biomass fuel to gasifier, kJ/h (Btu/h), (10^6)	17.6 (16.6)	73.7 (69.9)	85.0 (80.5)	170.6 (161.7)	Calc: ***2* 3***
5	Estimated syngas heating value, kJ/m^3 (Btu/ft^3)	3.29 (110)	3.29 (110)	3.29 (110)	3.29 (110)	Note 1
6	Gasifier efficiency, %	65%	65%	65%	65%	Note 2
7	Syngas produced (calculated), kJ/h (Btu/h) [calculated], (10^6)	11.4 (10.8)	47.9 (45.4)	55.2 (52.3)	110.9 (105.1)	Calc: ***4 * 6***
8	Gross heat produced in syngas, kW	3132	13166	15167	30497	Conversion of ***7***
9	Plant capacity factor, %	90%	90%	90%	90%	Assumption
10						
11	**Combined Heat and Power Production:**					
12	Estimated Heat Rate for IC generation, kJ/kWh (Btu/kWh)	10761(10200)	9717 (9210)	9717 (9210)	9717 (9210)	Note 3
13	Estimated electric power output (IC generation), kW	1060	4931	5682	11413	Calc: ***7 / 12***
14	Heat available after electric power generation, kW_{th}	2072	8235	9485	19084	Calc: ***8 – 13***
15	Net Heat available for process (assume 50% conversion efficiency), kW_{th}	1036	4118	4743	9542	Calc: ***14**** 0.50 Note 3a
16	Net heat available for process, $kW_{th}h$/year, 10^6	8.2	32.5	37.4	75.2	Calc: (***15****7884)/10^6
17	Electric power output, kWh/year (10^6)	8.4	38.9	44.8	90.0	Calc: (***13****7884)/10^6
18	Total electrical and thermal output, kWh/year (10^6)	16.6	71.4	82.2	165.2	Calc: ***16 + 17***
19						
20	**Heat Production Only:**					
21	Gross heat produced in syngas, kW	3132	13166	15167	30497	***Item 8***
22	Heat available for process (assume 50% conversion efficiency), kW_{th}	1566	6583	7584	15249	Calc: ***8**** 0.50 Note 3a
23	Heat available for process, $kW_{th}h$/year, 10^6	12.4	51.9	59.8	120.2	Calc: (***22****7884)/10^6

	Economic Analysis: (All costs in Canadian currency)					
	Capital costs, $					
	Combined Heat and Power Production:					
24	Fuel system biomass	$966,000	$2,900,000	$3,059,000	$4,381,000	Note 4
25	Fuel system SRM and other fuels	$483,000	$1,450,000	$1,529,500	$1,529,500	Note 5
26	Gasifier system (power plant)	$741,200	$3,120,000	$3,570,000	$6,333,000	Note 6
27	Balance of plant including drying	included	included	included	Included	
28	Emissions clean up equipment	included	included	included	Included	
29	Power generation plant – capital cost per unit of cost of IC plant, $/kW	$715	$550	$550	$550	Note 7
30	Power generation plant – capital cost, total IC plant, $ (output x $/kW)	$758,200	$2,712,046	$3,125,296	$6,277,000	Calc: ***13 * 29***
31	Heat exchange equipment, $/kW	$143	$110	$110	$110	Assume: ***29****0.20
32	Heat exchange equipment capital cost (output x $/kW output), $	$148,434	$453,200	$522,170	$1,048,850	Calc: ***31 * 15***
33	Engineering	included	included	included	Included	
34	Construction	$1,548,428	$5,317,601	$5,903,000	$9,784,662	Calc: 0.5*(***24+25+26+30+32***)
35	Commissioning	included	included	included	Included	
36	Estimated total installed cost (capital and installation), $	$4,645,284	$15,952,803	$17,709,003	$29,353,987	Calc: (***24+25+26+30+32+34***)
37	Present worth, $	$438,483	$1,505,834	$1,671,607	$2,770,812	Calc: ***36*** / 10.594 Note 12
38	Estimated installed capital cost per unit output (electrical and heat), $/kW output	$2,214	$1,763	$1,698	$1,401	Calc: ***36/(13+15)***
	Heat Production Only:					
39	Fuel system biomass	$966,000	$2,900,000	$3,059,000	$4,381,000	Note 4
40	Fuel system SRM and other fuels	$483,000	$1,450,000	$1,529,500	$1,529,500	Note 5
41	Gasifier system (power plant)	$741,200	$3,120,000	$3,570,000	$6,333,000	Note 6
42	Balance of plant including drying	included	included	included	Included	
43	Emissions clean up equipment	included	included	included	Included	
44	Heat exchange equipment , $/kW	$143	$110	$110	$110	Assume: ***29****0.20
45	heat exchange equipment - $ (output x $/kWth)	$224,276	$724,360	$834,735	$1,676,524	Calc: ***44*22***
46	Engineering	included	included	included	Included	
47	Construction	$1,207,238	$4,097,180	$4,496,618	$6,960,012	Calc: 0.50***(39+40+41+45)***
48	Commissioning	included	included	included	Included	
49	Estimated total installed cost (capital and installation), $	$3,621,714	$12,291,541	$13,489,853	$20,880,036	Calc: **(39+40+41+45+47)**
50	Estimated installed capital cost per unit heat output, $/kW output	$2,309	$1,867	$1,778	$1,370	Calc: ***49/22***
51	Present worth, $	$341,865	$1,160,236	$1,273,348	$1,970,930	Calc: ***49***/10.594 Note 12

	Operating Costs, $/yr					
	Combined Heat and Power Production:					
52	Auxiliary fuel (waste wood) cost	$145,400	$610,000	$704,000	$0	Note: 8
53	Poultry litter cost	$0	$0	$0	$0	
54	Poultry litter delivery cost	$0	$0	$0	$992,000	Note: 9
55	Annual O&M for fuel yard and gasification, $/yr	$277,146	$1,163,654	$1,340,967	$2,693,265	Note: 10
56	Annual O&M for internal combustion generation, $/yr	$209,009	$971,899	$1,119,992	$2,249,449	Note: 11
57	Annual O&M for surplus heat exchange, $/yr	Incl	Incl	Incl	Incl	
58	Total annual O&M cost, $/yr	$631,554	$2,745,553	$3,164,959	$5,934,714	Calc: ***52+55+56***
59	Total Annual Cost (capital present worth and total annual O&M cost), $/yr	$1,070,037	$4,251,387	$4,836,566	$8,705,526	Calc: **37+ 58**
60	Income from electrical generation, $/yr	$727,016	$3,380,653	$3,895,782	$7,824,482	Calc: 0.08696 * ***17***
61	Income from surplus heat, $/yr, natural gas offset	$247,181	$980,863	$1,130,323	$2,270,197	Calc: $0.0302*$***16***$*10^6$
62	Net annual cost, $/yr	$95,840	-$110,129	-$189,538	-$1,389,153	Calc: ***59-60-61***
63	Total cost per unit electrical and heat output, $/kWh	$0.065	$0.060	$0.059	$0.053	Calc: **59 / 18**
64	Net cost electrical and heat output, $/kWh	$0.006	-$0.002	-$0.002	-$0.008	Calc; ***62 / 18***
	Heat Production Only:					
65	Auxiliary fuel (waste wood) cost	$145,400	$610,000	$704,000	$0	Note: 8
66	Poultry litter cost	$0	$0	$0	$0	
67	Poultry litter delivery cost	$0	$0	$0	$992,000	Note: 9
68	Annual O&M for fuel yard and gasification, $/yr	$277,146	$1,163,654	$1,340,967	$2,693,265	Note: 11
69	Annual O&M for internal combustion generation, $/yr	n.a.	n.a.	n.a.	n.a.	
70	Total annual O&M cost, $/yr	$422,546	$1,773,654	$2,044,967	$3,685,265	Calc: ***65+68***
71	Total annual cost (capital present worth and total annual O&M cost), $/yr	$764,410	$2,933,890	$3,318,315	$5,656,195	Calc: ***51+70***
72	Income from electrical generation, $/yr	$0	$0	$0	$0	
73	Income from heat production, $/yr natural gas offset	$373,422	$1,567,890	$1,806,798	$3,628,864	Calc: $0.0302*$***23***$*10^6$
74	Net annual cost, $/yr	$390,988	$1,366,000	$1,511,517	$2,027,332	Calc: ***71-73***
75	Total cost per unit heat output, $/kWh output	$0.062	$0.057	$0.055	$0.047	Calc: ***71/23***
76	Net cost, $/kWh heat output	$0.032	$0.026	$0.025	$0.017	Calc: **74/23**
	Break-even Tipping fee					
	Combined Heat and Power Production:					
77	Total waste material not including poultry litter, tonnes/yr	8211	34492	39223	39223	From Table 1
78	SRM fuel cost (tipping fee) base, $/tonne	$130	$123	$123	$222	Calc: ***59/77***
79	SRM fuel cost (tipping fee) including electrical sales, $/tonne	$11.67	-$3.19	-$4.83	-$35.42	Calc: **62/77**
	Heat Production Only:					
80	Total waste material not including poultry litter, tonnes/yr	8211	34492	39223	39223	From Table 1
81	SRM fuel cost (tipping fee) base, $/tonne	$93	$85	$85	$144	Calc: ***71/80***
82	SRM fuel cost (tipping fee) including income from heat production, $/tonne	$48	$40	$39	$52	Calc:***74/80***

Note 1: Reference 4, Page 54, Table 5-16

Note 2: Reference 4, Page 54, Table 5-16

Note 3: Reference 4, Page 72, Table 6-5

Note 3a: Estimate from in-house data (based on reducing the temperature of the gas exiting the gasifier by approximately 50% to ensure that it remains above the gas dew point temperature, thereby minimizing the condensation of corrosive gases on the heat exchange surfaces).

Note 4: Biomass system including but not limited to fuel receiving, storing, preparation, conveyers and stackers. Reference 4, Page 26, Figure 4-3. (Sample calculation: 27.6 ton/day biomass = estimated capital cost for fuel system ($/ton/day) = 27.6 ton/day * $35000/ton/day = $966,000)

Note 5: SRM fuel handling cost estimated as 50% of biomass cost except for scenario 4 where SRM handling expected to be the same as Scenario 3.

Note 6: Reference 4, Page 54, Table 5-16

Note 7: Reference 4, Page 72, Table 6-5

Note 8: Biomass fuel cost assumed to be $1.90 /10^6 kJ ($2.00/10^6 Btu) delivered based on in-house data. Reference 4 Page 79 Table 7-1. (Sample calculation $2/10^6 Btu x 9.22 10^6 Btu x 7884 h/yr = $145,400)

Note 9: Poultry litter delivery cost assumed to be $0.95 /10^6 kJ ($1.00/10^6 Btu) (Sample calculation: $1/10^6 Btu x 125.84 10^6 Btu x 7884 h/yr = $992,000)

Note 10: Reference 4, Page 54, Table 5-15.

Note 11: Reference 6, Page 18 (use $0.01/kWh)

Note 12: Based on 20 year plant life and 7% interest rate.

Technology: Fluidized Bed Gasification
Possible Suppliers:
AE&E Von Roll
Enerkem (BFB Gasifier)
AgriPower 10 Ton/day 1.4 M 300 KW
Thermoselect Pyrolysis + Gasification
EPI (Air)
Metso Power (Kvaerner Enviropower)
Foster Wheeler (ACFB)
Foster Wheeler (O2 + Steam)
BTG
Silva Gas Pyrolyzing (CFB + CFB)
Repotec(Pyrolyzing CFB + CFB)
Suppliers Contacted:
AE&E Von Roll
EPI (Air)
Metso Power (Kvaerner Enviropower)
Advantages of Technology:
Capable of the producer gas having a higher heating value (up to 250 btu/ft^3) than fixed bed type of gasifier if using oxygen or steam as oxidant (advanced technologies). The study is based on air oxidation and a heating value of 110 btu/ft^3.
Capable of handling a wide range of feedstocks up to 30% moisture - better than fixed bed type
Higher capacities and better performance possible than fixed bed gasifiers
Better suited for centrally located plant than fixed bed due to the higher available capacity of a single unit
Hot gas clean-up prior to oxidation may be possible resulting in cleaner combustion.
Disadvantages of Technology:
More complicated design and additional equipment required than fixed bed gasifiers
Higher capital costs than fixed bed gasifiers due to additional auxiliary equipment.
Potential for tars in produced syngas. Gas may require cleaning before use depending on the final use of the gas.
Newly emerging technology for biomass; therefore expected reliability is unknown.
Does not appear to be used for SRM gasification.
Fluid bed not as commercial as direct fired combustion of biomass; however, the installed base is increasing
Technology Assessment:
Commercial units firing SRM – none discovered
Pilot plant recommended – yes (testing program using existing biomass fired fluidized bed gasifier and SRM would also be applicable)
Recommended technology – yes - providing successful completion of testing program

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Comments
	Technology: Fluidized Bed Gasification					
	Technical Analysis:					
1	Fuel moisture, %	54%	54%	53%	36%	From Table 1
2	Heating value of combined fuel, kJ/kg (Btu/lb)	8427 (3623)	8425 (3622)	8481 (3646)	9637 (4143)	From Table 1
3	Total fuel flow, kg/h (lb/h)	2083 (4593)	8750 (19290)	10017(22083)	17705(39032)	From Table 1
4	Biomass fuel to gasifier (calculated), kJ/h (Btu/h), (10^6)	17.6 (16.6)	73.7 (69.9)	85.0 (80.5)	170.6 (161.7)	Calc: ***2*3***
5	Estimated syngas heating value, kJ/m^3 (Btu/ft^3)	3.29 (110)	3.29 (110)	3.29 (110)	3.29 (110)	Note 1
6	Gasifier efficiency, %	71%	71%	71%	71%	Note 2
7	Syngas produced (calculated), kJ/h (Btu/h) [calculated], (10^6)	11.8	49.6	57.2	114.8	Calc: ***4*6***
8	Gross heat produced in syngas, kW	3426	14386	16578	33296	Conversion of ***7***
9	Plant capacity factor, %	90%	90%	90%	90%	Assumption
	Combined Heat and Power Production:					
10	Estimated Heat Rate for IC generation, kJ/kWh (Btu/kWh)	10761(10200)	9717 (9210)	9717 (9210)	9717 (9210)	Note 3
11	Estimated electric power output (IC generation), kW	1158	5386	6207	12466	Calc: ***7/10***
12	Heat available after electric power generation. kW_{th}	2268	9000	10371	20830	Calc: ***8-11***
12a	Net Heat available for process (assume 50% conversion efficiency), kW_{th}	1134	4500	5186	10415	Calc: 0.50****12*** Note 3a
13	Net heat available for process, kW_{th}h/year, 10^6	8.9	35.5	40.9	82.1	Calc: (***12a****7884)/10^6
14	Electric power output, kWh/year (10^6)	9.1	42.5	48.9	98.3	Calc: (***11****7884)/10^6
15	Total electrical and thermal output, kWh/year (10^6)	18.1	77.9	89.8	180.4	Calc:***13+14***
16						
17	**Heat Production Only:**					
18	Gross heat produced in syngas, kW	3426	14386	16578	33296	See line ***8***
19	Heat available for process (assume 50% conversion efficiency), kW_{th}	1713	7193	8289	16648	Calc: 0.50****18*** Note 3a
20	Heat available for process, kW_{th}h/year, 10^6	13.5	56.7	65.4	131.3	Calc: (***19****7884)/10^6
21						
22	**Economic Analysis: (All costs in Canadian currency)**					
23	**Capital costs, $**					
24	**Combined Heat and Power Production:**					
25	Fuel system biomass	$966,000	$2,900,000	$3,059,000	$4,381,000	Note 4
26	Fuel system SRM and other fuels	$483,000	$1,450,000	$1,529,500	$1,529,500	Note 5
27	Gasifier system (power plant)	$2,339,000	$9,843,000	$11,268,000	$17,415,000	Note 6
28	Balance of plant including drying	included	included	included	Included	
29	Emissions clean up equipment	included	included	included	Included	
30	Power generation plant – capital cost per unit of cost of IC plant, $/kW	$706	$550	$550	$550	Note 7
31	Power generation plant – capital cost, total IC plant, $ (output x $/kW)	$817,763	$2,962,389	$3,413,785	$6,856,416	Calc: ***11*30***
32	Heat exchange equipment, $/kW	$141	$110	$110	$110	Assume: ***30****0.20
33	Heat exchange equipment capital cost (output x $/kW output), $	$160,118	$494,986	$570,409	$1,145,639	Calc: 32****12a***

34	Engineering	Included	included	included	Included	
35	Construction	$2,382,941	$8,825,187	$9,920,347	$15,663,777	Calc: 0.50*(***25+26+27+31+33***)
36	Commissioning	included	included	included	Included	
37						
38	Estimated total installed cost (capital and installation), $	$7,148,822	$26,475,562	$29,761,041	$46,991,331	Calc: (***25+26+27+31+33+35***)
39	Present worth, $	$674,799	$2,499,109	$2,809,236	$4,435,655	Calc: ***38***/10.594 Note 12
40	Estimated installed capital cost per unit output (electrical and heat), $/kW output	$3,119	$2,678	$2,612	$2,054	Calc: ***38/15***
	Heat Production Only:					
41	Fuel system biomass	$966,000	$2,900,000	$3,059,000	$4,381,000	Note 4
42	Fuel system SRM and other fuels	$483,000	$1,450,000	$1,529,500	$1,529,500	Note 5
43	Gasifier system (power plant)	$2,339,000	$9,843,000	$11,268,000	$17,415,000	Note 6
44	Balance of plant including drying	Included	included	included	Included	
45	Emissions clean up equipment	Included	included	included	Included	
46	Heat exchange equipment, $/kW	$141	$110	$110	$110	Assume: ***30****0.20
47	heat exchange equipment - $ (output x $/kWth)	$241,894	$791,224	$911,788	$1,831,280	Calc: ***46*19***
48	Engineering	included	included	included	Included	
49	Construction	$2,014,947	$7,492,112	$8,384,144	$12,578,390	Calc: 0.50*(***41+42+43+47***)
50	Commissioning	included	included	included	Included	
51	Estimated total installed cost (capital and installation), $	$6,044,842	$22,476,337	$25,152,432	$37,735,170	Calc: (***41+42+43+47+49***)
52	Present worth, $	$570,591	$2,121,610	$2,374,215	$3,561,938	Calc: ***51***/10.594 Note 12
53	Estimated installed capital cost per unit output (heat), $/kW output	$3,529	$3,125	$3,034	$2,267	Calc: ***51/19***
	Operating Costs, $/yr					
	Combined Heat and Power Production:					
54	Auxiliary fuel (waste wood) cost, $	$145,400	$610,000	$704,000	$0	Note 8
55	Poultry litter cost, $	$0	$0	$0	$0	
56	Poultry litter delivery cost, $	$0	$0	$0	$992,000	Note 9
57	Annual O&M for fuel yard and gasification, $/yr	$302,728	$1,271,069	$1,464,749	$2,941,874	Note 10
58	Annual O&M for internal combustion generation, $/yr	$228,302	$1,061,612	$1,223,376	$2,457,090	Note 11
59	Annual O&M for surplus heat exchange, $/yr	Incl	Incl	Incl	Incl	
60	Total annual O&M cost, $/yr	$676,430	$2,942,681	$3,392,125	$6,390,964	Calc: ***54+56+57+58***
61	Total Annual Cost (capital present worth and total annual O&M cost), $/yr	$1,351,229	$5,441,790	$6,201,360	$10,826,619	Calc: ***39+60***
62	Income from electrical generation, $/yr	$794,125	$3,692,713	$4,255,392	$8,546,742	Calc: 0.08696****14****10^6
63	Income from surplus heat, $/yr natural gas offset	$269,997	$1,071,404	$1,234,660	$2,479,753	Calc: $0.0302****13****$10^6$

64	Net annual cost, $/yr	$287,107	$677,673	$711,308	-$199,876	Calc:***61-62-63***
65	Total annual cost per unit output (electric and heat), $/kWh	$0.075	$0.070	$0.069	$0.060	Calc: ***61/ 15***
66	Net annual cost per unit output (electric and heat), $/kWh output	$0.016	$0.009	$0.008	-$0.001	Calc: ***64/15***
	Heat Production Only:					
67	Auxiliary fuel (waste wood) cost	$145,400	$610,000	$704,000	$0	Note 8
68	Poultry litter cost	$0	$0	$0	$0	
69	Poultry litter delivery cost	$0	$0	$0	$992,000	Note 9
70	Annual O&M for fuel yard and gasification, $/yr	$302,728	$1,271,069	$1,464,749	$2,941,874	Note 10
71	Annual O&M for internal combustion generation, $/yr	n.a.	n.a.	n.a.	n.a.	
72	Total annual O&M cost, $/yr	$448,128	$1,881,069	$2,168,749	$3,933,874	Calc: ***67+69+70***
73	Total Annual Cost (capital present worth and total annual O&M cost), $/yr	$1,018,719	$4,002,679	$4,542,963	$7,495,812	Calc: ***52+72***
74	Income from electrical generation, $/yr	$0	$0	$0	$0	
75	Income from surplus heat, $/yr natural gas offset	$407,892	$1,712,618	$1,973,580	$3,963,836	Calc: $0.0302****20****$10^6$
76	Net annual cost, $/yr	$610,828	$2,290,060	$2,569,384	$3,531,976	Calc: ***73-75***
77	Total cost per unit heat output, $/kWh output	$0.075	$0.071	$0.070	$0.057	Calc: ***73/20***/10^6
78	Net cost, $/kWh heat output	$0.045	$0.040	$0.039	$0.027	Calc: ***76/20***/10^6
	Break-even Tipping fee					
	Combined Heat and Power Production:					
79	Total waste material not including poultry litter, tonnes/yr	8211	34492	39223	39223	From Table 1
80	SRM fuel cost (tipping fee) base, $/tonne	$165	$158	$158	$276	Calc: ***61/79***
81	SRM fuel cost (tipping fee) including electrical and heat sales, $/tonne	$34.97	$19.65	$18.13	-$5.10	Calc: ***64/79***
	Heat Production Only:					
82	Total waste material not including poultry litter, tonnes/yr	8211	34492	39223	39223	From Table 1
83	SRM fuel cost (tipping fee) base, $/tonne	$124	$116	$116	$191	Calc: ***73/82***
84	SRM fuel cost (tipping fee) including income from heat production $/tonne	$74	$66	$66	$90	Calc: ***76/82***

Note 1: Reference 4, Page 54, Table 5-16

Note 2: Reference 4, Page 54, Table 5-16

Note 3: Reference 4, Page 72, Table 6-5

Note 3a: Estimate from in-house data (based on reducing the temperature of the gas exiting the gasifier by approximately 50% to ensure that it remains above the gas dew point temperature, thereby minimizing the condensation of corrosive gases on the heat exchange surfaces).

Note 4: Biomass system including but not limited to fuel receiving, storing, preparation, conveyers and stackers. Reference, Page 26, Figure 4- (Sample calculation: 27.6 ton/day biomass = estimated capital cost for fuel system ($/ton/day) = 27.6 ton/day * $35000/ton/day = $966,000)

Note 5: SRM fuel handling cost estimated as 50% of biomass cost except for scenario 4 where SRM handling expected to be the same as Scenario 3.

Note 6: Reference 4, Page 54, Table 5-16

Note 7: Note 7: Reference 4, Page 72, Table 6-5

Note 8: Biomass fuel cost assumed to be \$1.90 / 10^6 kJ (\$2.00/10^6 Btu) delivered based on in-house data. Reference 4, Page 79, Table 7-1. (Sample calculation \$2/10^6 Btu x 9.22 10^6 Btu x 7884 h/yr = \$145,400)

Note 9: Poultry litter delivery cost assumed to be \$0.95 / 10^6 kJ (\$1.00/10^6 Btu)
(Sample calculation: \$1/10^6 Btu x 125.84 10^6 Btu x 7884 h/yr = \$992,000)

Note 10: Reference 4, Page 54, Table 5-15.

Note 11: Reference 6, Page 18 (use \$0.01/kWh)

Note 12: based on 20 year plant life and 7% interest rate.

Technology: Fluidized Bed Combustion
Possible Suppliers:
AE&E Von Roll Copeland Reactor (Air)
Metso Power (Air)
Foster Wheeler (Air)
Babcock and Wilcox (Air)
Alstom (Air)
Lurgi (Air)
EPI (Air)
Suppliers Contacted:
AE&E Von Roll Copeland Reactor (Air)
Metso Power (Air)
EPI (Air)
Advantages:
Suitable for large central power plant producing steam and /or electricity.
Established technology for commercial biomass combustion also commercially used in Sweden for the combustion of SRM while co-firing with biomass.
Proven biomass combustion and power generation technology.
Appropriate technology for joint venture between existing biomass plants and SRM derived fuel such as (Biomal)
Suitable for combined heat and power (CHP) plants.
Disadvantages:
Produces power and heat and not producer gas therefore not as flexible final product
Flue gas cleanup is required after combustion rather than prior to combustion
May require a steam host such as a pulp mill to use the steam produced for the most efficient arrangement. Without steam host the heat in the steam turbine exhaust steam is lost thereby lowering the overall plant efficiency.
Operation of the boiler plant may require more operations personnel and higher qualifications due to the high pressure steam operation and advance equipment such as steam turbines and generators required for efficient power production.
Technology Assessment:
Commercial units firing SRM – yes (European)
Technically acceptable – yes
Pilot plant recommended - technology test using existing boilers (or new boilers as a result of the latest BC Hydro power call)
Recommended technology – yes

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Comments
	Technology: Fluidized Bed Combustion					
	Technical Analysis:					
	Combined Heat and Power:					
1	Fuel moisture, %	54%	54%	53%	36%	From Table 1
2	Heating value of combined fuel, kJ/kg (Btu/lb)	8427 (3623)	8425 (3622)	8481 (3646)	9637 (4143)	From Table 1
3	Total fuel flow, kg/h (lb/h)	2083 (4593)	8750 (19290)	10017(22083)	17705(39032)	From Table 1
4	Biomass fuel to boiler (calculated), kJ/h (Btu/h), (10^6)	17.6 (16.6)	73.7 (69.9)	85.0 (80.5)	170.6 (161.7)	Calc: ***2 * 3***
5	Boiler efficiency, % (based on fuel moisture)	66%	66%	66%	74%	Note 1
6	Boiler heat output, kJ/h (Btu/h), (10^6)	11.6 (11.0)	48.5 (46.0)	56.4 (53.5)	125.5 (119.0)	Calc: ***4 *5***
7	Boiler heat output, kWth	3185	13373	15410	34703	Conversion of ***6***
8	Estimated steam outlet pressure, MPa (psig)	3.45 (500)	3.45 (500)	3.45 (500)	3.45 (500)	
9	Estimated steam outlet temperature, ^oC (^oF)	288 (550)	288 (550)	288 (550)	288 (550)	
10	Enthalpy of boiler output steam, kJ/kg	3012	3012	3012	3187	Steam tables
11	Enthalpy at STG exhaust, kJ/kg	2570	2570	2570	2570	Steam tables
12	Steam flow to turbine, kg/h	3841	16127	18726	39406	
13	Steam turbine isentropic efficiency, %	70%	80%	80%	80%	Assumed
14	Steam turbine mechanical efficiency, %	97.5%	97.5%	97.5%	97.5%	Assumed
15	Theoretical Steam Rate (TSR) kg/kWh	8.146	8.146	8.146	5.840	Database
16	Estimated steam turbine generator output, kW	322	1544	1793	5263	Calc: ***12/15*13*14***
17	Surplus heat in steam turbine exhaust, kWth	2863	11829	13617	29440	Calc: ***7-16***
18	Surplus heat available for process (assume 50% conversion), kWth	1432	5915	6809	14720	Calc: 0.50***17** Note 1a
19	Surplus heat available for process, kWth/year, 10^6	11.3	46.6	53.7	116.1	Calc: (***18****7884)/10^6
20	Plant capacity factor, %	90%	90%	90%	90%	Assumed
21	Electric power output, kWh/yr, 10^6	2.5	12.2	14.1	41.5	Calc: (***16****7884)/10^6
22	Total output (electric and heat) kWh/yr, 10^6	13.8	58.5	67.8	157.6	Calc: ***19 + 21***
23						
24	**Heat Production Only:**					
25	Boiler heat output, kJ/h (Btu/h), (10^6)	11.6 (11.0)	48.5 (46.0)	56.4 (53.5)	125.5 (119.0)	Line ***6***
26	Boiler heat output, kWth	3185	13373	15410	34703	Line ***7***
27	Heat available for process (assume 50% conversion efficiency), kW_{th}	1593	6687	7705	17352	Calc: 0.50****26*** Note 1a
28	Heat available for process, $kW_{th}h$/year, 10^6	12.6	52.7	60.7	136.8	Calc: (***27****7884)/10^6
	Economic Analysis: (All costs in Canadian currency)					
	Capital costs, $					

	Combined Heat and Power Production:					
29	Fuel system biomass	$964,000	$2,900,000	$3,059,000	$4,381,000	Note 2
30	Fuel system SRM and other fuels	$482,000	$1,450,000	$1,529,500	$1,529,500	Note 3
31	Boiler and combustion system (power plant)	$3,396,000	$5,590,000	$6,400,000	$11,350,000	Note 4
32	Balance of plant	included	included	included	Included	
33	Emissions clean up equipment	included	included	included	Included	
34	Power generation plant – capital cost per unit of output - steam turbine, $/kW	$540	$540	$540	$540	Note 5
35	Power generation plant -capital cost, total steam turbine plant,$	$173,800	$833,900	$968,300	$2,841,900	Calc: ***34*16***
36	Heat exchange equipment, $/kW$_{th}$	$108	$108	$108	$108	Calc: 0.20****34***
37	Heat exchange equipment, $ (output x kW)	$154,700	$638,800	$735,400	$1,589,800	Calc: ***36*18***
38	Engineering	included	included	included	Included	
39	Construction	$2,585,250	$5,706,350	$6,345,850	$10,846,100	Calc: 0.50*(***29+30 +31+35+37***)
40	Commissioning	included	included	included	Included	
41	Estimated total installed cost, $ (capital and installation)	$7,755,750	$17,119,050	$19,037,550	$32,538,300	Calc: (***29+30+31+ 35+37+39)***
42	Estimated total installed cost per unit heat and electric output, $/kW (capital and installation)	$4,421	$2,295	$2,213	$1,628	Calc: ***41/(16+18)***
43	Present worth, $ [Note 8]	$732,088	$1,616,000	$1,797,000	$3,071,400	Calc: ***41***/10.594 Note 9
	Heat Production Only:					
44	Fuel system biomass [Note 3]	$964,000	$2,900,000	$3,059,000	$4,381,000	Note 2
45	Fuel system SRM and other fuels [Note 4]	$482,000	$1,450,000	$1,529,500	$1,529,500	Note 3
46	Boiler and combustion system (power plant) [Note 4a]	$3,396,000	$5,590,000	$6,400,000	$11,350,000	Note 4
47	Balance of plant	included	included	included	Included	
48	Emissions clean up equipment	included	included	included	Included	
51	Heat exchange equipment, $/kW	$108	$108	$108	$108	Calc: 0.20****34***
52	Heat exchange equipment, $ (output x kW)	$172,044	$722,196	$832,140	$1,874,016	Calc: ***27*51***
53	Engineering	included	included	included	Included	
54	Construction	$2,507,000	$5,331,100	$5,910,320	$9,567,300	Calc: 0.50*(***44+45 +46+52)***
55	Commissioning	included	included	included	Included	
56	Estimated total installed cost, $ (capital and installation)	$7,521,000	$15,993,300	$17,730,960	$28,701,900	Calc: **(44+45+46+ 52+54)**
57	Estimated total installed cost per unit heat output, $/kW (capital and installation)	$4,721	$2,392	$2,301	$1654	Calc: ***56/27***
58	Present worth, $	$709,930	$1,509,700	$1,674,000	$2,709,300	Calc: ***56***/10.594 Note 9
	Operating Costs, $/yr					
	Combined Heat and Power Production:					
59	Auxiliary fuel (waste wood) cost	$145,400	$610,000	$704,000	$0	Note 5
60	Poultry litter cost	$0	$0	$0	$0	
61	Poultry litter delivery cost	$0	$0	$0	$992,000	Note 6
62	Annual O&M for fuel yard and boiler, $/yr	$453,500	$1,909,000	$2,190,000	$3,880,000	Note 7

63	Annual O&M for steam turbine, $/yr	$25,372	$121,750	$141,366	$414,913	Note 8
64	Total annual O&M cost, $/yr	$624,272	$2,640,750	$3,035,366	$5,286,913	Calc: ***59+62+63***
65	Total Annual Cost (capital present worth and operating cost), $/yr	$1,308,830	$4,256,750	$4,832,366	$8,358,313	Calc: ***43+64***
66	Income from electrical generation, $/yr	$177,606	$852,249	$989,563	$2,904,394	Calc: 0.08696****21****10^6
67	Income from heat generation, $/yr	$341,260	$1,407,320	$1,621,740	$3,506,220	Calc: $0.0302****19****$10^6$
68	Net annual cost, $/yr	$837,500	$1,997,200	$2,221,000	$1,947,700	Calc: ***65-66-67***
69	Total cost per unit electrical and heat output, $/kWh	$0.098	$0.072	$0.071	$0.053	Calc: ***65/22***
70	Net cost per unit electrical and heat output, $/kWh	$0.061	$0.034	$0.033	$0.012	Calc: ***68/22***
	Heat Production Only:					
71	Auxiliary fuel (waste wood) cost	$145,400	$610,000	$704,000	$0	Note 5
72	Poultry litter cost	$0	$0	$0	$0	
73	Poultry litter delivery cost	$0	$0	$0	$992,000	Note 6
74	Annual O&M for fuel yard and boiler incl heat exchanger, $/yr	$453,500	$1,909,000	$2,190,000	$3,880,000	Note 7
76	Total annual O&M cost, $/yr	$598,900	$2,519,000	$2,894,000	$4,872,000	Calc: ***71+74***
77	Total Annual Cost (capital present worth and operating cost), $/yr	$1,337,736	$4,028,700	$4,568,000	$7,581,300	Calc: **58+76**
79	Income from heat generation, $/yr	$380,520	$1,591,540	$1,833,140	$4,131,360	Calc: $0.0302****27****$10^6$
80	Net annual cost, $/yr	$956,216	$2,437,160	$2,734,860	$3,450,000	Calc: ***77-79***
81	Total cost per unit heat output, $/kWh	$0.106	$0.076	$0.075	$0.030	Calc: ***77/28***/10^6
82	Net cost per unit heat output, $/kWh	$0.076	$0.046	$0.045	$0.025	Calc: ***80/28***/10^6
	Break-even Tipping Fee					
	Combined Heat and Power Production:					
83	Waste material not including poultry litter, tonnes/yr	8211	34492	39223	39223	From Table 1
84	SRM fuel cost (tipping fee) base, $/tonne	$159	$123	$123	$213	Calc: **65/83**
85	SRM fuel cost (tipping fee) including electrical and heat sales, $/tonne	$102	$58	$57	$50	Calc: **68/83**
	Heat Production Only:					
86	Waste material not including poultry litter, tonnes/yr	8211	34492	39223	39223	From Table 1
87	SRM fuel cost (tipping fee) base, $/tonne	$163	$117	$117	$193	Calc: **77/86**
88	SRM fuel cost (tipping fee) including income from heat production, $/tonne	$116	$71	$70	$88	Calc: **80/86**

Note 1: Database based on fuel moisture level

Note 1a: Estimate from in-house data (based on reducing the temperature of the gas exiting the combustor by approximately 50% that it remains above the gas dew point temperature, thereby minimizing the condensation of corrosive gases on the heat exchar

Note 2: Biomass system including but not limited to fuel receiving, storing, preparation, conveyers and stackers. Reference 4, Pa Figure 4-3. (Sample calculation: 27.6 ton/day biomass = estimated capital cost for fuel system ($/ton/day) = 27.6 ton/day * $3500 $964,000)

Note 3: SRM fuel handling cost estimated as 50% of biomass cost except for scenario 4 where SRM handling expected to be the Scenario 3.

Note 4: Reference 4 , Page 39, Table 5-4

Note 5: Biomass fuel cost assumed to be \$1.90 / 10^6 kJ (\$2.00/10^6 Btu) delivered based on in-house data. Reference 4, Page 79 (Sample calculation \$2/10^6 Btu x 9.22 10^6 Btu x 7884 h/yr = \$145,400)

Note 6: Poultry litter delivery cost assumed to be \$0.95 / 10^6 kJ (\$1.00/10^6 Btu)
(Sample calculation: \$1/10^6 Btu x 125.84 10^6 Btu x 7884 h/yr = \$992,000)

Note 7: Reference 4, Page 54, Table 5-15.

Note 8: Reference 4, Page 39, Table 5-4

Note 9: based on 20 year plant life and 7% interest rate

Technology: Plasma Gasification
Possible Suppliers:
Plasco Energy
Alter NRG
Suppliers Contacted:
PlascoEnergy
Supplier Considered for Analysis:
PlascoEnergy – Website information only
Advantages and Disadvantages: Refer to section 3.4 below
Technology Assessment:
Commercial units firing SRM – no
Technically acceptable – appears to be applicable technology for SRM destruction application
Pilot plant recommended – yes
Recommended technology – pending results of pilot test program
Economic Analysis:
PlascoEnergy operates on a build, own and operate model for the implementation of their plants. The owner is charged a negotiated tipping fee for the disposal of the waste.

Technology: Reductive Thermal Processing
Possible Suppliers:
Vertus Technologies (Rotary Kiln)
Suppliers Contacted:
Vertus Technologies (Rotary Kiln)
Supplier Considered for Analysis:
Vertus Technologies (Rotary Kiln)
Advantages and Disadvantages: Refer to section 3.5 below
Technology Assessment:
Commercial units firing SRM – no
Technically acceptable – requires completion of testing program
Pilot plant recommended – yes
Recommended technology – providing successful testing program
Economic Analysis: Vertus builds, owns and operates its facilities and thus there is no direct capital cost charged upfront to any of its partners or operating sites. Vertus typically negotiates a fee per ton of material processed.

3.1 FIXED BED GASIFICATION

The fixed bed gasification process considered appropriate for this application is the updraft type fixed bed. The operation is such that the fuel (biomass and SRM) is introduced near the top of the reactor and moves downward. The oxidant (air) is introduced into the bottom and flows upwards with the produced gas extracted at the top of the vessel. There is some drying of the fuel within the reactor; however, the maximum allowable moisture level in the fuel is approximately 20%.

The advantages of the updraft type fixed bed gasifier compared to the downdraft fixed bed gasifier type are: the ability to handle higher moisture biomass and the ability to operate at higher temperatures which would be better suited to destroying toxins and producing slagging of minerals and metals. The tar content in the gas produced is higher than in downdraft systems resulting in higher heating values. This may also be considered as a disadvantage depending on the final use of the syngas, that is, a higher heating value (with a higher tar content) may be required for sustained combustion of syngas in a heat recovery component. In this case, the amount of tar present in the syngas would require analysis to ensure operational issues (such as plugging) in the heat recovery component are minimized. Another significant advantage of the fixed bed gasification system is the potential of lower particulate emissions leaving the combustor. This is due to the low air flow and velocity entering the combustor and the resulting relatively low turbulence at the air/fuel mixing zone. This is expected to minimize the amount of particulates carried over with the producer gas and result in a smaller, more economical gas clean-up system.

The disadvantage of the updraft type gasifier is that the production of higher tar content can foul engines or compressors. This is a disadvantage if the unit is used for power generation by an I.C. engine. The economic analysis of this option considered this requirement. It may not be as significant if the gas is to be used for combustion in a heating system.

There is no inert bed material in this type of gasification system which allows the fuel to lie directly on the grate. This may allow portions of the grate to be exposed to high temperatures resulting in overheating. The grate may require cooling or may otherwise need to be protected.

The efficiency of the fixed bed gasification system is less than the efficiency of the fluidized bed gasification system due to the more thorough mixing of the fuel on the fluidized gasifier bed.

The total cost per unit output of this system was found to drop as the output increased for all of the fuel scenarios. The cost reduction is more apparent when the income from electrical power generated is included in the calculation. In this case, the cost for fuel scenario 4 is actually negative. This trend is reflected in the break-even tipping fee for the case where electrical generation is included in the calculation, that is, case 4 with the highest electrical generating rate has the lowest estimated tipping fee.

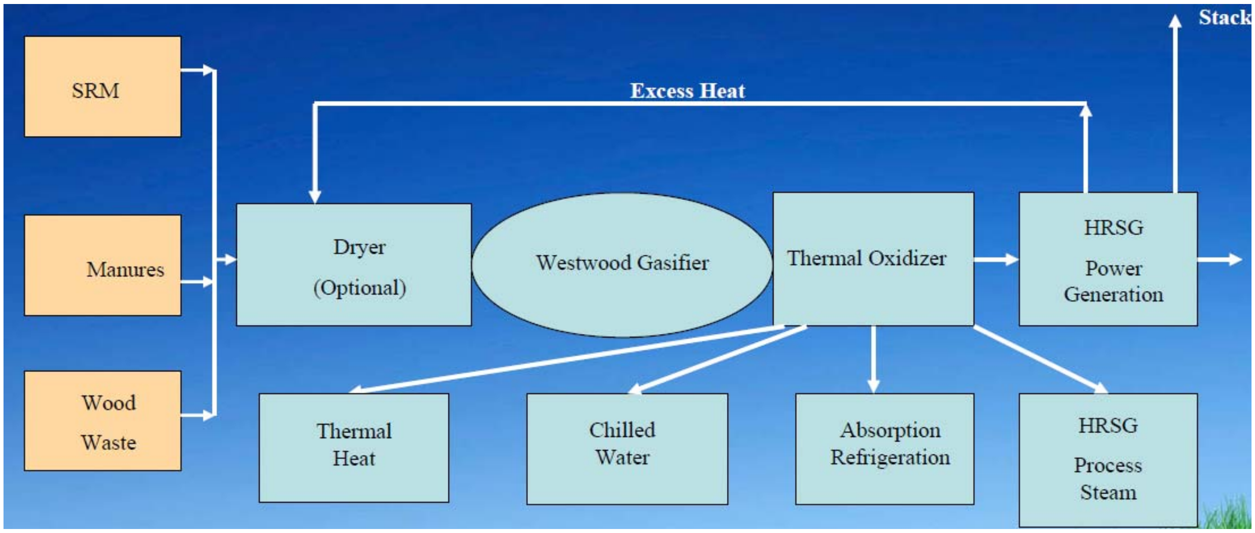

Figure 1 (Sample Gasification Process Flow – Westwood)

Figure 1 above shows an example of a gasification process flow for a Westwood system producing heat used for a process such as a heat exchanger, boiler, heat recovery steam generator or absorption chiller.

Figure 2 below is a sketch of a typical Westwood Gasifier system showing the main components of the system.

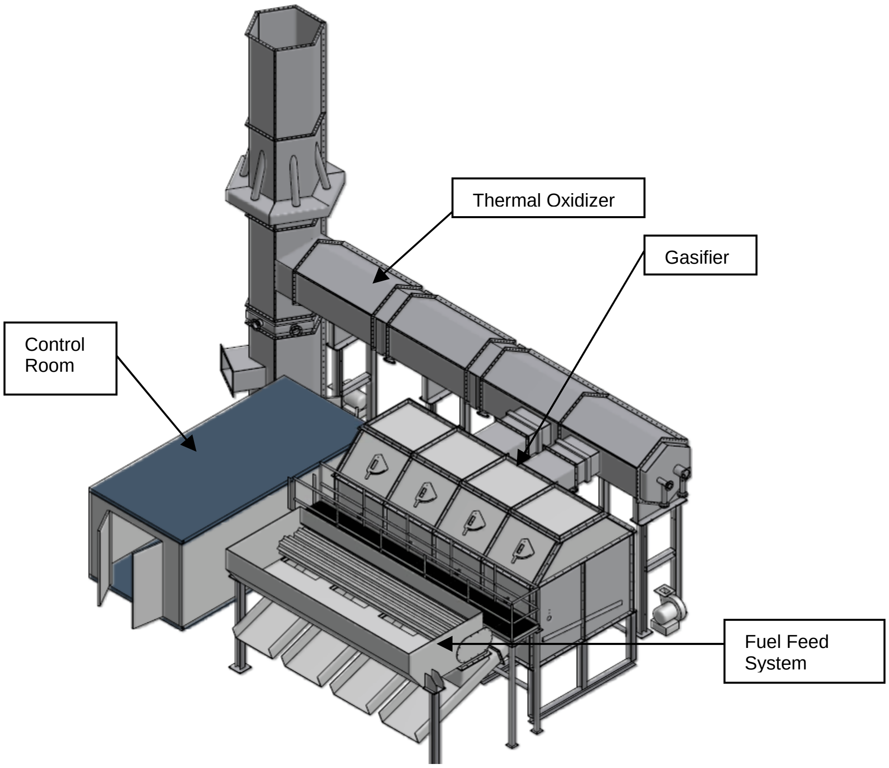

Figure 2 (Westwood Gasifier Section)

The analysis for the fixed bed combustion was based on published data and a multiple unit scenario. The use of separate units could be incorporated into a distributed SRM disposal system. These units are not transportable, however, and would not be able to be rapidly moved to a central location if required for a mass destruction situation.

Budget pricing and technical information were received from Thermogenics, Inc., Vidir Best (Biomass Energy System Technologies) Inc. and Westwood Energy Systems, Inc.

Nexterra stated that there is a concern about the potential of slagging in the combustor. A complete fuel and ash analysis is required to thoroughly understand this risk.

3.2 FLUIDIZED BED GASIFICATION

The minimum size of fluidized bed gasification units for biomass and SRM necessitates the use of a single unit located at a central site. This arrangement has the advantage of the economy of scale of a central plant as the common services for fuel delivery and ash disposal systems are minimized.

Commercialization of biomass gasification is in a relatively early stage of development; there is, therefore, limited information on availability or reliability. It is expected that availability in the range of 85% to 95% will be achievable with such units once initial trouble areas have been resolved. Potential operational trouble spots of this technology include moisture content in the fuel greater than 30% which may cause handling difficulty and increased drying equipment requirements and increased gas clean-up requirements to remove the tars and other contaminants. The issues with slagging and fouling as described in the fixed bed gasification section are valid for fluidized gasification as well.

The efficiency of the fluidized bed gasification system is greater than the efficiency of the fixed bed gasification system due to the more thorough mixing of the fuel on the bed.

The total cost per unit output of this system was found to drop as the output increased for all of the fuel scenarios. The cost reduction is more apparent when the income from electrical power generated is included in the calculation. The cost reduction trend as the unit size increases is similar to the fixed bed gasification case.

Figure 3 below is a sketch of a typical Energy Products of Idaho (EPI) fluidized bed gasifier showing the fluidized reactor and gas flow path to the cyclone separator. It can be seen that the fluidizing air enters the furnace below the grate which fluidizes the inert bed which acts to suspend the fuel during the gasification process. The amount of air entering the reactor is limited such that oxidation of the syngas does not occur. The produced syngas exits the top of the reactor and enters the cyclone separator which removes particulates of the hot syngas. The fuel enters the reactor from above the bed and falls on to the fluidized bed where the fluidized motion of the inert bed distributes the fuel throughout the bed.

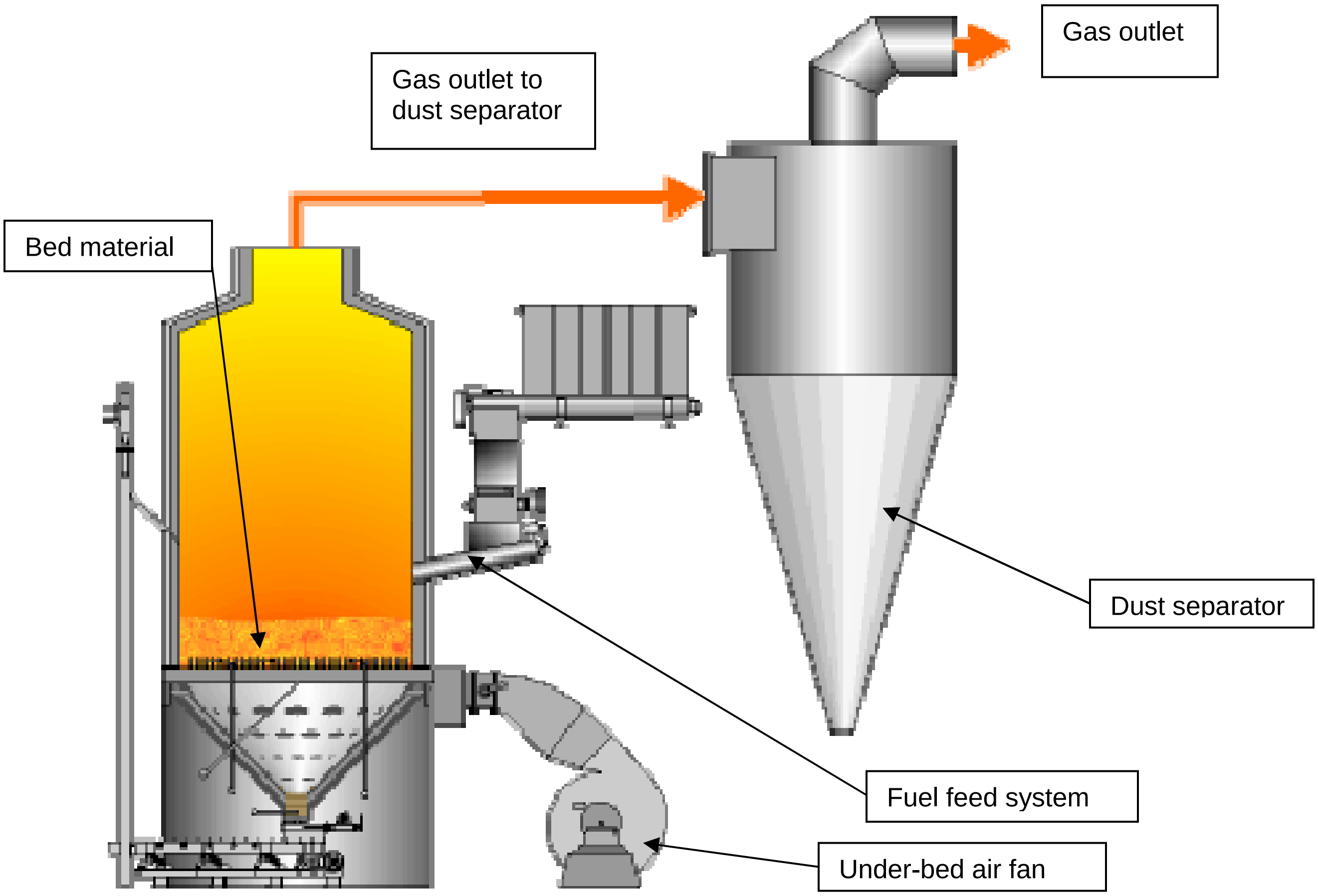

Figure 3 (Fluidized bed gasification unit (Energy Products of Idaho - EPI))

3.3 FLUIDIZED BED COMBUSTION

The process involved in fluidized bed combustion is similar to fluidized bed gasification with the exception that additional oxygen is introduced to the furnace to allow complete combustion of the fuel. In this case the gas produced by the pyrolysis of the fuel off the bed is oxidized in the same chamber or furnace which produces a hot flue gas. The hot flue gas then passes over heat exchange surfaces to produce steam for heat or power generation or hot water for heating systems. The hot flue gas is cleaned by an electrostatic precipitator (ESP) or other component prior to discharge to atmosphere. The advantages of this system are:

- The possibility to efficiently combust biomass and other low grade fuels (SRM) that are difficult or impractical to burn with conventional methods by using the thermal inertia and effective mixing inherent in the inert bed of the fluidized bed gasifier.

- The more efficient mixing of fuels on the bed resulting in a higher heat release rate per unit area thus allowing a more compact design of combustor than conventional grate type spreader stoker type water tube boilers.

- The longer residence times which may result in the fuel being burned at lower temperatures (760°C to 870°C (1400 to1600°F)) than conventional combustion processes (1204°C (2200°F)) such as spreader stoker combustion. It should be noted that the published temperature range is acceptable for the destruction of the SRM providing the residence time is greater than 15 minutes.

- The lower risk of slagging and fouling in the heat exchange surfaces of the fluidized bed boiler compared to the spreader stoker type boiler due to combustion temperatures that may be less than the ash fusion temperature for the particular fuel fired.

- The possibility of the thermal efficiency being as much as 3% higher than fixed grate biomass boilers as the unburned carbon loss is reduced due to the more effective fuel bed mixing.

- These systems are typically large systems used for steam production for electric power generation or in combined heat and power applications.

Disadvantages of these systems are:

- The fuel must be carefully sized and processed to ensure steady heat input into the boiler. This will require thorough mixing of the various biomass fuels before feeding to the boiler.

- They are typically larger in size and more suitable for combined heat and power (CHP) applications. The CHP applications require access to a steam host such as a pulp mill so that the highest cycle efficiency may be achieved.

- Regulatory hurdles for a central plant.

- Shipping of the fuel to a central plant. The larger plants typical of these systems will require a high volume of truck traffic for fuel delivery.

Co-firing combustion of SRM and biomass is a possibility with the cooperation of a joint venture biomass developer. This development scenario may provide the best solution to utilize the existing combustion infrastructure within the province. In this case, the SRM material would be processed in an off-site facility and transported to the biomass fired power plant in bulk tank trucks, off-loaded to storage tanks at the plant site, and then pumped directly (unmixed) into the boiler combustion chamber and sprayed onto the bed. This combustion technique is currently in commercial operation in Sweden at four power plants. The total amount of SRM material and slaughterhouse waste currently being disposed of annually is approximately 85,000 tonnes. The scheme is attractive in that the preparation of the SRM takes place in a central location and involves a relatively low energy process. The SRM is ground into a pumpable consistency. This is a much less energy intensive process than rendering. The product is referred to as Biomal. The advantage of the introduction of Biomal into the boiler is the stabilizing effect of the constant fuel stream. It has also been found that the NO_x emissions have also dropped due to the ammonia in the Biomal product.

The commercialization of the Biomal project in Sweden was the culmination of a project sponsored in part as a LIFE Environmental project. LIFE is the European Union’s financial instrument supporting environmental and nature conservation projects throughout the European Union, as well as in some candidate, acceding and neighbouring countries.

The relative unit cost of the capital cost required for a steam plant tends to drop as the size of the plant increases. The operating and maintenance costs also tend to decrease as the size of the unit increases.

The total cost per unit output of this system was found to drop as the output increased for all of the fuel scenarios. The cost reduction is more apparent when the income from electrical power generated is included in the calculation. The cost reduction trend as the unit size increases is similar to the gasification cases.

It should be noted that the cost per unit output is higher than the gasification options which appears to be due to the lower overall plant efficiency of the steam turbine generator than the IC gensets considered on the gasification options. The lower plant efficiency is the result of the heat in the steam turbine exhaust being lost when it is condensed. The overall plant efficiency would improve if the heat in the steam turbine exhaust is utilized.

Figure 4 shows the fluidizing air entering under the inert bed material much like the fluidizing gasification unit. In this case, however, additional combustion air is added in the furnace above the bed to permit oxidation of the gas produced by the initial combustion of the fuel on the bed. The introduction of the fuel to the inert fluidized bed is similar to the fluidized gasification technology in that the fuel enters the furnace above the bed where it is distributed by the fluidized motion of the bed.

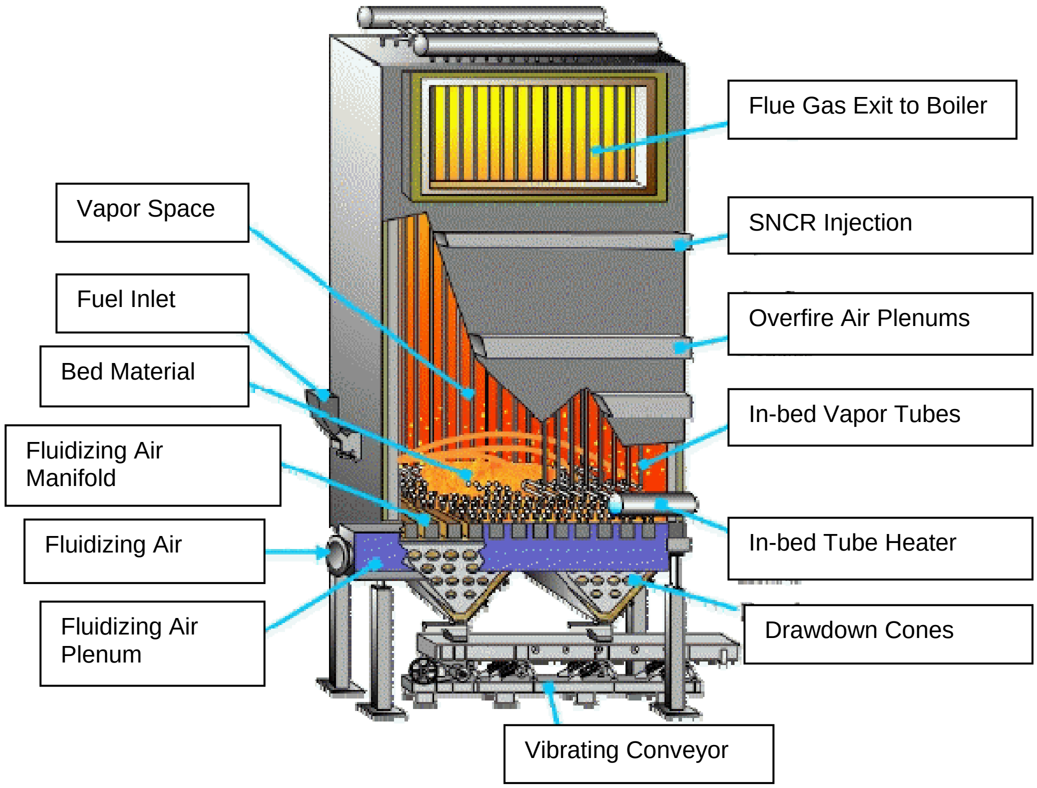

Figure 4 (Fluidized Bed Combustion Unit - Energy Products of Idaho - EPI)

It should be noted that Energy Products of Idaho (EPI) has included in their response to the enquiry an offer ($12,000 total) for the following design package which may prove beneficial as the project progresses:

- Process Calculation Sheet – Including temperature, pressures, heat transfer rates, efficiencies, fuel flow analysis, steam production, flue gas flow and stack temperature.
- Emissions Predictions – Including SOx, NOx, CO, particulate emissions, limestone consumption, HCl and VOC.
- General Arrangement Drawings – Including dimensional elevation and plan views as well as representative process flow through the equipment.

3.4 EMERGING TECHNOLOGIES

The following technologies are considered as emerging technologies that show promise in the destruction of specified risk material. These technologies are close to becoming commercially available and in the near future they are expected to be a viable alternative to gasification and combustion technologies for the destruction of SRM.

3.4.1 Plasma Gasification

Plasma gasification is a process promoted by the private PlascoEnergy Group that uses a proprietary technology to convert municipal household, commercial or industrial waste into electrical power and other products. This technology is mainly focused on the disposal of municipal solid waste. Confirmation of the ability to destroy SRM is required. The technology of the PlascoEnergy Group system is described as follows:

Waste is fed into the primary chamber of the converter where the material is gasified by heat recovered from the gases exiting the refining chamber. Within the refining chamber, there are two plasma torches. The gasified product from the primary chamber contains carbon monoxide, hydrogen, tars and un-reacted carbon. This gas is refined into a cleaner and lighter gas in the secondary chamber. Process air and plasma heat are combined with the gas and the plasma heat is adjusted to maintain the desired process chamber conditions. All long-chain hydrocarbons are destroyed in the process. Since process heat is recycled to the converter, plasma is never applied directly to the garbage. Instead it is used as a highly efficient way to refine the resulting gas.

With the Plasco Conversion System, the gas is cleaned prior to generating electricity. After passing through the heat recovery unit, the gas flows to the Gas Quality Control Suite (GQCS) where the gas is cooled and cleaned of particulates, metals and acid components. All of the process units that comprise the GQCS have been extensively used and proven in other industries that process gas. Agricultural sulfur and commercial salt are recovered from the GQCS processes.

The solid residue from the primary chamber is sent to a separate high-temperature chamber equipped with a plasma torch where it is melted. Plasma heat is used to stabilize the solids by driving off any remaining volatile compounds. Any volatile gas is passed through several cleaning steps before being combined with the main gas stream. The melted material is poured into a water bath where rapid cooling creates small solid pellets. This vitrified residue is an inert, non-hazardous, glass-like solid. Leachability tests have been conducted on the solid material emerging from the process and have confirmed that it does not leach and is not toxic. According to the tests, it is safer than a common soda bottle and is valuable as construction aggregate for roads, concrete, or other building materials.

At the end of the conversion process, more than 99% of the residual waste sent to a PlascoEnergy facility is recycled into valuable products. For each tonne of waste, approximately 1.3 kilograms of heavy metals and filter screenings require disposal. These heavy metals are due to improper disposal of hazardous waste, such as batteries, by the public and are not due to the Plasco Conversion System. The moisture recovered from the waste is cleaned, and is suitable for irrigation or for use in industrial processes.

This process is shown in Figure 5 below:

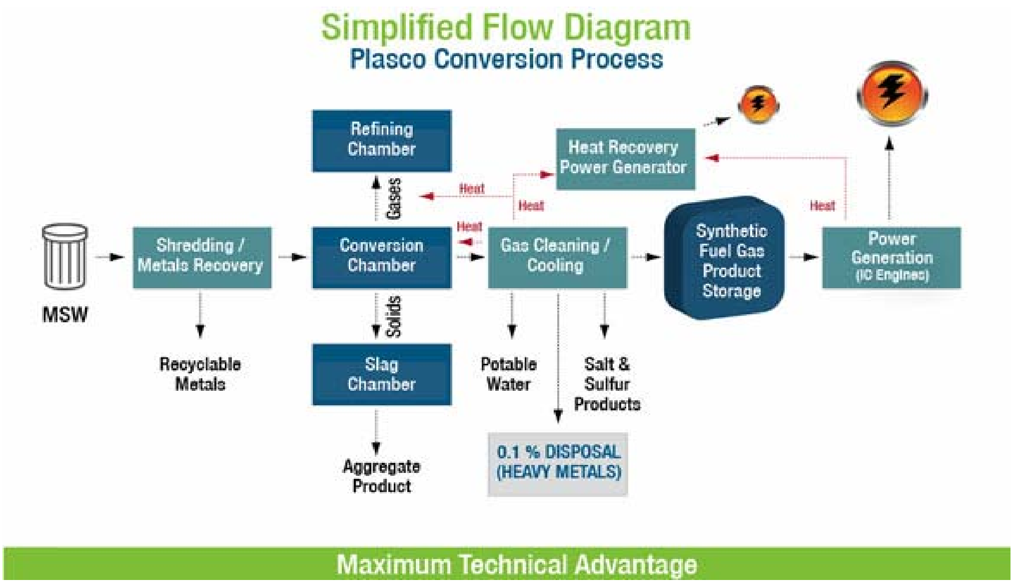

Figure 5 (PlascoEnergy Process)

The advantages of this system are:

- PlascoEnergy finances the construction and commissioning of its own facilities.
- PlascoEnergy earns revenue primarily through the sale of electricity and tipping fees for the waste processed. The market determines electricity prices, and tipping fees are set in a long-term contract.
- The primary requirements to build a facility are a guaranteed waste stream, guaranteed sale of electricity and a location.
- The facilities are built in identical 100 tonne-per-day modules. This ensures the highest level of quality and allows a facility to be constructed and commissioned in a single year.

The key disadvantage of this system is the lack of commercial plants used for the combustion of SRM and slaughterhouse waste. This technology should be considered as the project progresses.

PlascoEnergy builds, owns and operates Plasco Conversion System facilities.

3.4.2 Reductive Thermal Processing

The Reductive Thermal Processing (RTP) technology used in the Vertus Facility incorporates sophisticated thermal processing systems to create a continuous solid materials/fuel treatment method that separates the fuel from the non-fuel components (unwanted air contaminants, toxins, and moisture). RTP technology is suitable for treating materials to more than 1000°C in a contained and controlled manner. Unlike fixed temperature systems the RTP technology is highly flexible allowing for wide ranges of input material moisture levels, ash contents, BTU levels, and material consistency. The rotating nature of the system allows efficient and thorough transport of materials through the system. The system is easily sterilized before and after material processing. During the processing of materials that contain volatile carbon compounds, a combustible gas containing these volatile carbon compounds and in addition many hazardous air contaminants are driven into the gas phase and into a combustion system where they are converted to carbon dioxide, steam, and to a small extent nitrogen oxides. The combusted fuel gas, now a flue gas, is treated with a sophisticated emission control system that collects and neutralizes particulate matter, acid gases, and any non-combustible species such as heavy metals. RTP technology allows collection of ash and other non-combustible mineral material and conversion to usable/saleable materials which can be utilized as raw materials in many other industries. As discussed in more detail below, RTP technology is modular and allows efficient deployment of capital equipment. Additionally, RTP technology anticipated for use with non-SRM materials can be quickly and easily reconfigured to treat emergency situations which are generating SRM materials. After the SRM materials are treated the RTP system can be returned to its former commercial application.

The Vertus Reductive Thermal Processing (RTP) is presented schematically in Figure 6 below.

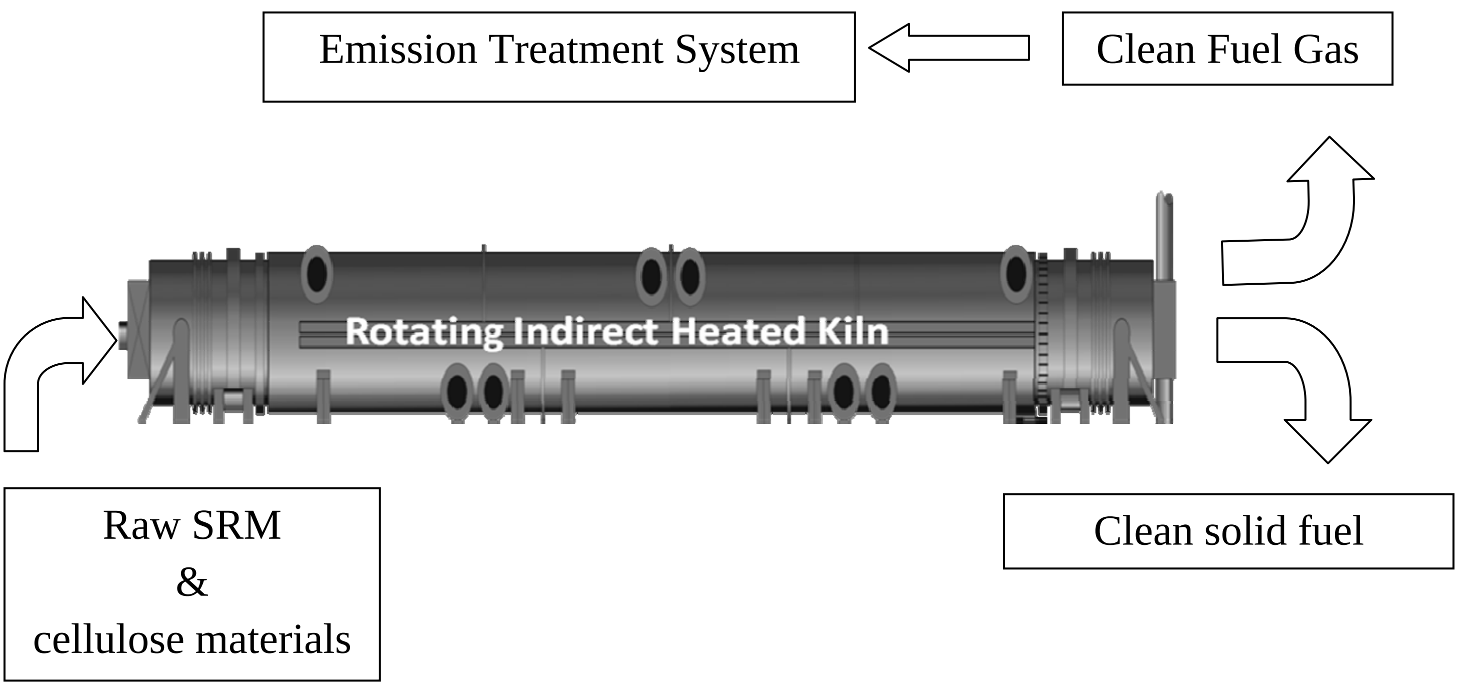

Figure 6 (Vertus – Reductive Thermal Processing)

Vertus has plans to construct and perform an operational pilot test of its Reductive Thermal Processing (RTP) material processing facility in early 2009 in the Vancouver region. Several sites are now under investigation and evaluation. Vertus appear to understand the need to operate in an effective and regulatory compliant manner for SRM material processing.

The Vertus RTP facility and technology will simultaneously solve two regional problems: 1) the need for treatment and disposal of cellulose based waste streams and 2) the need for clean burning solid fuels.

The Vertus RTP facility planned for installation in 2009 will treat cellulose based waste systems in the Vancouver region. The facility will treat waste materials with the intention of generating a clean burning solid fuel for use in various industries in the region including the greenhouse industry. In order to control and remove unwanted contaminants such as sulfur, chlorine, nitrogen, and toxins that may be present in raw cellulose based materials the facility will incorporate state-of-the-art particle and emission control systems.

Vertus has a strong commitment to treating difficult animal and cellulose based materials, with the intention of generating both clean energy and by-products useful for treating industrial environmental problems.

Initial studies of animal-cellulose based waste materials now present in the Vancouver region are already underway. Spent poultry bedding waste and the raw materials (wood/fiber) used to prepare new poultry bedding have been analyzed. Results indicate that the Vertus technology and processes can handle the moisture levels of these materials. Results also indicate that this waste material can be processed in a manner to yield either a gaseous fuel product or a solid clean burning fuel product. Process operating conditions are available to provide a wide range of different ratios of gas/solid fuel ratios desired. Note that different gaseous and solid fuel ratios are obtained by Vertus using only one core piece of equipment - a heated rotating kiln system - and varying the process conditions of this system.

Initial discussions with industrial sites in need of clean burning fuels have indicated a strong desire to have Vertus install and operate RTP systems on their site. Early evaluations by Vertus support the concept that RTP systems for processing animal and cellulose based waste can be operated safely and cost-effectively on many poultry and greenhouse sites. Operations at these sites allow the direct use of fuel gases generated by the Vertus RTP technology.

The Vertus RTP technology is modular and implemented in a range of sizes which are dictated by site needs. A modular system approach allows operational redundancy, wider input material treatment opportunities, and operational cost efficiencies. Modularity also allows mobile systems to be designed and implemented. In some cases, energy needs for mobile operations can be completely supported with fuel gas combustion (self-sustained operation).

Vertus employs a build-own-operate business model which eliminates up-front capital costs to sites. Additionally, this business model allows new Vertus technology and process equipment to be installed and utilized to improve operational efficiency and to reduce costs. Vertus Technologies typically negotiates a fee per ton of material processed.

The possible disadvantage of this technology is the chance that this technology will not operate as predicted for the destruction of the SRM waste. It is important to ensure a thorough pilot test is implemented prior to proceeding with a full-scale commercial plant.

Confirmation of the ability of the Reductive Thermal System to achieve the required temperatures to ensure destruction is a necessary goal of any potential pilot testing program.

4.0 CONCLUSION

It was confirmed by potential equipment suppliers that each of the technologies reviewed appears to be capable of gasification or combustion of SRM material while blended with biomass (wood waste for fuel scenario 1, 2, 3 and poultry litter for fuel scenario 4).

Confirmation of the applicability of the fixed bed gasification, fluidized bed gasification, plasma gasification and reductive thermal processing technologies requires the institution of a pilot plant testing program. The pilot plant testing program would confirm the capability of the particular technology to achieve the required destruction of the SRM. Further, fuel and ash analysis of the SRM / biomass blend is required as the project proceeds. The testing program for plasma gasification and reductive thermal processing technologies may consist of testing in newly announced facilities provided approval is established with the developer, government agencies and the public.

Fluidized bed combustion using the Biomal fuel delivery is a commercially available technology and used for the destruction of 85,000 tonnes of SRM material in four plants in Sweden. It is expected that this technology could be readily adapted to the destruction of SRM in British Columbia. The co-firing of the Biomal material and biomass in a new or existing power boiler will require cooperation between the possible developer, the related government agency, BC Hydro and the public.

The maximum plant size of the fixed bed gasification unit necessitates the use of multiple units to process the required biomass and SRM volume for scenarios 2, 3 and 4. This arrangement can be advantageous in that the units may be permanently located in a distributed manner close to the various sources of the SRM / biomass material. Further, it may be possible depending on the specific supplier to move these units to a central location if required during an emergency period of SRM destruction. The disadvantage of this arrangement is the necessity to install up to six units at a single location to act as a central processing station with this technology for fuel scenario 2, 3 and 4. This may lead to the duplication of common services such as fuel and ash handling equipment. The advantage of this arrangement is the redundancy of the multiple units.

The fluidized bed gasification and fluidized bed combustion systems can accommodate the required fuel (SRM and biomass) for scenarios 2, 3 and 4 in a single unit. The advantage is that common equipment is minimized and larger more efficient and more commercially proven units are used. The disadvantage is that these units must be located at a central site and the SRM transported from the various sources.

The following are general advantages of gasification versus combustion:

- Produced gas can be cleaned and filtered to remove problem chemicals before burning.

- Produced gas is more versatile than the solid fuel, i.e., the gas can be used in boilers, process heaters, turbines and engines.
- Produced gas can be distributed in pipelines and blended with other gaseous fuels.
- Gasification is suitable for a wide range of biomass feedstocks without changing the process.
- Gasification is suitable for processing waste fuels and providing safe removal of biohazards and entrainment of heavy metals in non-reactive slag.

The cost of disposal of the SRM / biomass tends to decrease as the size of the unit increases for each of the technologies. This is as expected as the larger units take advantage of the economies of scale and combined common services.

The relative cost of the technologies studied shows that the two gasification options are very close with the fixed bed units slightly less expensive. Both of the gasification options are less expensive than the fluidized bed combustion option mainly due to the lower plant efficiency of the combustion based plant with the steam generator.

The model for the cost of material processed by plasma gasification and reductive thermal system suppliers is negotiated at the initiation of the project. The systems are provided on the basis of building, owning and operating with the tipping fee included to capture all associated costs.

5.0 RECOMMENDATIONS FOR FURTHER STUDY

The following are recommendations for future study:

- Conduct lab tests on the various fuel blends to determine the ultimate and proximate analysis.
- An ash analysis is required to determine the ash fusion temperature.
- Study the feasibility of establishing a Biomal processing facility in the Fraser Valley. This facility may be considered in conjunction with the existing West Coast Reduction rendering operations.
- Initiate a pilot plant testing program to combust SRM and slaughterhouse material using existing power stations in relation to new biomass plants being developed in conjunction with BC Hydro’s latest power call.
- Study the feasibility of firing the SRM material in the proposed Vertus Technology RTP facility.
- Study the feasibility of firing the SRM material in the proposed PlascoEnergy plasma gasification facility.

6.0 DEFINITIONS

TERM	DEFINITION
Ash fusion temperature	The temperature at which ash melts sufficiently to adhere or coalesce on the heat exchange surface
Biomal	Processed animal by-product which is converted to a biofuel by crushing and grinding rather than rendering
Biomass	Biological material that can be converted into fuel
Fouling	The formation of ash deposits on convection heat surfaces
Genset	Diesel or gas powered electric generator
IC engine	Internal combustion engine
Slagging	The formation of molten or partially fused deposits on furnace walls or convection surfaces exposed to radiant heat
Syngas	A gas mixture that contains varying amounts of carbon monoxide and hydrogen generated by the gasification of a carbon containing fuel to a gaseous product with a heating value
	ACRONYM
AAFC	Agriculture and Agri-Food Canada
BCMAL	British Columbia Ministry of Agriculture and Lands
RFP	Request for Proposal
MSW	Municipal Solid Waste
EOI	Expression of Interest
Btu	British Thermal Unit
Btu/ft^3	British Thermal Unit per cubic foot
Btu/h	British Thermal Unit per hour

kJ	Kilojoule
Kg	Kilogram
kJ/kg	Kilojoule per kilogram
kW	Kilowatt
kW_{th}	Kilowatt (thermal)
LHV	Lower heating value – heating value of material including moisture in analysis
HHV	Higher heating value - heating value of material not including moisture in analysis
O&M	Operating and maintenance
BFB	Bubbling fluidized bed
ACFB	Atmospheric circulating fluidized bed
CFB	Circulating fluidized bed
HRSG	Heat recovery steam generator
CHP	Combined heat and power is a system that involves the recovery of waste heat from power generation to form useful energy like useable steam. Combined heat and power is also the production of electricity and thermal energy in a single integrated site.
STG	Steam turbine generator
TSR	Theoretical steam rate
ESP	Electrostatic precipitator
RTP	Reductive Thermal Processing
SRM	Specified Risk Material is defined as tissue that, in BSE-infected cattle, has been shown to contain the infective prion and can transmit the disease. The following tissues are defined in federal regulations as SRM: skull, brain, trigeminal ganglia (nerves attached to the brain), eyes, tonsils, spinal cord, and dorsal root ganglia (nerves attached to the spinal cord) of cattle aged 30 months or older, and the distal ileum (part of the small intestine) of cattle of all ages. The entire carcass or any part thereof of condemned cattle and cattle dead stock, regardless of age, must be treated as SRM if they contain SRM. Any inedible material that is mixed

	with SRM, such as floor waste or recovered solids from waste water, must also be treated as SRM.

7.0 References

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3. “Demonstration of a Small Modular BioPower System Using Poultry Litter”, DOE SBIR Phase 1, Final Report, February 25, 2001.

4. EPA Combined Heat and Power Partnership, Biomass CHP Catalog of Technologies (Chapter 4: Biomass Preparation and Chapter 5. Biomass Conversion Technologies).

5. An Assessment of Gasification as an Alternative Technology for the Disposal of Slaughterhouse Waste, March 15, 2006, Thompson River University.

6. EPA Combined Heat and Power Partnership, Catalog of CHP Technologies, Technology Characterization – Reciprocating Engines – Page 18.

7. EPA Combined Heat and Power Partnership, Catalog of CHP Technologies, Technology Characterization – Steam Turbines – Page 15.