Technical Evaluation of Yukon College Gasifier

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Executive Summary

A technical and economic evaluation of a biomass gasifier situated at Yukon College in Whitehorse has been carried out. The 2 MW_{th} gasifier, designed to provide space and water heating, was originally installed in 1987 but was never commissioned. In addition to a detailed examination of the equipment and its current condition, the results of a "gasification" trial are reported.

CANMET staff inspected the gasifier facility during the week of March 22 to 27, 2004. The status of the equipment may be summarized as follows:

> The biomass feed system appeared to be in good working order. The feedrate is set by a manual dial (0 -5). In order to prepare for a test run of the gasifier, calibration tests were carried out for the feed system and a calibration curve was prepared. The nominal feedrate corresponds to ~ 2000 MW_{th} or 7 MBTU/h.
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> The air delivery system was in good working order but lacked any capability to measure the flowrate or affect the portion of air diverted to the fuel feed system.
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> The gasifier is preheated by firing an oil "burner" into an air plenum where the air is heated to 650 C.. The pre-heater required some servicing but was successfully fired.
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> The fluidized bed gasifier, a 36" ID 170" high refractory lined (est. 8" thick) vessel, was found to be in good working order. Internal inspection of the gasifier found no damage to either refractory or air distribution pipes. The gasifier was found to contain sand which was determined to be suitable for further testing.
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> The syngas produced in the gasifier is combusted in a firetube boiler (B1) which can also be fired with No. 2 fuel oil. Syngas is supplied via a manifold to diffusers within the combustion chamber. The boiler is equipped with a Fuel Master Burner Model CO-300 firing No. 2 fuel oil @ 400 psi with a high fire rate of 80 USGPH (3664 kW; 12.5 million Btu/h). Examination of the combustion chamber found that the ceramic fibre blanket was in good condition. The syngas diffusers were found to have suffered severe corrosion. These would have to be replaced before any long term operation (with consideration given to better material of construction) however it was decided that the diffusers were adequate for the trial planned in this work.
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> Portions of the control system were found to be inoperative and had to be bypassed. After careful review including consideration of health and safety concerns, it was decided that the gasifier pilot plant could be run (in trial mode only) with a combination of additional temperature and pressure monitoring and manual control.

Once the various sub-systems had been tested, additional instrumentation installed (temperature and pressure sensors, manometers, data acquisition) and control strategy developed, a trial run of the gasifier was carried out on March 27, 2004.

The efficiency of boiler B1 was initially determined using only the No. 2 fuel oil burner. Under Lo-fire conditions (est. 20 USGPH) with 85% excess air, the thermal efficiency of the boiler was determined to be 85.8%. Under Hi-fire conditions (est. 80 USGPH) with 12^ excess air, the thermal efficiency of the boiler was determined to be 86.5%. It should be noted that these tests were conducted over a relatively short period of time and so true steady state was not achieved, however the tests do indicate that as an oil-fired system, B1 boiler operates with good efficiency. The exact heat input for Lo and Hi-fire settings was not determined and documentation for these was unavailable.

The fluidized bed gasifier was successfully operated in combustion mode. Wood chips were fed at approximately 40 kg/h (0.75 dial setting) representing an input of 210kW (700,000 BTU/h). The fluidized bed temperature was easily maintained at approximately 750 C and the unit operation was very stable. It is estimated that this unit without modifications could be used to produce at least 250 kW by operating in combustion mode. The size of the unit is such that up to 1000 kW could be produced by introducing a heat transfer surface in the fluidized bed region.

The fluidized bed gasifier was successfully operated as a gasifier for a brief period. Wood chips were fed at approximately 390 kg/h (3.0 dial setting) representing an input of 2050 kW (7 million BTU/h). The fluidized bed temperature was between 600 -700 C during the gasification period. Control of the air flowrate to the unit was done manually based on unit temperature response - this is a very poor control method especially since the actual flowrate is unknown and directions were generally of the type "turn the valve half a turn to the left". The trial was prematurely terminated due to two principal factors: a jammed fuel supply due to very large non-homogeneous chips and because the paint on the outside of the burner section of B1 boiler began to smoke and burn. This in itself was a sign of successful production of large quantities of syngas.

The findings of this evaluation are that the gasifier can be operated but not in its present condition. There are no significant health and safety issues with the operation of the gasifier. The major requirement is for new instrumentation for monitoring and control. The recommended changes are listed below under three categories: "Required" which have to be made for safe and controlled operation, "Strongly Suggested" for proper long-term operation and "Optimal" for optimal performance.

Required

Air Flow Measurement necessary for proper control of the gasifier.

New Control System (hardware/sensors/software) as the existing control system is completely inadequate to properly operate the gasifier.

Quality Control of Fuel to ensure a continuous stream of homogeneous dry chips.

B1 Dilution Air Hood (Health and Safety Issue) to ensure that exhaust venting even under upset conditions is outdoors. (The potential is currently that exhaust could spill into the boiler room)

Oil Lance (Pilot) and New Syngas Diffusers for B1 Boiler. A small oil lance/burner (1 USGPH) would be adequate to provide a source of ignition. In order to ensure proper mixing and burning of the syngas the existing diffusers which are badly corroded have to be replaced.

Water Injection into the gasifier in order to prevent high temperature excursions which could cause premature shutdown of the gasifier.

Strongly Suggested

A new pre-heat oil burner as the existing oil burner used to pre-heat the gasifier is of rather crude design and performs very poorly.

Emissions Control (Baghouse /Stack Modifications) The existing stack rise 44" above the roof line. This does not provide any significant draft and also leads to the release of particulates and odours into the outside area around the physical plant. The stack height can be compensated for by the ID fan however the emissions require an emissions control device prior to the stack.

Emergency exhaust / flare system to flare the syngas in the event of a problem with the B1 boiler or ID fan.

Optimal

Minimize Cooling in Syngas Path to prevent excessive cooling of the syngas which could allow tars in the syngas to condense and eventually plug the ducts.

New Air Distributor in the Gasifier as the existing distributor is bulky and reduces mixing in the bed.

*Bed Solids Handling System*s for bed ash removal or sand addition during operation. In the case of upset conditions, sand may be blown out of the system. This material must be replaced in order for the fluidized bed to function properly. Without an ash withdrawal system larger particles will accumulate and eventually necessitate a shutdown for their removal.

An ID Fan Speed Controller to reduce power consumption and also allow sealing of the dilution air ports in B1 boiler

The economic evaluation of operating the gasifier obviously ties into the costs of carrying out these modifications. The total cost of making the gasifier operational is thus estimated to range from $270k for all required and recommended changes to $560k for a fully optimized system with the most expensive emissions (electrostatic precipitator) control measures. An additional contingency of $90k has been estimated for the overall installation. A detailed engineering study would have to be carried out to arrive at a more precise cost.

Given uncertainty regarding the requirement for additional personnel (i.e. above normal heating plant requirements with oil/electrical) the following table summarizes the break-even cost of wood according to how many additional staff are required. In this table (taken from Figs. 30 and 31) it has been assumed that fuel oil costs 60 cents per litre and electricity costs 6 cents per kWh:

Maximum Cost of Wood per Tonne to Break Even

	vs 60c/litre oil	vs 6c/kWh
3 Add. PY	$160	$100
2 Add PY	$200	$150
1 Add PY	$250	$200
No Add PY	$290	$250

This means that if a wood price can be obtained lower than the number in this chart then wood becomes more economical. The actual cost savings of using wood depend on the cost of modifications but clearly wood heating should be a practical and economical approach.

In terms of wood supply for the gasifier, in terms of complete harvesting an area of only 2.4 hectares per year (0.024 sq km) would be required. This is very small when one considers the amount of forest fire kill (> 1000 sq km/year) and the beetle kill (~ 2200 sq km) areas available.

In order to operate the gasifier in a sustainable manner (i.e. growth rate equals to harvesting rate) the area required is only 1.9 sq km. The gasifier operation could thus easily be supported by forest biomass in a sustainable manner.

Aside from the environmental and economic benefits of operating the gasifier to provide heat from a renewable resource, the gasifier installation itself offers the opportunity to serve as the basis of future economic and technical developments. The syngas produced by the gasifier (CO and H_2) provides the building blocks upon which an entire field of research on renewable fuels could be established at Yukon College. This research could position the College at the forefront of investigations into advanced power generation technologies, production of liquid fuels (bio-diesel, ethanol and methanol) and as an entry point to the hydrogen economy.

Acknowledgements

The authors wish to acknowledge the hard work, long hours, enthusiasm and daring of the following participants who made every effort to ensure successful equipment preparation and test program: Jim MacPherson, Paul Leslie, Wes Rudolph, Neil MacPherson, Deryck Hockley, Jim Irwin, Tom Renwick and Robert Collins who shepherded us through this entire process. Thanks also to Albert Rock for the loan of data acquisition sensors.

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1.0 Introduction

The objective of the proposed work was to carry out the technical and economic evaluation of an existing biomass gasifier as a potential greenhouse gas neutral energy system to provide space heating for a Yukon College in Whitehorse. The 2 MW_{th} gasifier, shown schematically in Fig.1, was designed to provide space and water heating and was originally installed in 1987 but was never commissioned.

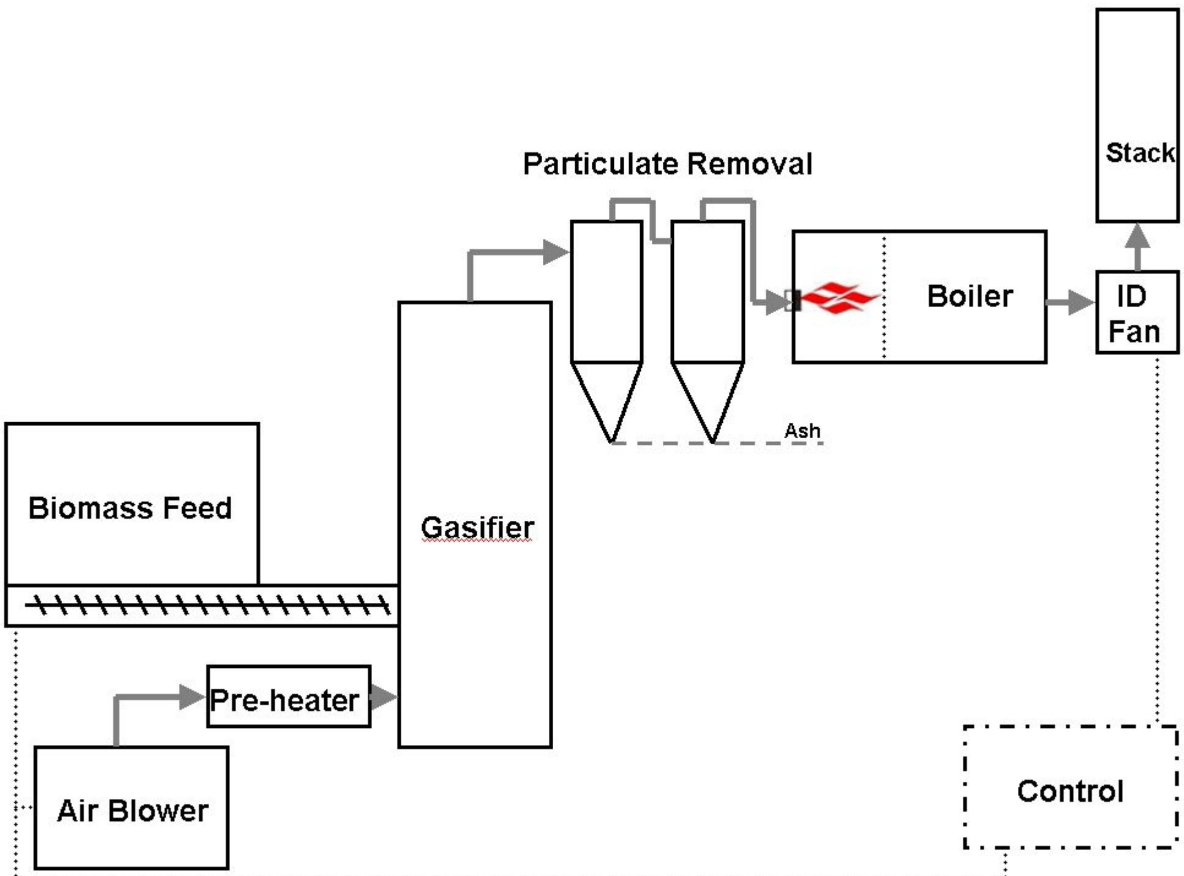


Figure 1. Schematic of Yukon Gasifier Facility

The gasifier was originally installed by Sur-Lite Corporation. Sur-Lite Corporation of Santa Fe Springs, California claimed to have successfully gasified rice hulls, shredded tires, manure, refuse derived fuel. Literature claims to have supplied gasifiers for cotton gins ranging in size from 0.6 to 5 tons hour (10 to 80 MBTU/h). In the case of the Yukon College gasifier, Sur-Lite was unable to commission the unit and settled with the Yukon Government for non-performance. ACR Mechanical Systems of Whitehorse was contracted to troubleshoot and commission the unit, however these efforts failed and the unit was taken out of service in 1991. Since then, a number of contracts and studies have been carried out to consider the economics of operating the unit, consider dismantling the unit or even consider re-furbishing the unit. Some of the studies have been contradictory and even made questionable assumption but the end result is that the unit has been decommissioned and the boiler plant derated.

At the start of 2004, the gasifier and its boiler had been physically disconnected from the heating system at the college. The college had been running on an electric boiler using secondary electricity as its primary fuel source for over 2 years. However this equipment is ageing and a decision will soon be required as to a replacement and whether the gasifier installation should be removed in order to accommodate the new system. At this point, the CANMET Energy Technology Centre (CETC-O) in Ottawa (part of Natural Resources Canada) was contracted by the Government of the Yukon, Department of Energy, Mines and Resources to carry out a technical evaluation of the gasifier unit and recommend potential courses of action. The tasks to be carried out by CETC-O were:

Task #1. Review background information on gasifier; Carry out fuel analyses and assess heating potential and ash issues; Discuss with Yukon staff to consider other potential gasifier fuels.

Task #2. Visit to Whitehorse; Inspect unit; assess current status; Examine feed system, gasifier unit, gas cleaning, emission controls, ash handling, safety equipment review monitoring and control system; Install portable CETC-O on-line analyzers; Attempt to run equipment to carry out emissions trial (CO, CO_2; O_2; PM); collect solid samples; Gather grab samples to allow for the later determination of hydrocarbon and nitrogen species; Take measurements to determine the overall efficiency of gasifier and boiler unit operated on biomass and oil. [The attempt to run the unit will be made during a five (5) day visit - If the attempt is successful then the results will be reported. If the attempt is not successful then the report will describe the causes of the failure. Time on-site will be limited to five (5) days].

Task #3. Deliver test samples to CETC-O's analytical laboratory; Carry out a review of expected equipment update and operating costs; Carry out economic assessment of heating with biomass versus conventional fossil fuel systems; Identify safety deficiencies and normal and special operating requirements; Analyze grab samples for hydrocarbons and nitrogenous emission speciation.

Task #4. Carry out assessment of alternative approaches to fluid bed operation (gasifier/combustor) or other potential modifications, including GHG reduction potential of the various approaches

Task #5. Carry out analysis of run data from the trials in Whitehorse and prepare a final report containing the results from Tasks 1 - 4.

Task #6. F. Preto and E.J. Anthony travel to Whitehorse to present results of study and fluid bed basics lecture.

CETC-O staff conducted the evaluation during the week of March 22 to 27, 2004 and the results are reported in this report. Task 6 was carried out during the week of June 21, 2004 and the comments received at the time were incorporated into this report.

1.1 Greenhouse Gas Reduction Potential

It is commonly assumed that biomass fuel cycles based on renewable harvesting of wood or agricultural wastes are greenhouse-gas (GHG) neutral because the combusted carbon in the form of CO_2 is soon taken up by regrowing vegetation. Hydro electricity is also considered to be GHG neutral, therefore if biomass is used to replace hydro generated electricity then no additional GHG benefit is accrued. If on the other hand biomass is to replace oil then a GHG reduction of 2.6 kg of CO_2 per litre of oil is gained. For the Yukon College Gasifier the annual heat demand is of the order of 6,000,000 kWh which corresponds to approximately 600,000 litres of oil. The maximum GHG reduction would therefore be 1,560 kilotonnes of CO_2 for 100% oil offset. This would of course be reduced if the biomass was used to offset hydro generated electricity.

2.0 Evaluation of Existing Gasifier Plant

During the visit of CANMET staff (March 22 to 27, 2004) the gasifier facility was inspected. The current status of the equipment was reviewed and an evaluation of each sub-system is presented in this section. Documentation for the gasifier was difficult to find but was eventually collected from a number of sources. In some two different versions of diagrams were found without any indication of which was the most recent. Operating instructions were very rudimentary and required some interpretation. In order to provide a complete record, copies of the original drawings for the gasifier plant are included in Appendix A.

2.1 Biomass Feed System

Figure 2. Truck dumping wood chips into underground bunker

The feed system is designed to transport chips from an outdoor underground bunker (Fig. 2) through conveyor belts to a feed hopper. Level sensors in the hopper automatically operate the conveyors to keep a minimum amount of fuel in the hopper. From the hopper fuel is transported by a series of screws. The hopper is isolated from the gasifier by an airlock rotary valve (Fig. 4). In addition, air from the principal air blower is introduced below the airlock to pressure this region and prevent escape of gases from the gasifier. The biomass feed system appeared to be in good working order. Feedrate is set by a manual dial (0 -5). In order to prepare for a test run of the gasifier, calibration tests were carried out for the feed system and a calibration curve was prepared. The calibration was carried out by running the feed system at different setting and collecting and weighing the amount of wood chips fed into the bed. The system is a volume based system, i.e. the screws and airlock feeder move a given volume of fuel. The bulk density of the wood chips used in this calibration was 207.6 kg/m3. The calibration results are reported in Appendix E. The Sur-Lite recommended feed dial setting of 3 corresponds to a feedrate of 400±20 kg/h. At the time of this evaluation, a fresh load of feed was delivered (Fig.2 and 3) containing large pieces (as long as 12" or 30 cm) and the bulk density of this material was found to be 172.5 kg/m3. There is no specification set for the feed material (i.e. size or composition) and therefore this load was accepted as “wood chips”, although one of the key tasks in future operation should probably be to establish some sort of fuel specification.

Figure 3. Woods chip delivered prior to gasifier test (March 24)

Figure 4. Wood chip feed system (airlock valve)

2.2 Air Supply / Pre-heater

Figure 5. Air compressor and pre-heater seen from above

Air for the gasifier is supplied by a Spencer Turbo-Compressor rated at 743 cfm at 3 psi (850 cfm maximum, 650 cfm normal) - Fig. 5. The compressor is powered by a 20 hp motor. In addition to air for the gasifier and pre-heat oil burner, the compressor supplies air to the fuel feed system (nominally 70 cfm). Control for the air feed to the compressor is by a combination of manual gate valve (MGV) and an electrically operated control valve (ECV). The MGC is set up as a bypass of the ECV. Recommended operation is to run with the MGV open 2.5 turns and allowing the ECV to open and close depending on the gasifier temperature limits. There is no capability to measure the flowrate of air or affect the portion of air diverted to the fuel feed system.

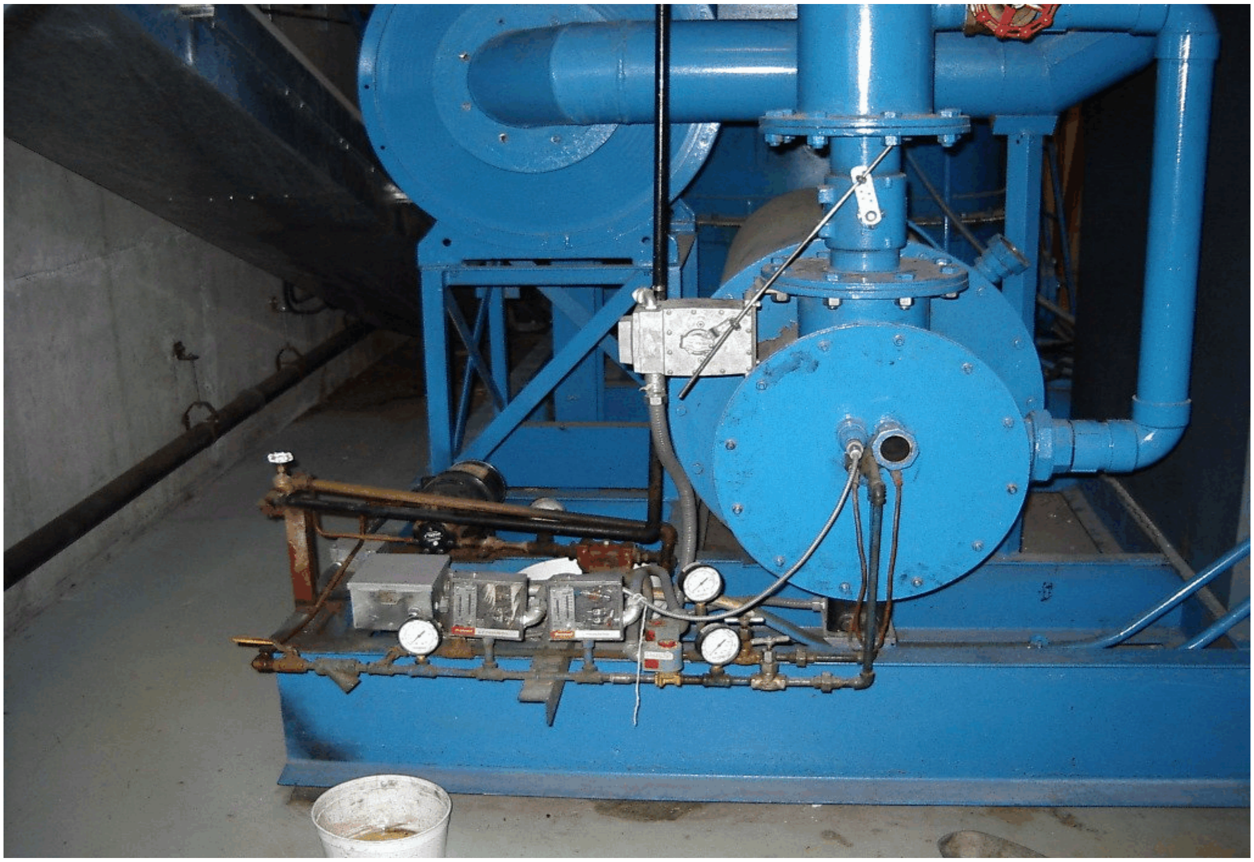


Figure 6. Oil-fired pre-heat system

Pre-heating of the gasifier is carried out by firing a oil "burner" into an air plenum - Fig 6. Although it does have a flame guard system the oil "burner" appears to be a crude design consisting of essentially a small pilot flame and an oil "pipe" for the main flame. The normal operating temperature of the preheater is 650 C. The pre-heater required some servicing but it was successfully fired as designed.

2.3 Fluidized Bed Gasifier

Figure 7. Refractory-lined gasifier vessel

The gasifier (Fig. 7) is a 36" ID 170" high refractory lined (est. 8" thick) vessel with a reduced diameter vertical duct extending the total height to 202". Based on the nominal air supply of 650 SCFM and an operating temperature of 700 C this translates into a superficial fluidizing velocity of 1.7 m/s which is within the normal range for a bubbling fluidized bed with coarse sand.

Figure 8. Sand removal port at bottom of gasifier

In order to allow for internal examination, the gasifier was emptied of sand present in the unit from previous attempts at operation - Fig.8. A few small agglomerates (approx 2 - 3" max) were found (Fig. 11) but generally the sand was in good condition and could be reused.

Internal inspection of the gasifier found no damage to either refractory or air distribution pipes - Fig. 9. The air distribution system is quite elaborate - a central (8" pipe) horizontal manifold feeds nine (2" pipe) horizontal pipes at its top - Fig. 10. These pipes then feed varying numbers of (1" pipe) vertical pipes (55 pipes total) which rise 4.25 to 7.25 inches. The gap between the 2" pipes is less than 2". This tight spacing plus the bulk of the distribution system itself considerably reduces the mixing within the fluidized bed thus partially negating one of the advantages of using a fluidized bed in the first place.

It was noted that there is no provision for removal of material during operation, i.e. the unit has to be shut down and the drain port cover removed in order to empty the unit.

Figure 9. Air distribution system seen from ash removal port

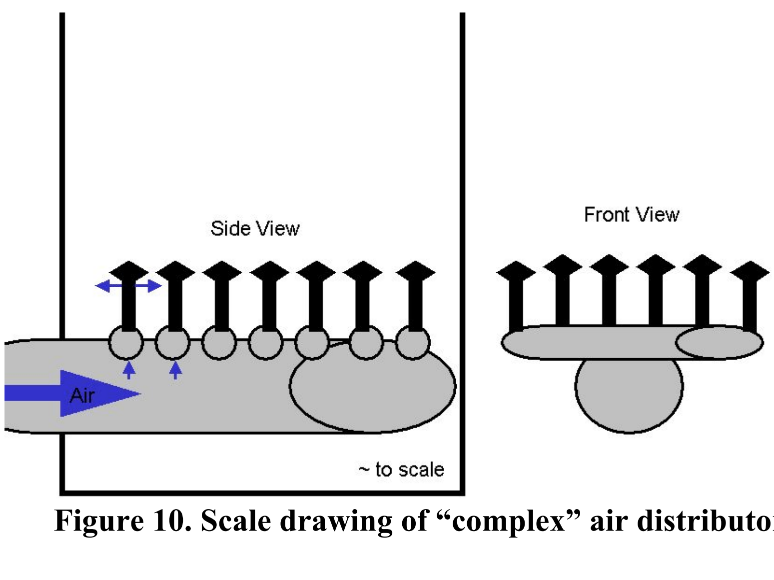


Figure 10. Scale drawing of "complex" air distributor

Figure 11. "Chunks" removed from gasifier during pre-test evaluation

2.4 Particulate/Ash Removal

Figure 12. Cyclones to remove ash from "syngas" stream

The gasifier system is equipped with two cyclones in series (Fig. 12) to remove particulate matter (ash). The cleaned gas is then delivered to the B1 boiler manifold. The cyclones appear to be in good working order. An evaluation of their effectiveness would require a longer period trial than is planned in this work and hence will not be considered.

One important factor which was noted is that the flue gas path from gasifier to boiler is quite long (Fig. 13) which could lead to excessive cooling of the syngas. This cooling could allow tars in the syngas to condense and eventually plug the ducts.

Figure 13. "Syngas" path from second cycle to boiler inlet

2.5 B1 Boiler

Figure 14. B1 fire tube boiler

The B1 boiler (Fig. 14) is a fire tube boiler manufactured by Wells Hall Fabrication. The boiler can operate with either No.2 fuel oil and also by firing the syngas produced in the gasifier. The combustion chamber is 3.8 m long with 1.7 m ID and internally insulated with ceramic fibre blanket.

The boiler is equipped with a Fuel Master Burner Model CO-300 firing No. 2 fuel oil @ 400 psi with a minimum firing rate of 20 USGPH and a maximum of 90 USGPH - Fig. 15. The burner has been configured for a high fire rate of 80 USGPH (3664 kW; 12.5 million Btu/h). The burner requires 20 amps and is configured for a furnace pressure of 0.5" W.C. The oil burner nozzle was found to be in good condition. In terms of oil burner operation, as with the pre-heat burner some service was required but otherwise the burner performed satisfactorily.

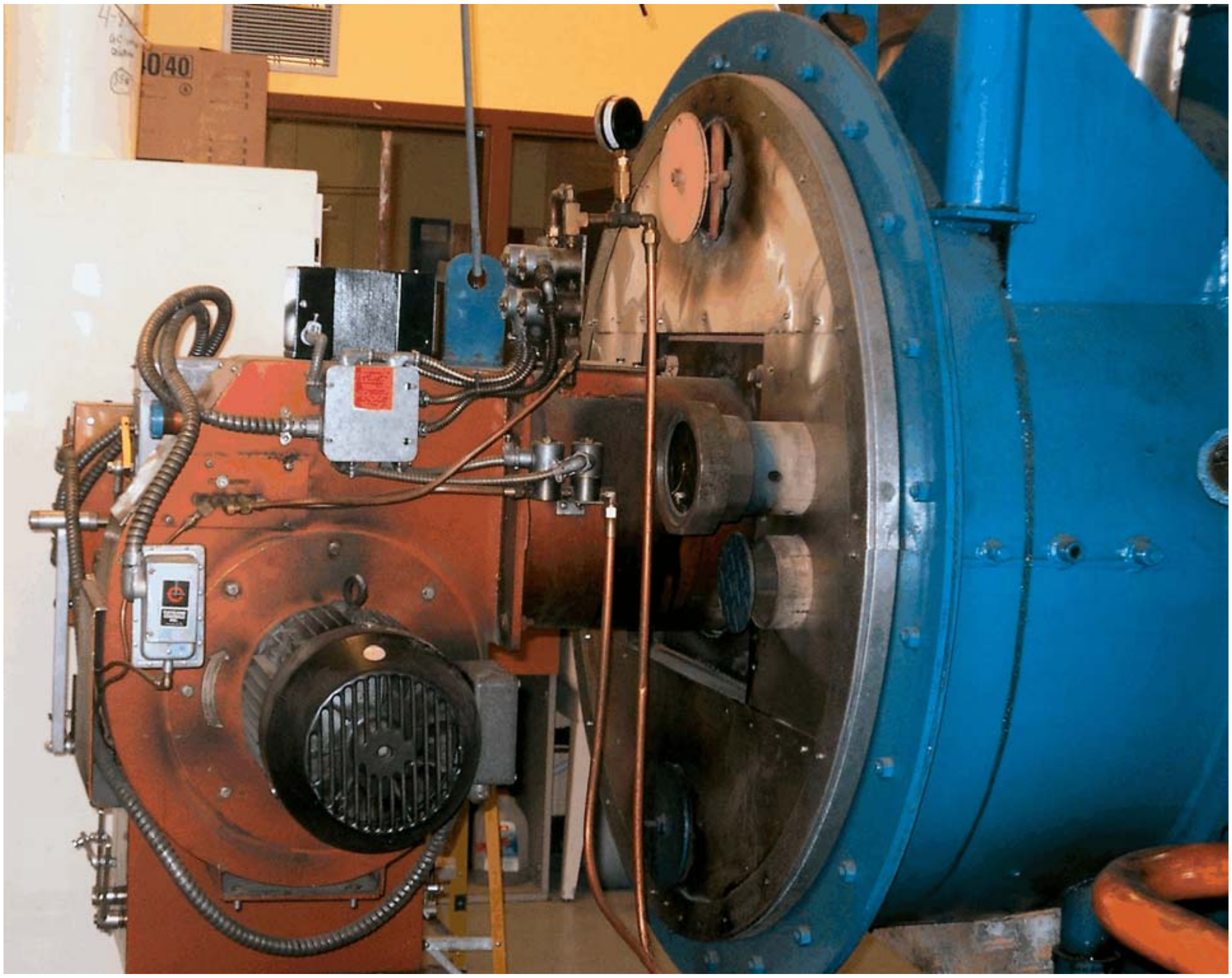


Figure 15. Fuel oil burner (No.2 fuel oil, 80 USGPH)

Examination of the combustion chamber found that the ceramic fibre blanket was in good condition - Fig. 16. The insulation around the manway cover was insufficient and there was also evidence of external paint damage in the area of the manway cover. Syngas is supplied via a manifold to diffusers within the combustion chamber. The syngas diffusers were found to have suffered severe corrosion - Fig. 17. These would have to be replaced before any long term operation (with consideration given to better material of construction) however it was decided that the diffusers were adequate for the trial planned in this work.

Exhaust from the boiler is ensured by an ID fan located immediately above the boiler.. The exhaust end of the boiler is equipped with dilution air ports - 16 sets of four 4 1" holes, i.e. a total of 64 1" holes - Fig. 18. These ports supply dilution air to cool down the boiler flue gases before they enter the ID fan/stack. The ports can be partially but not completely closed. The ID fan feeds a stack which rises approximately 44" above the roof of the building - Fig. 19. This stack is too short to provide any appreciable natural draft and is also too close to the roof and may result in ground level emission near the Yukon College Energy Centre. This is acceptable for a one day trial but would have to be remedied for long term operation of the plant.

Figure 16. Interior of “Syngas” combustion chamber (B1 Boiler)

Figure 17. “Syngas” nozzles inside B1 Boiler

Figure 18. Back End (Exhaust) of B1 Boiler

Figure 19. Stack of B1 Boiler/Gasifier RHS

2.6 Controls

A considerable portion of time was spent deciphering the control diagrams (see Appendix B). Some portions of the control system were inoperative and some portions had to be bypassed.

Figure 20. Existing Gasifier Control Panel

The main control panel, shown in Fig. 20 was completely inoperative and had to be bypassed. After careful review including consideration of health and safety concerns, it was decided that the gasifier pilot plant could be run (in trial mode only) with a combination of additional temperature and pressure monitoring, manual control and some controls which were still operational.

As an example of the current state of the control system, Table 1 shows a calibration curve test which was carried out on the preheat controller. As can be seen from this table the controller error can be quite significant.

Table 1.
Preheat Controller Calibration Curve

Calibrator Value *C	Controller Value *C	Error %
0	25	
50	75	50.0
100	120	20.0
150	160	6.7
200	200	0.0
250	240	-4.0
300	280	-6.7
350	320	-8.6
400	360	-10.0
450	400	-11.1
500	440	-12.0
550	480	-12.7
600	520	-13.3
650	570	-12.3
700	620	-11.4

After assessing the available documentation a summary of equipment tags was prepared - Appendix B. Appendix B also includes a listing of instrumentation changes which would be required to make the gasifier “operational”.

Based on the available documentation a new control strategy/operating procedure was developed and is given in Appendix C. In running the gasifier the following approaches to control is suggested::

1. approach the desired gasification temperature from the low side
   (i.e. increase temperature toward the target)
2. run with low fuel setting
3. increase fuel to target but drop air simultaneously
4. increase air to target setting and control to maintain temperature

3.0 Fuel Analysis

Samples of wood fuels from the Whitehorse area including chips and bark were analyzed to determine heating potential and identify potential ash issues. The complete results of these analyses are included in Appendix G.

The wood chip fuel intended for the gasifier, shown in Table 2, was found to be a low ash (0.67% ash d.b.) and high volatile fuel (84.3% volatiles d.b.) which is well suited as gasifier fuel.

Table 2 - Wood Chips Proximate and Ultimate Analyses
(Characterization Lab - ASTM Standard Method)

Component	**Dry Basis** (wt%)
Carbon	49.51
Hydrogen	5.95
Nitrogen	0.10
Sulfur	0.25
Oxygen (difference)	42.18
Ash	**0.67**
Volatile	**84.28**
Fixed Carbon (difference)	**15.05**
Heating Value (BTU/lb)	8573
Heating Value (MJ/kg)	19.94

The calorific value was found to be 19.9 MJ/kg (8570 BTU/lb) on a dry basis. The principal metal oxides found in the fuel were CaO (50.4 %) and SiO_2 (12.5%). All other species such as potassium were found to be relatively low indicating that this fuel should not have any significant agglomeration or ash handling problems.

The bulk density of the existing fuel supply in the bunker was found to have a bulk density of 207.6 kg/m3. The chips are uniform, dry and should an ideal gasifier fuel. At the time of this evaluation, a fresh load of feed was delivered (Fig.2 and 3) containing large pieces (as long as 12" or 30 cm) and the bulk density of this material was found to be 172.5 kg/m3. There is no specification set for the feed material (i.e. size or composition) and therefore this load was accepted as "wood chips", although one of the key tasks in future operation should probably be to establish some sort of fuel specification.

4.0 Fluidizing Sand Analysis

In order to allow for internal examination, the gasifier was emptied of sand present in the unit from previous attempts at operation - Fig.8. A few small agglomerates (approx 2 - 3" max) were found (Fig. 11) but generally the sand was in good condition and could be reused. A sample of sand was sent for analysis to CETC-O's labs and the results of that analyses are included in Appendix G.

Sieve analysis of the sand determined the mean particle size to be 1.1 mm in diameter with over 66% of the material being larger than 0.85 mm. Based on a true density of 2751 kg/m3 for the sand the fluidization properties can be estimated. The minimum air velocity to fluidize this sand at 700 C (the nominal temperature of the gasifier) was calculated as being 0.43 m/s. The terminal velocity of the sand was calculated as 10 m/s (this is the velocity at which all sand would be blown out of the bed). Normally, in order to get "good" fluidization it is desirable to operate at 2 - 3 times the minimum fluidizing velocity, or in this case 0.8 to 1.2 m/s.

This gasifier is a 36" ID vessel. Based on the nominal air supply of 650 SCFM and an operating temperature of 700 C this translates into a superficial fluidizing velocity of 1.7 m/s which is approximately 4 times the minimum fluidizing velocity but well below the terminal velocity. At 300 C the superficial velocity in the gasifier is ~1 m/s which is twice the minimum fluidizing velocity and at this point the bed will start to mix reasonable well. This sand is therefore well suited for operation within the design conditions for the gasifier.

In terms of chemical composition, the sand is basically SiO_2 (52.3%) and Al_2O_3 (42.6%) which should not cause any problems at the gasifier conditions.

In order to carry out the testing described in the next section, the gasifier was charged with 4.5 barrels of sand - equivalent to a bed depth of 54" or 1.37 m.

5.0 Test Program

Once the various sub-systems had been tested, additional instrumentation installed (temperature and pressure sensors, manometers, data acquisition) and control strategy developed, a trial run of the gasifier was carried out on March 27, 2004. Fig. 21 summarizes the key temperatures during this trial. The complete data, including comments on actions taken during testing, are given in Appendix D. Temperatures and pressures were recorded by computerized data acquisition (supplied by ACR Mechanical Systems). Flue gas analysis at the exit from the boiler was monitored using a continuous IR analyzer measuring NO, SO_2, CO, CO_2 and O_2. Readings were manually recorded and are also included in Appendix D.

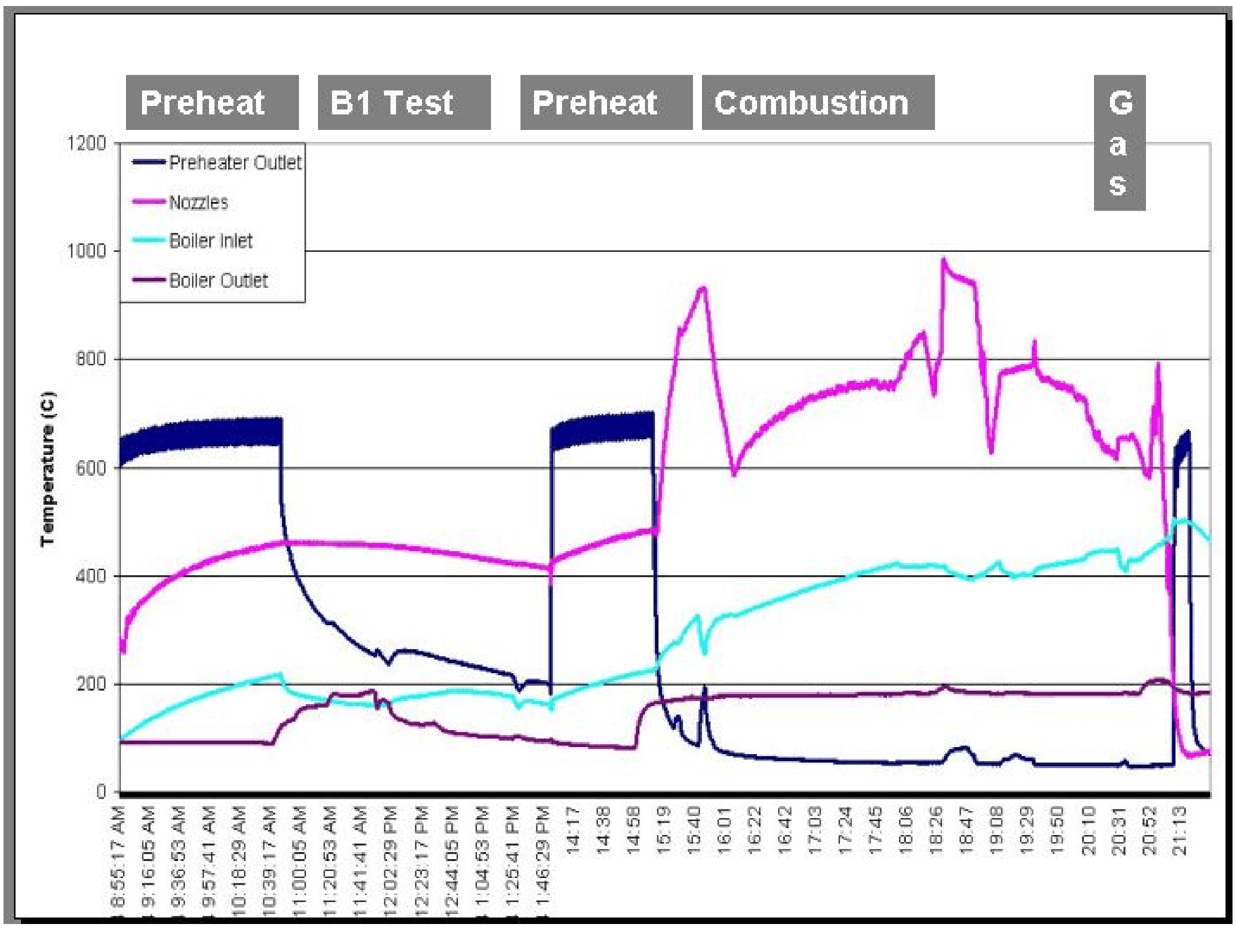


Figure 21. Temperature profiles during testing on March 27, 2004

The grey bars along the top of the figure indicate the principal focus during that period. The pre-heat periods are self-evident. In addition to these there are three periods of interest: B1 test, Combustion and Gas. In B1 Test, the B1 boiler efficiency and operation was tested using only the oil burner. In Combustion the gasifier was run as a fluidized bed combustion system. In this mode of operation all heat is generated in the fluidized bed and the hot gases are then passed through the boiler. In the final mode "Gas", the unit was successfully run as a biomass gasifier, albeit for a short period of time. The principal findings of each of these portions are discussed below.

5.1 B1 Boiler Efficiency Test

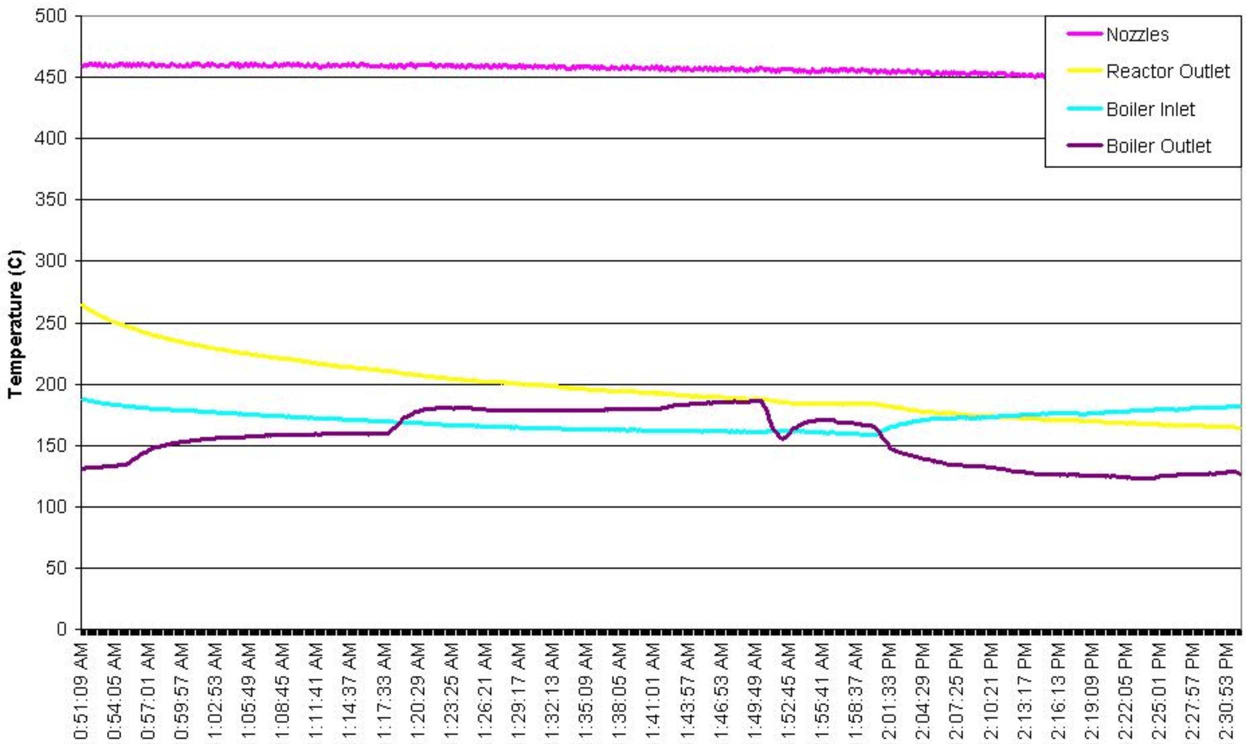


Figure 22. Temperature profiles during boiler efficiency test

After a one hour pre-heat period, the gasifier system was shut off and B1 was fired solely on oil set on low fire. After 45 minutes the oil burner was switched to high fire. Based on the flue gas temperatures, as shown in Fig. 22, reasonably steady operation was obtained. Based on these temperatures and flue gas analysis (Appendix D) the boiler thermal efficiency can be estimated:

Lo-fire Results: Flue Gas: CO 3ppm; NO 60 ppm; CO_2 8.0 %; O_2 10.4 %
FG Temperature: 159 C
Excess Air: 85%
Efficiency: 85.8 %

Hi-Fire Results: Flue Gas: CO 312 ppm; NO 152 ppm; CO_2 14.7; O_2 2.2%
FG Temperature: 180 C
Excess Air: 12%
Efficiency: 86.5%

It should be noted that these tests were conducted over a relatively short period of time and so true steady state was not achieved, however the tests do indicate that as an oil-fired system, B1 boiler operates with good efficiency. The exact heat input for Lo and Hi-fire settings was not determined and documentation for these was unavailable.

Once the Hi-fire efficiency test was completed, it was decided to test the option of running the system without the ID fan to see if natural draft is adequate to run the boiler. The draft at the exit of the boiler immediately dropped from ~2"wc to less than 0.5"wc, the oxygen level dropped to 0 and the CO level rose to above 5000 ppm. Black smoke was seen coming from the stack. The test was stopped immediately. Clearly the natural draft is insufficient to support this system (and by extension the same can be said for operation with the gasifier). In fact the short stack (~44") not only does not generate significant draft but by being so close to the roof it results in wind eddies carrying flue gas directly into the heating plant.

5.2 Fluidized Bed Combustion Test

The gasifier was successfully operated in combustion mode - Fig. 23. Wood chips were fed at approximately 40 kg/h (0.75 dial setting) representing an input of 210kW (700,000 BTU/h). The fluidized bed temperature was easily maintained at approximately 750 C and the unit operation was very stable (note steady temperature in Figure 23 from 5:10 pm to 6:00 pm). The combustion inside the gasifier is clearly illustrated by Fig. 25.

The gasifier pilot plant could, without modifications, be used to produce at least 250 kW by operating in combustion mode. The size of the unit is such that up to 1000 kW could be produced by introducing a heat transfer surface in the fluidized bed region.

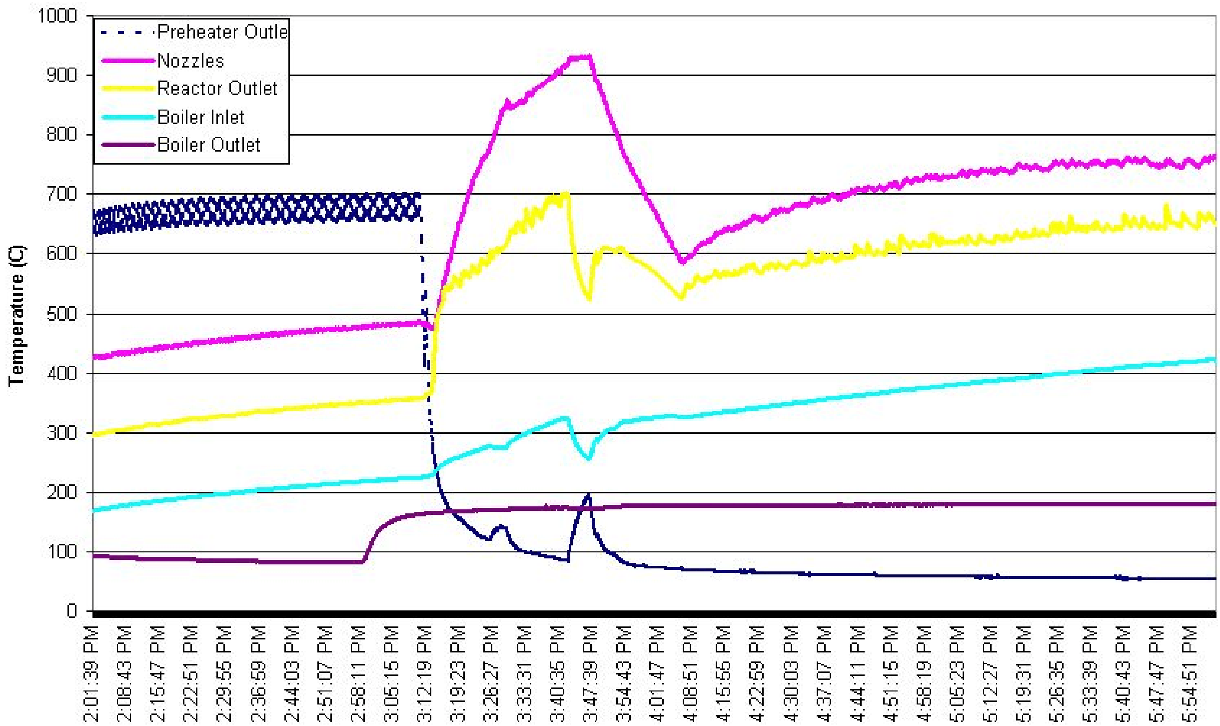


Figure 23. Temperature profile during fluidized bed combustion test

5.3 Fluidized Bed Gasifier Test

The gasifier was successfully operated as a gasifier for a brief period - the "blow-by-blow" description is included in Appendix D. The temperature profile during the "gasifier" operation is shown in Fug. 24. The period of true gasifier operation is shown by the curve for the boiler outlet temperature. The rise in boiler outlet temperature from 8:45 pm to 9:05 pm is due to combustion of syngas in the boiler. During this period, wood chips were fed at approximately 390 kg/h (3.0 dial setting) representing an input of 2050 kW (7 million BTU/h). Fig. 26 offers an internal view of the gasifier during this period.

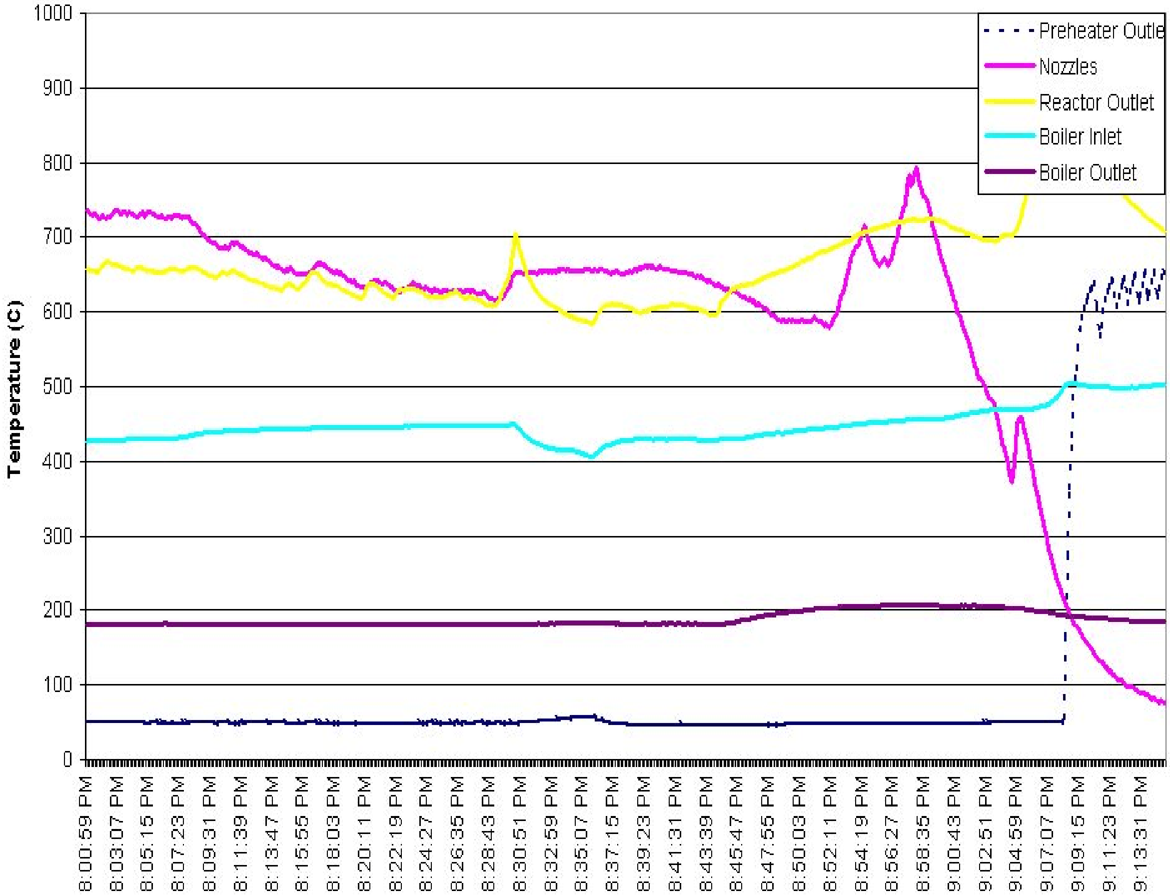


Figure 24. Temperature profile during fluidized bed gasifier test

The fluidized bed temperature was between 600 -700 C during the gasification period. Control of the air flowrate to the unit was being done manually based on unit temperature response - this is a very poor control method especially since the actual flowrate is unknown and directions were generally of the type “turn the valve half a turn to the left”.

Unfortunately as the operators were trying to keep the air flow balanced a series of events necessitated the termination of the trial:

- the wood chip feed system had a major jam due to very large non-homogeneous chips (note the rapid drop in temperature in the gasifier after 9:05 om). Fig. 28 shows the feed inlet inside the building at the bottom of the outdoor bunker. The jammed material was on the outside of the building at the bottom of the bunker and since all the fuel is above this point it became impossible to clear the jam within any reasonable time frame.

- an attempt was made to start the pre-heater to keep the unit hot, however the control system had locked out the pre-heater (when the temperature had previously risen to 900 C - the lockout does not reset until the temperature drops below 200 C) and finally

- the paint on the outside of the burner section of B1 boiler began to smoke and burn. Fig. 29 shows the outside of the boiler right after the gasifier test. A surface temperature measurement showed temperatures in excess of 300 C.

All of these events of served to illustrate items which need to be addressed in order for the gasifier to be fully operational.

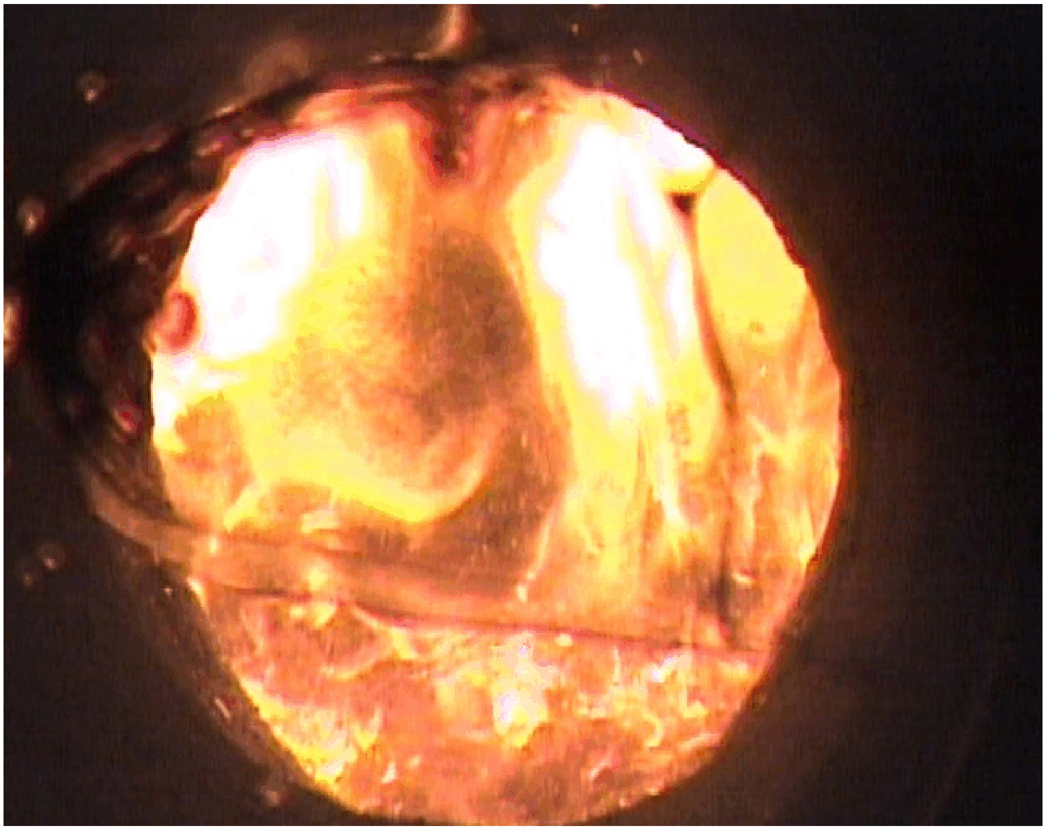


Figure 25. View inside gasifier during "combustion" test

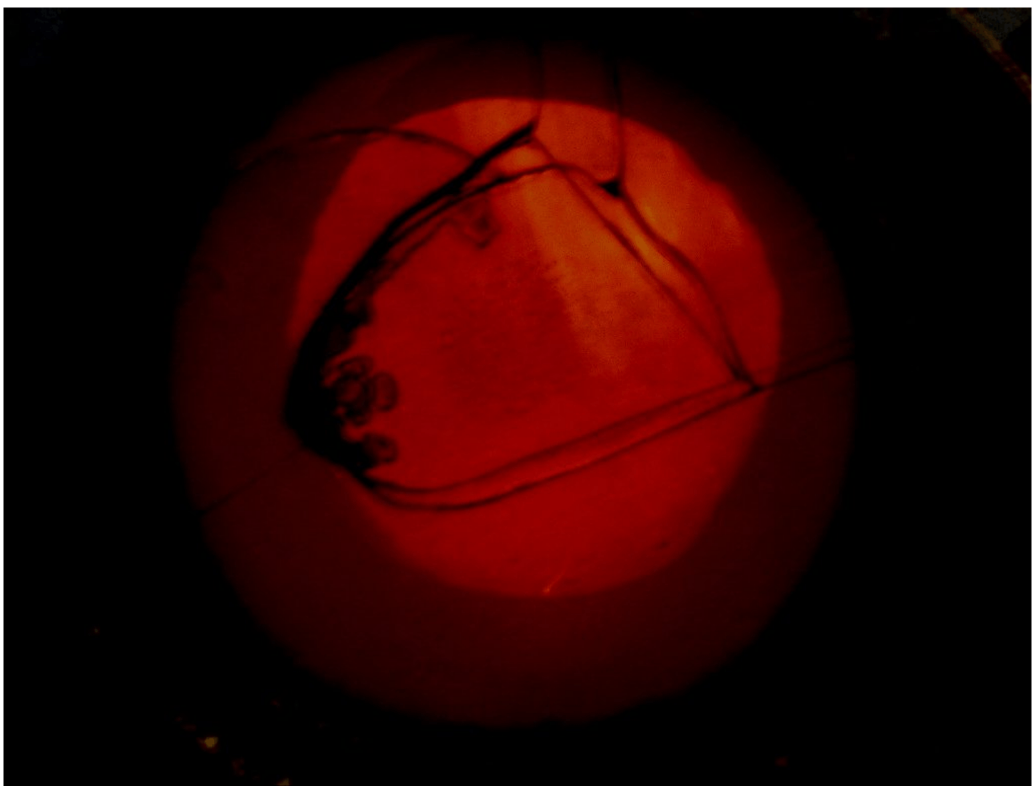


Figure 26. View inside gasifier during "gasifier" test

Figure 27. View of stack during "gasifier" test

Figure 28. Steel grate installed to prevent jamming in feed system

Figure 29. Damaged paint on B1 Boiler after gasifier test

5.4 Emissions

Fig. 27 shows the visible stack emissions during the gasifier operation. Some additional form of emissions control is necessary if the gasifier is to operate on a regular basis.

Particulate matter (PM) is one of the primary forms of air pollution. PM is emitted from numerous industrial, mobile, residential and even natural sources. PM-10 and PM 2.5 are tiny particles that can be extremely deleterious to human health and can cause a variety of environmental problems, including impaired visibility even in areas far removed from the source. Particles have unique characteristics that influence how we may capture them and remove them from the gas stream. Efficient collection of particles is especially dependent on their size, but the calculation of collection efficiency is based only on the mass percent collected.

A number of devices have been developed to collect particles, among which are cyclones, wet scrubbers, ESPs and baghouses. Each device has advantages and disadvantages, and their costs may vary widely, thus making a site-specific engineering study imperative to find the optimum solution to any particulate control problem.

A cyclone is designed to remove particles by causing the entire gas stream to spin in a vortex at high velocity inside a cylindrical chamber. The centrifugal force acts more strongly on the larger, denser particles and flings them preferentially toward the inside wall of the cyclone where they impact and then fall to the bottom of the cyclone. The gas flows out through the top of the cyclone (still carrying some of the smaller, lighter particles), while the collected dust is removed from the bottom. Advantages of cyclones are that they are simple, rugged, and inexpensive. Also, they collect the PM in a dry form so that it can be re-used or recycled. The major disadvantage is that the collection efficiency tends to be somewhat low. In fact, the efficiency of a cyclone is often too low to be able to use the cyclone as a final control device. Therefore, cyclones are often used as pre-cleaners. Furthermore, moving the gas through a cyclone at high enough velocities to collect a reasonable fraction of the PM, creates a substantial pressure drop (which means an increase in operating costs). The gasifier plant is equipped with two cyclones which remove large particulates from the syngas prior to combustion in the boiler. Clearly from Fig. 27 the cyclones are not efficient enough to remove the fine particulate matter. In addition some particulate matter is generated during the combustion of the syngas.

Wet scrubbers operate on the principle of collision between particles and water droplets, collecting particles in the larger, heavier water drops. The water falls through the upward-flowing gases, colliding with and removing particles, and accumulates in the bottom of the scrubber. The "dirty" water is pumped from the scrubber and treated to remove the solids as a wet sludge. Advantages of wet scrubbers include being able to handle flammable or explosive dusts, provide cooling of the gases, and neutralize acid mists and vapours. Disadvantages include potential for corrosion, requirement for water and disposal. Scrubbers do offer the potential to recover additional energy for biomass fuels this can mean increases in thermal efficiency of up to 20%.

A baghouse can be thought of as a giant multiple-bag vacuum cleaner. The polluted gas stream (containing the particles) is forced to flow through cloth filter bags. The dust is filtered from the gas stream, while the cleaned gas passes through the cloth and is exhausted to the atmosphere. The bags are periodically cleaned (two methods are by shaking the bags or by blowing clean air backwards through them) to knock the dry dust down to the bottom hoppers where it can be removed to be either recycled or disposed. Baghouses are extremely efficient, and have a moderate pressure drop. The fabrics have temperature and humidity limitations, but are generally able to collect any type of dust The biggest operating cost comes from forcing large volumetric flows of air or combustion gases through the bags, which creates a substantial pressure drop.

An electrostatic precipitator (ESP) removes particulate matter from a gas stream by creating a high voltage drop between electrodes. A gas stream carrying particles flows into the ESP and between sets of large plate electrodes; gas molecules are ionized, the resulting ions stick to the particles, and the particles acquire a charge. The charged particles are attracted to and collected on the oppositely charged plates while the cleaned gas flows through the device. While the gas flows between the plates at velocities in the range of 1 to 3 metres per second, the particles move towards the plates at a velocity (called the drift velocity) that is in the range of 1 to 10 metres per minute. During the operation of the device, the plates are rapped periodically to knock off the layer of dust that builds up. The dust is collected dry and can be disposed of or recycled.

ESPs are large and very expensive to buy, but have the important advantage that they collect particles with very high efficiencies. Another major advantage is that they present very little resistance to gas flow therefore cause only a slight pressure drop even when operating on flows as large as a million cubic feet per minute. Therefore their operating costs are not as large as one might expect. Many coal-fired power plants use ESPs.

For the Yukon College gasifier emissions control costs will vary according to the chosen system. The baghouse and scrubber options could probably be installed for between $50k and $100k, and the electrostatic precipitator for the size of equipment involved would cost in the order of $250k.

6.0 Evaluation & Recommendations

In answer to the question "Can the gasifier be operated?" the answer is a qualified yes. The gasifier can be operated but not in its present condition. There are no significant health and safety issues with the operation of the gasifier. The major requirement is for new instrumentation for monitoring and control. The recommended changes are listed below under three categories: "Required" which have to be made for safe and controlled operation, "Strongly Suggested" for proper long-term operation and "Optimal" for optimal performance.

6.1 Required Modifications

Air Flow Measurement
Air flow measurement is necessary for proper control of the gasifier. The gasifier operates by burning part of the fuel to generate the energy required for gasification. There is a large excess of fuel and no cooling in the bed and therefore slight changes in air flow lead to significant changes temperature. In order to control the air flow properly it must be measured and controlled.

New Control System (hardware/sensors/software)
The existing control system is completely inadequate to properly operate the gasifier. A new control system including increased temperature and pressure monitoring is required. The capital cost of a satisfactory system is in the $50k range.

Quality Control of Fuel
The fuel feed system was found to perform satisfactorily with the fuel for which it was designed, i.e. uniform small chips. The load of fuel delivered prior to the trial carried out in this work contained long pieces (up to 10-12 inches long). These pieces passed through the initial screen for the underground bunker but caused severe jamming in the feed system.

B1 Dilution Air Hood (Health and Safety Issue)
The back end of B1 boiler is open into the heating plant room. Sixty-four 1" holes provide dilution air for the flue gases. As was demonstrated in the boiler tests reported here, the system requires operation of the ID fan in order to ensure venting under high fire (or gasifier operation) conditions. If the ID fan were to fail during operation, flue gases would spill into the room. If a power failure or similar event were to knock out the ID fan and the burner flame during gasifier operation then raw syngas could spill into the room. If the dilution air requirement is maintained then some sort of hood should be installed so that air is drawn from outside. In this manner any gas spills would also go outside.

Oil Lance (Pilot) and New Syngas Diffusers for B1 Boiler
During the trial of the gasifier the oil burner on B1 was run on Lo-fire to ensure the presence of a flame to light any syngas produced. The exact heat input of this burner was undetermined, however it may have been significantly more than the minimum (20 USGPH) setting. This may have contributed to the excessive temperature in the combustion chamber of B1 which led to smoking and burning of exterior paint (surface temperature sensors reported temperatures in excess of 300 C on the outside surface). A

small oil lance/burner (1 USGPH) would be adequate to provide a source of ignition. In order to ensure proper mixing and burning of the syngas the existing diffusers which are badly corroded have to be replaced.

Gasifier Water Injection
In order to prevent temperature excursions which could cause premature shutdown of the gasifier a water injection system should be installed. In this manner the bed could be rapidly and temporarily cooled to allow for changes in the air/fuel parameters to be made. Due to large thermal inertia, fluidized beds do not react quickly and therefore means must be available to provide rapid cooling when required. This can be accomplished with injection of a small stream of water.

6.2 Strongly Suggested Modifications

New pre-heat oil burner
The oil burner used to pre-heat the gasifier is of rather crude design and performs very poorly. Operation of this burner immediately led to a burning oil smell in the heating plant. Even at extremely high excess air levels (O_2 readings above 19%) this burner still produced carbon monoxide readings of over 300 ppm.

Emissions Control (Baghouse /Stack Modifications)
The existing stack rise 44" above the roof line. This does not provide any significant draft and also leads to the release of particulates and odours into the outside area around the physical plant. The stack height can be compensated for by the ID fan however the emissions require control device prior to the stack. There are three options which could be considered: a baghouse (fabric filter which removes most particulates), a water spray scrubber (this would have the added benefit of recovering latent heat from the flue gas and could substantially improve overall efficiency) and an electrostatic precipitator (removes very fine particulates but is very expensive).

Emergency exhaust / flare system
This would be a system which could flare the syngas in the event of a problem with the B1 boiler or ID fan. This system would evacuate the syngas to a flare system where is would be burned. The need for this system is reduced by the installation of the dilution hood on B1. If the dilution hood is not installed then this system is required.

6.3 Modifications for Optimal Operation

Minimize Cooling in Syngas Path
The flue gas path from gasifier to boiler is quite long which could lead to excessive cooling of the syngas. This cooling could allow tars in the syngas to condense and eventually plug the ducts. In the trial carried out here the system was heated until the temperature in the gas manifold at B1 exceeded 400 C. This practice should be required for all gasifier operation. The temperature of 400 C is only a guideline. In order to determine the exact temperature required, further testing should be carried to determine the temperature at which tars begin to condense. Build-up of tars is one of the most common causes of shutdowns for similar gasifier heating units.

New Air Distributor in Gasifier
The existing distributor (described above) is bulky and reduces mixing in the bed. This can lead to poor conversion efficiency and hot/cool spots in the bed. The distributor prevents any large material (e.g. agglomerates) from dropping to the bottom of the bed.

Bed Solids Handling Systems
In the current design these is no possibility of bed ash removal or sand addition during operation. In the case of upset conditions, sand may be blown out of the system. This material must be replaced in order for the fluidized bed to function properly. There is no mechanism for feed sand in a controlled manner. The current option is to add sand to the fuel feed hopper, therefore this need is not urgent. If the unit is to be operated for prolonged periods then some sort of bed material or ash removal is required. The system is designed so that all ash and unconverted is carried out of the bed by the syngas and collected in the cyclones. This works for fines, however it would not work for larger particles (> 1 mm) such as rocks or agglomerates. Without an ash withdrawal system these larger particles will accumulate and eventually necessitate a shutdown for their removal.

ID Fan Speed Controller
The ID fan does not need to operate at full capacity on a continuous basis. A speed controller would allow the fan to operate to maintain a set draft in B1. This would result in reduced power consumption and also allow sealing of the dilution air ports.

6.4 "Refurbishment" Costs

The economic evaluation of operating the gasifier obviously ties into the costs of carrying out these modifications. Although "ballpark" figures for these modifications are available, the exact costs require a detailed engineering assessment. Based on previous assessments the key consideration is the operating cost of the gasifier and further research and discussion is required in order to complete any economic justification. The following is a ballpark estimate of costs in making the gasifier operational, broken down into the "change" categories described above:

Required

Air Flow Measurement		10
Control System		100
Dilution Hood		20
Oil Pilot / Gas Diffusers		20
Water Injection		10
	Required Changes	$160k

The cost estimates for the required systems are based on CETC-O staff experience with these types of equipment and actual quotes for instrumentation (Appendix B) and this cost estimate should be fairly accurate. An additional contingency of $20k should cover the upper bound for these expenses.

Recommended

New Preheat Oil Burner		10
Emissions Control		50 - 200
Exhaust Flare		50
	Recomm. Changes	$110 - 310k

The cost estimates for the recommended modifications are based on equipment for similar sized projects carried out by CETC-O. For example a baghouse for a similar unit was purchased by CETC-O for approximately $50k and an electrostatic precipitator for this scale at a recent demonstration project cost just under $200k. The least certain cost for this set of equipment is the exhaust flare as this equipment would probably have to be designed and built from "scratch". The estimate of $50k is based on similar systems designed by CETC-O, however it does not take into account the specific geometry and requirements at the Yukon College Energy Facility. Given this uncertainty a contingency of $50 should be adequate for this set of changes.

Optimal

Minimize Cooling	30
New Air Distributor/Solids Handling	50
IF Fan Speed Controller	10
Optimal Op. Changes	$90k

This last set of estimates is once again based on similar equipment and is assigned a contingency of $20k

The cost for modifications may be summarized as follows

	Minimal Changes	Moderate Emissions	Full Optimal &Emissions	Contingency
Required Changes	$160k	$160k	$160k	$20k
Recommended	$110k	$110k	$310k	$50k
Optimal.	----	$90k	$90k	$20k
Total	$270k	$360k	$560k	$90k

The total cost of making the gasifier operational is thus estimated to range from $270k for all required and recommended changes to $560k for a fully optimized system with the most expensive emissions (electrostatic precipitator) control measures. An additional contingency of $90k has been estimated to the overall installation. Obviously a choice of emissions control would have to be made and a detailed engineering study carried out to arrive at a more precise cost.

7.0 Economic Feasibility

The economic evaluation of operating the gasifier obviously ties into the costs of carrying out these modifications. Although “ballpark” figures for these modifications are available, the exact costs require a detailed engineering assessment. Based on previous assessments of the gasifier, the key consideration will be the operating cost of the gasifier. As an estimate of the cost of operating the gasifier the following assumptions have been made:

Annual heating requirement: 6,000,000 kWh

Wood calorific value (dry basis) : 19.9 MJ/kg

Oil-fired thermal efficiency: 80%

Wood-fired thermal efficiency: 75%

Electric heating efficiency: 100%

Person-year cost: $65,000

The actual cost of wood is obviously a key factor in any analysis. Previous studies of this system have used costs of wood of approximately $200/tonne. Although this is possible and the authors certainly are not experienced in the wood market in the Yukon it seems that this is very high compared with other regions in Canada. Waste wood is commonly available for as little as $7 per tonne to $40-50/tonne for premium residues. Forestry studies have shown that wood can be collected, chipped and shipped short distances for $60-70/tonne. The authors consider that $100.tonne should be a reasonable estimate for wood in the Yukon and based on this, the operating costs for the Yukon College gasifier should be very competitive with other fuels.

Fig. 30 shows a comparison of fuel costs for wood and No.2 fuel oil. Curves have been generated for annual heating costs for wood costs plus up to 3 additional staff in comparison with fuel oil at from 40 to 80 cents per litre.

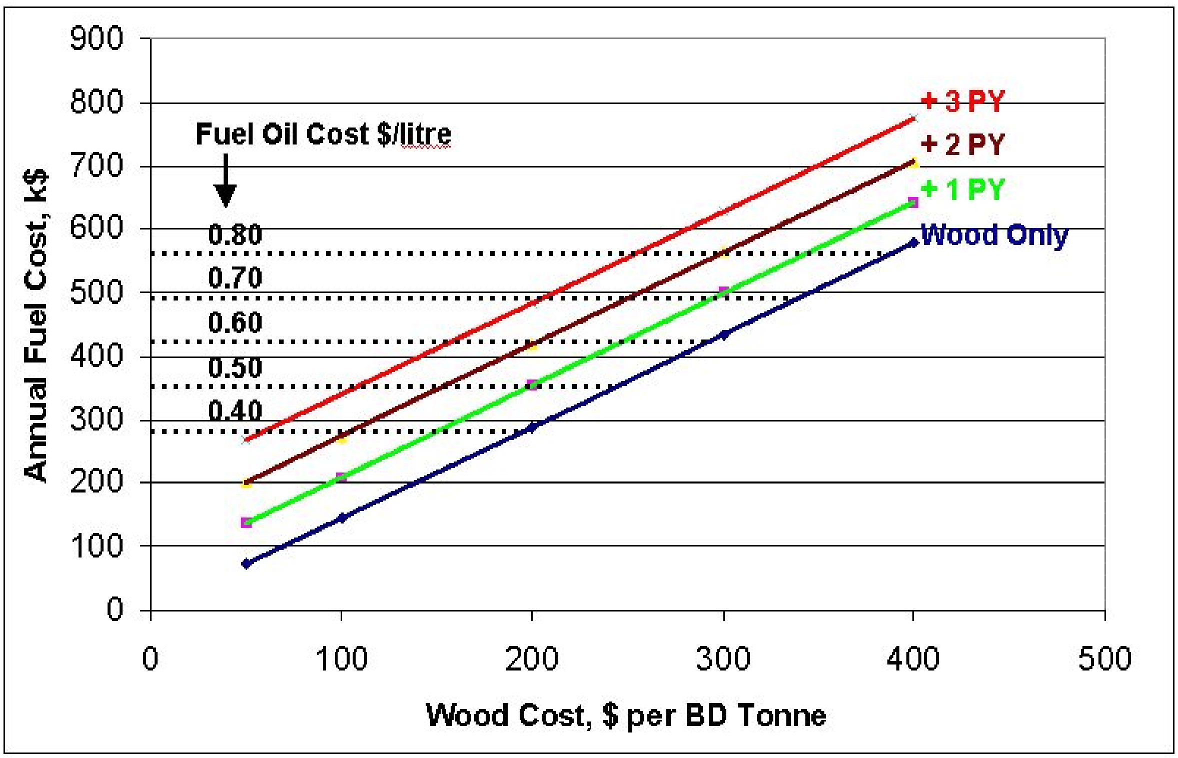
Fig. 31 is a similar figure for electrical based heating and the cost for electricity. Curves have been generated for annual heating costs for wood costs plus up to 3 additional staff in comparison with electricity at 3 to 10 cents per kWh.

Given uncertainty regarding the requirement for additional personnel (i.e. above normal heating plant requirements with oil/electrical) the following table summarizes the break-even cost of wood according to how many additional staff are required. In this table (taken from Figs. 30 and 31) it has been assumed that fuel oil costs 60 cents per litre and electricity costs 6 cents per kWh:

Maximum Cost of Wood to Break Even

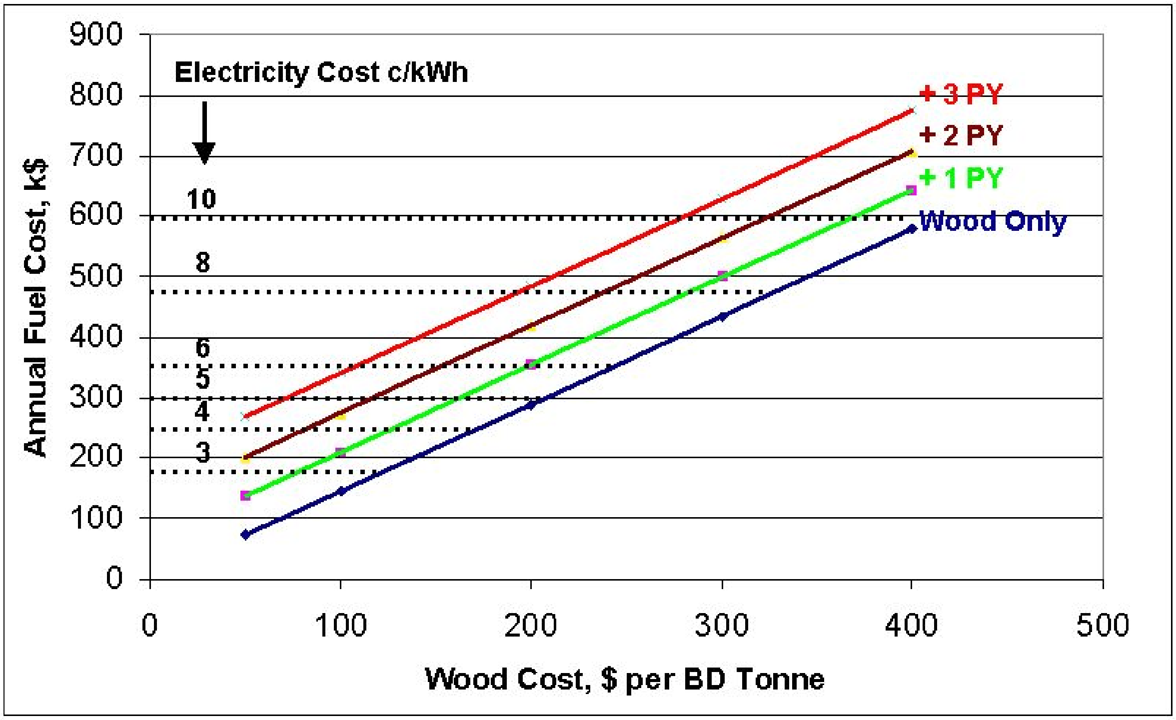
	vs 60c/litre oil	vs 6c/kWh
3 Add. PY	$160	$100
2 Add PY	$200	$150
1 Add PY	$250	$200
No Add PY	$290	$250

This means that if a wood price can be obtained lower than the number in this chart then wood becomes more economical. The actual cost savings of using wood depend on the cost of modifications but clearly wood heating should be a practical and economical approach.



Annual Cost Based on 6,000,000 kWh Heating with Fuel Oil or Wood;
Oil 45.3 MJ/ka: Wood 19.9 MJ/ka: Oil 80% eff: Wood 75% eff.

Figure 30. Comparison of heating costs for wood vs oil



Annual Cost Based on 6,000,000 kWh Heating with Electricity or Wood;
Wood 19.9 MJ/kg; Elect. 100% eff; Wood 75% eff.

Figure 31. Comparison of heating costs for electricity vs oil

7.1 Boiler De-Rating Considerations

In order to minimize costs and increase the feasibility of operating the gasifier, the number of staff required to attend to the boiler should be minimized. Information has been collected on boiler regulations throughout Canada - collected in Appendix F.

Yukon regulations closely approximate those in Alberta and therefore are examined here to consider whether the operation of the gasifier/heating plant would require additional staff. According to ALBERTA REGULATION 300/94 (Safety Codes Act) BOILERS AND PRESSURE VESSELS EXEMPTION ORDER the Safety Codes Act and the regulations made pursuant to the Act and any code, standard or body of rules declared to be in force pursuant to the Act <u>do not apply to:</u>

- a boiler that is intended to be used in connection with a hot water heating system and that has no valves or other obstructions to prevent circulation between the boiler and the expansion tank but only if the expansion tank is fully vented to the atmosphere;

- a hot water heating boiler to supply hot water for circulation through a building heating system. The service restrictions are as follows:
  - · steam boiler pressure not exceeding 103 kPa (15 psi) with a temperature not exceeding 121 C (250 F); AND
  - · water boiler pressure not exceeding 1 100kPa (160 psi) with a temperature not exceeding 121 C (250 F) at or near the boiler outlet.

Furthermore, the Engineers' Regulations (Alta. Reg. 319/75) do not apply to
(I) a power plant that
(ii) is used for a heating process when the heat is generated as a result of burning inherent in the process or any other reaction inherent in the process, and
(iii) does not generate steam,
or
(iv) a power plant that heats a fluid other than water in a process where heating the fluid is inherent in the process.

Also, in Alberta, although hot water boilers may be exempted from the Safety Codes Act requirements, the equipment must be properly vented with no flow restrictions or be equipped with adequate pressure-relieving capacity to ensure that the equipment will not be over-pressurized. Operation procedures and process requirements should not be relied on to prevent over-pressure and catastrophic failures.

Based on this it seems clear that operation of the Yukon College Gasifier coupled with the B1 Boiler as in the current configuration and within the current limits should not require additional staff.

In order to further consider potential requirements a survey has been carried out of regulations across Canada (Appendix F) a specific case applied to these regulations. The case consideration is based on the following criteria: Operation of a hot water boiler, with a maximum water delivery temperature of 116˚C (240˚F) and maximum boiler heat input of 12,000,000 BTH/hr. If the boiler is operated as an open-circuit boiler, i.e. no valve between the boiler and expansion tank and expansion tank fully vented to atmosphere, then unattended operation regulations are summarized in Table 3.

Table 3. Unattended boiler operation criteria

Jurisdiction	Unattended boiler operation	Comment
Ontario	No	Exceeds BHP req't
Quebec	Conditional surveillance	
British Columbia	No	Exceeds operating temperature req't
Alberta	Yes	If no obstruction between boiler and expansion tank and expansion tank fully vented to atmosphere
Manitoba	Yes	
New Brunswick	Yes	If boiler water content < 3,375 liters
Nova Scotia	No	Exceeds BHP req't
Newfoundland	Yes	
N-W Territories and Nunavut	No	Exceeds BHP req't
Yukon	Yes	If no obstruction between boiler and expansion tank and expansion tank fully vented to atmosphere

Notes:
-All criteria regarding safety, pressure relief equipment and instrumentation must be met in order to be eligible for code exemption.

Other than some provinces which have low BHP allowance in the majority of cases, operation of the Yukon College Gasifier coupled with the B1 Boiler as in the current configuration and within the current limits should not require additional staff.

8.0 Sustainability and Future Potential

8.1 Biomass "Sustainability"

Canada is a forest nation. Its forests cover 42% of its land mass and represent 10% of the world's forests and more than 30% of the Boreal Forest. Forests play an important role in the economic, social and spiritual well-being of Canadians. The majority of Canada's forests lie within eight ecozones delineated on the basis of the interactions of geological, landscape, soil, vegetation, climate, wildlife, water and human factors.

The Boreal Cordillera ecozone, covering sections of northern British Columbia and the southern Yukon, has a Pacific Maritime influence that moderates temperatures over most of its area. The climate is marked by long, cold winters and short, warm summers. The ecozone is 61% forested. Vegetative cover ranges from closed to open canopy forest. Tree species include white and black spruces, alpine fir, lodgepole pine, trembling aspen, balsam poplar and white birch. The tree line ranges from 1 500 metres in the southeast to about 1 200 metres in the northwest, where the stands are generally open, and there are almost no lodgepole pine or alpine fir. This ecozone is sparsely populated, with the majority of the population of approximately 32 904 (density 0.1) residing in the larger communities of Whitehorse and Dawson. The major economic activity is mining followed by forestry, tourism, and hydroelectric development.

The mean annual increment (MAI) is the average net annual increase in the yield of living trees to a given age, and is calculated by dividing the yield of a stand of trees by its mean age. The MAI is dependent on a number of factors, including climate and elevation, soil conditions and forest management practices. MAI is a measure of the net biomass production of the forest. For the Boreal Cordillera, the MAI ranges from 0.69 for poplar to 1.57 for larch. The values (from Natural Resources Canada surveys) include 1.30 for spruce, 1.11 for pine, 1.46 for fir, 1.20 for hemlock and 1.17 for birch. In estimating how much forest area would be required for a given amount of energy (in Table 3) on overall value of 1.1 has been assumed. For comparison purpose, spruce in the Pacific Maritime region have an MAI of 3.8.

In addition to the annual growth of forest there are two other factors affecting the potential for energy from biomass in the Yukon Territory: forest fires and spruce bark beetle infestations.

A forest fire kills trees and shrubs but often does not consume them; instead, it turns them into dead fuel. Combustion rarely consumes more than 10 to 15 percent of the organic matter, even in stand-replacement fires, and often much less. Consequently, much of the forest remains in the form of live trees, standing dead trees, and logs on the ground. Forest fires typically kill over 1000 square kilometres of forest in the Yukon each year. A considerable amount of biomass is therefore available to be used for energy systems.

The infestation of the mature spruce forests by the spruce bark beetle of the in the area around Haines Junction (Champagne and Aishihik Traditional Territory) has been epidemic since 1992 and shows no signs of abating. The infestation has contributed to a potential fire hazard for communities, increased the risk of catastrophic loss of property, affected visual landscapes, reduced the value of the forest for timber, recreation and tourism and impacted ecosystems. The scale of the infestation is extreme. Based on a forest health survey conducted by the Canadian Forest Service and the Forest Management Branch the infestation over the last 10 years has expanded its range and now occupies a total area of more than 220,000 hectares in the region. The annual rate of change in the amount of forest infested over this decade has been dynamic, but except for one three-year decline, the overall trend has been a growing increase. In some of the 18 planning areas in the region, the infestation has killed 100 per cent of the infested stands. These means that a potential area of 2200 square kilometres of dead forest is potentially available for energy use.

Table 4 has been prepared to assess the sustainability of biomass energy for space heating at Yukon College and in the Yukon Territory itself (assumed 3000 TJ heating load).

Table 4. Forest Area Required for Space Heating Using Biomass

	Yukon Territory	**Yukon College Gasifier**
Energy/Area Reqd		
Yearly Space Heating Consumption, TJ	3000	1.7
Wood Required@18 MJ/kg, tonnes	167000	94
Cords of Wood Equivalent	167000	94
Volume of Wood Required, m3	367000	208
Hectares/year based on complete harvest	4313	2.4
Square km/year based on complete harvest	43	0.02
Assume Growth of 1.1 m3/hectare/year		
Hectares based on sustainable harvest	333000	189
Square km/year based on sustainable harvest	3330	1.9

The initial part of Table 4 estimates how much forest would be required if the forest were harvested without any regard for growth. For space heating of the entire Territory, 43 sq km would be consumed which is a small figure when one considers the amount of forest fire kill (> 1000 sq km/year) and the beetle kill (~ 2200 sq km) areas available. In terms of wood for the gasifier the numbers become insignificant, i.e. only 2.4 hectares per year (0.024 sq km).

In the second part of Table 4, a requirement for sustainability has been introduced. A growth rate of 1.1 m3/hectare/year has been assumed. For space heating the entire Territory, an area of 3330 sq km would be required which is not an unreasonable number in a properly managed forest system. In order to operate the gasifier in a sustainable manner the area required is only 1.9 sq km.

The gasifier operation could thus easily be supported by forest biomass in a sustainable manner.

8.2 Future Potential

Aside from the environmental and economic benefits of operating the gasifier to provide heat from a renewable resource, the gasifier installation itself offers the opportunity to serve as the basis of future economic and technical developments. In its simplest form, the syngas produced by the gasifier is composed of two diatomic molecules, CO and H_2 that aside from being useful as gaseous fuels, provide the building blocks upon which an entire field of liquid fuel synthesis is based. An operating gasifier could be integrated into research activities at Yukon College and provide a pathways to investigations into advanced power generation technologies, production of liquid fuels (bio-diesel, ethanol and methanol) and as an entry point to the hydrogen economy.

8.3 Advanced Power Generation

Biomass fuels exist in many areas that lack conventional infrastructure, e.g. an electrical supply grid. Many of these sites must use imported fuel oil to generate small-scale power at substantial cost. There is therefore substantial interest in using the local biomass resource (in many cases a residue stream) to generate power. The size of these would typically be in the 250 kWe to 5 MWe range. This is a size range in which the conventional Rankine steam cycle, although technically feasible, is not economically feasible due principally to the need for continuous manned attendance. Efforts underway within the last five years have been aimed at developing "small modular" automated, safe and reliable biomass-fired systems, which can meet these needs. There are as yet no systems that can approach these criteria. Typical costs for existing systems are in the $4,000-$5,000/kWe range. The consensus is that the current price barrier for these systems is about $3,000/kWe.

Small gasifiers coupled to diesel or gasoline engines (typically for systems of 100-500 kilowatts of electricity with an approximate electrical efficiency of 15-25 percent) are being pursued by a large number of companies worldwide. The basic principle of power generation is illustrated in Fig. 32. The limiting factors to date have been high costs and the need for gas cleaning and unmanned control systems. Some crude systems are being applied fairly successfully in rural India and in China and Indonesia. For example, in China at least 20 fluidized bed gasifier/internal combustion engine plants are operating but the engines require shutdown and overhaul every 100 hours due to the contaminants in the syngas. In Europe a few units are operating with some success but they depend on very expensive multi-stage gas cleaning. Gas cleaning and conditioning remains a key requirement for these systems and a facility such as the Yukon College Gasifier would provide a good platform for such research.

Jenbacher Energiesysteme Ltd. has developed gas engines that can utilize an unmatched range of different gases such as syngas, pyrolysis gas and almost any other combustible gas. The heating value of gases that can be turned into electricity at an efficiency of up to 40% lies between 0.5 kWh/m3 and 34 kWh/m3, which is well within the range which could be produced by the Yukon College Gasifier. Jenbacher systems apply combustion technologies that have been patented worldwide and achieve guaranteed emission levels below 250 mg/m3 of NOx and below 300 mg/m3 of CO when operated with natural gas. The overall energy efficiency of the systems is as high as 88% when operated in cogeneration mode - i.e. simultaneous production of heat and power. For example, the Yukon College Gasifier could produced syngas which after cleaning is used to run an internal combustion engine. The hot exhaust from the engine could then be run through a boiler thus generating hot water to provide space heating. Such a project at Yukon College would be the first in Canada and certainly a showcase for advanced energy from biomass.

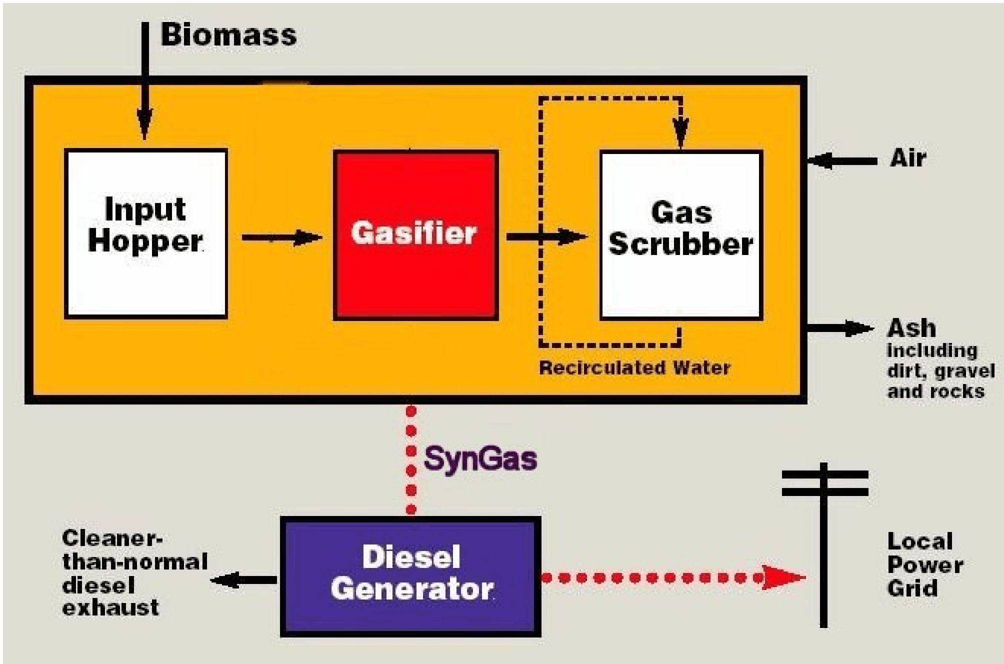


Figure 32. Small Scale Power Generation from Biomass Gasification

8.4 Fuel Synthesis

The synthesis of hydrocarbons from CO hydrogenation has been studied since the early 1900's when researchers first produced methane by passing CO and H_2 over Ni, Fe, and Co catalysts. Many of the syngas conversion processes were developed in Germany during the first and second world wars at a time when natural resources were becoming scarce and alternative routes for hydrogen production, ammonia synthesis, and transportation fuels were a necessity. With the development of the petroleum industry in the 1940s and beyond, the unattractive economics of many of these syngas routes became an issue and were replaced by petroleum-based processes. Increasing environmental concerns and tighter regulations surrounding fossil fuel have provided the impetus for syngas conversion technologies to produce cleaner (virtually no sulfur) fuels and chemicals. The latest environmental driver to likely increase demand for syngas even more is the goal of establishing a hydrogen economy. The vision is that hydrogen will be the fuel of choice for transportation and electricity generation via high efficiency, environmentally benign fuel cells.

Through gasification biomass can be converted into a large number of organic compounds that are useful as chemical feedstocks, fuels and solvents. At the centre of this transformation is use of selective catalysts (under heat and pressure) to convert the carbon monoxide and hydrogen into larger, more useful compounds. Fig. 33 shows a simplified schematic of the many conversion schemes that can be applied to syngas. Much of the research which has gone into these processes has in the past been based on coal gasification. Biomass gasification brings with it a whole new set of technical problems that have to be resolved, principally in cleaning and conditioning the syngas. Raw biomass syngas has tars and contaminants which not only reduce the viability of the conversion processes but can actually act as poisons the various catalysts.

Raw syngas from the gasifier needs to first have contaminants removed that would inactivate the catalyst. This includes sulfur compounds (e.g. H_2S, mercaptans), nitrogen compounds (e.g. NH_3, HCN), halides (e.g. HCl), and heavy organic compounds that are known collectively as "tar".

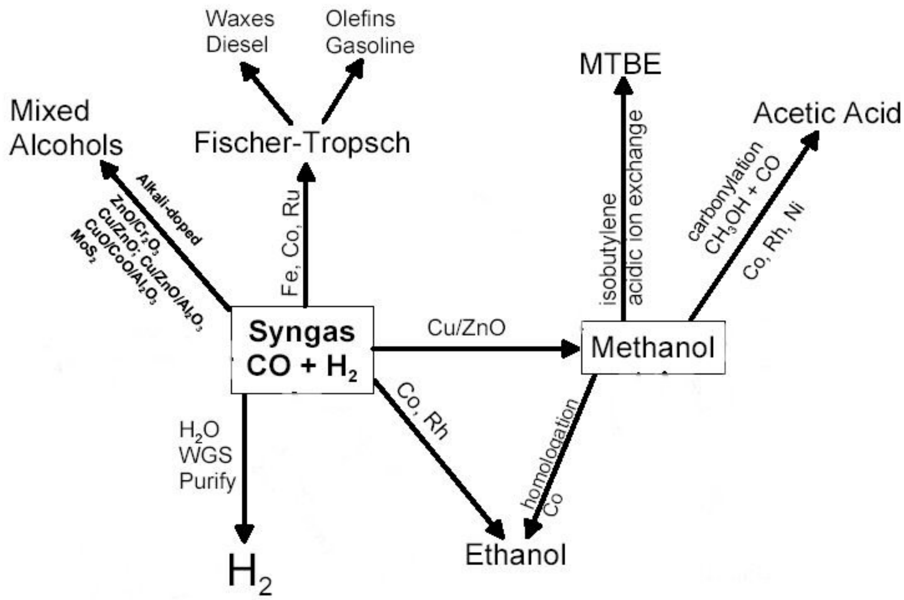


Figure 33. A simplified set of pathways for chemical conversion of syngas

A facility such as the Yukon College Gasifier could provide a syngas stream to be used by researchers to study advanced gas cleaning, conditioning and conversion. These activities would not interfere with the use of the gasifier as a heat source for the campus but would be based on drawing off a small "slip stream" of gas prior to B1 boiler. This type of activity is common at many European universities where the heating plant is incorporated into advanced energy research. The operation of the equipment by heating plant staff serves as an enormous benefit to researchers by removing the requirement to have research staff operating large combustors and gasifiers.

The process of converting CO and H_2 mixtures to liquid hydrocarbons over a transition metal catalyst has become known as the Fischer-Tropsch (FT) synthesis. The first FT plants began operation in Germany in 1938 but closed down after the Second World War. Common problems of Fisher-Tropsch synthesis (FTS) are low product unavoidable production of olefins, paraffins, and oxygenated products) and the sensitivity of the catalyst to contamination in the syngas that "poison" or inactivate the catalyst. Research to improve both the selectivity of catalysts to make purer, high value products and better resistance to "poisons" both contribute to lowering the cost of production.

A second, important, conversion processes for syngas is to methanol. Methanol is a commodity chemical, one of the top ten chemicals produced globally and is an important chemical intermediate used to produce a number of chemicals, including: formaldehyde, dimethyl ether, methyl tert-butyl ether, acetic acid, and olefins, to name a few. Methanol can also be used directly or blended with other petroleum products as a clean burning transportation fuel. Higher alcohols or methanol mixed with higher alcohols would be better than straight methanol as a gasoline additive to boost octane, avoiding certain drawbacks of straight methanol. Modified catalysts for these processes are among the more seriously pursued processes for producing higher alcohols from synthesis gas. No commercial production exists at the current time.

Anaerobic bacteria can also be used to convert syngas into ethanol. In the US, Bioresource Engineering Inc. has developed synthesis gas fermentation technology that can be used to produce ethanol from biomass wastes. After gasification, anaerobic bacteria such as Clostridium ljungdahlii are used to convert the CO, CO_2, and H_2 into ethanol. The process of combined gasification/fermentation has been under development by for several years and is currently at the pilot plant stage.

8.5 Hydrogen

Biomass has the potential to accelerate the realization of hydrogen as a major fuel of the future. However, hydrogen from biomass has major challenges. There are no completed technology demonstrations. The key to hydrogen utilization is fuel cell applications and so product purity requirements for the fuel cell will drive the gas purity requirements of all production systems. In gasification, the presence of hydrocarbons and trace levels of nitrogen, sulfur, and chlorine compounds must be addressed, not only for end use applications, but also for shift reaction catalysts and separation systems, such as pressure swing adsorption (PSA) . The basic steps in the production of hydrogen from biomass are as follows:

I. Biomass gasification
ii. Gas clean-up
iii. Catalytic Steam Reforming
iv. Water Gas Shift Reaction
v. Gas Separation (PSA)

The water-gas shift reaction is the mechanism used to convert carbon monoxide to carbon dioxide and hydrogen through the following reaction with water

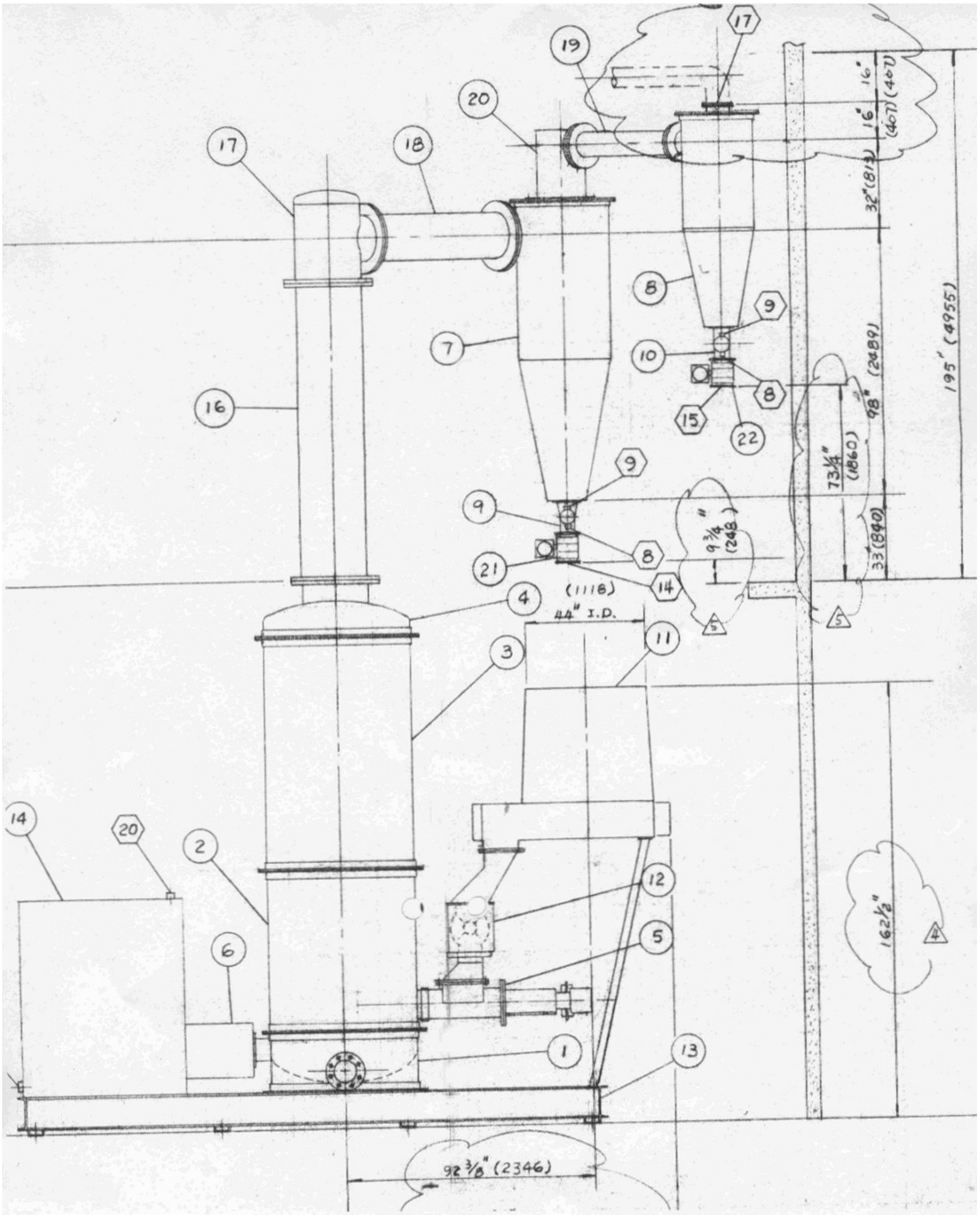
$$CO + H_2O <> CO_2 + H_2$$

This reaction is exothermic, which means that the reaction equilibrium shifts to the right and favours the formation of hydrogen at lower temperatures. At higher temperatures the equilibrium shifts to the left which limits the conversion of to hydrogen.

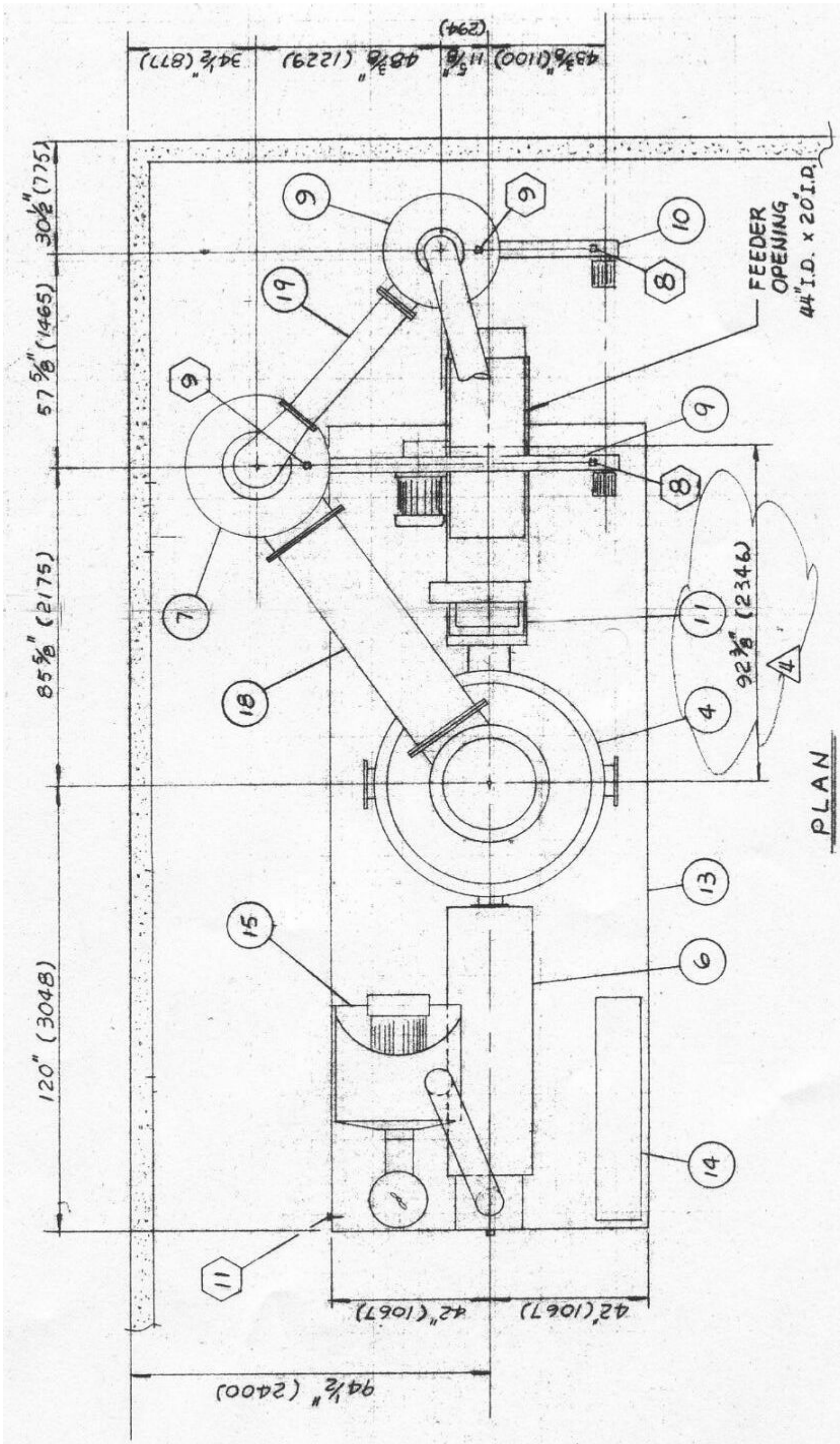
Most of the steps involved in the conversion of biomass to hydrogen are understood. The one requiring the most development is the gas clean-up and as has been noted throughout this section the Yukon College Gasifier would be an excellent platform on which to build a research program for the development of bio-fuels including hydrogen.

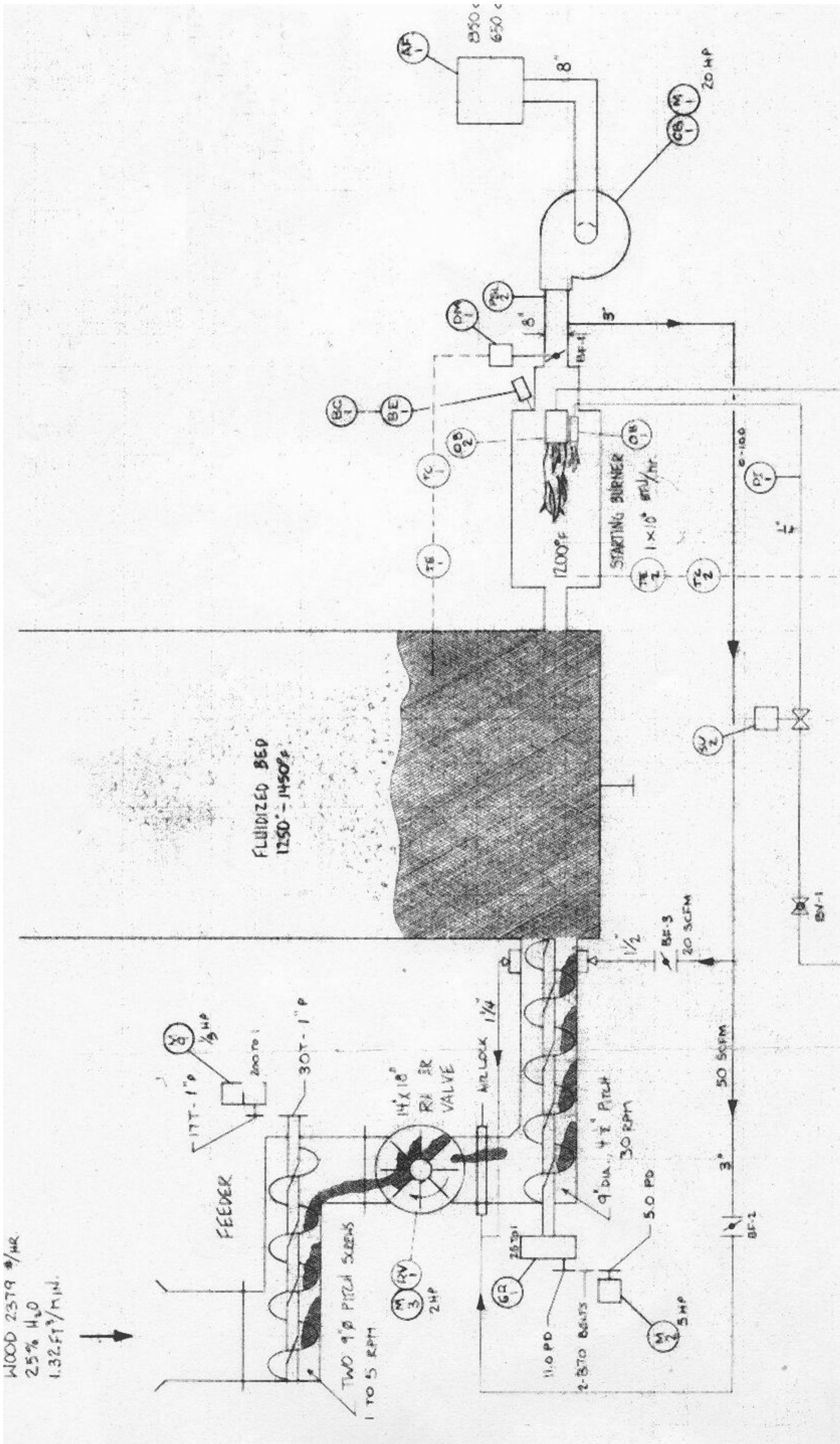
APPENDICES

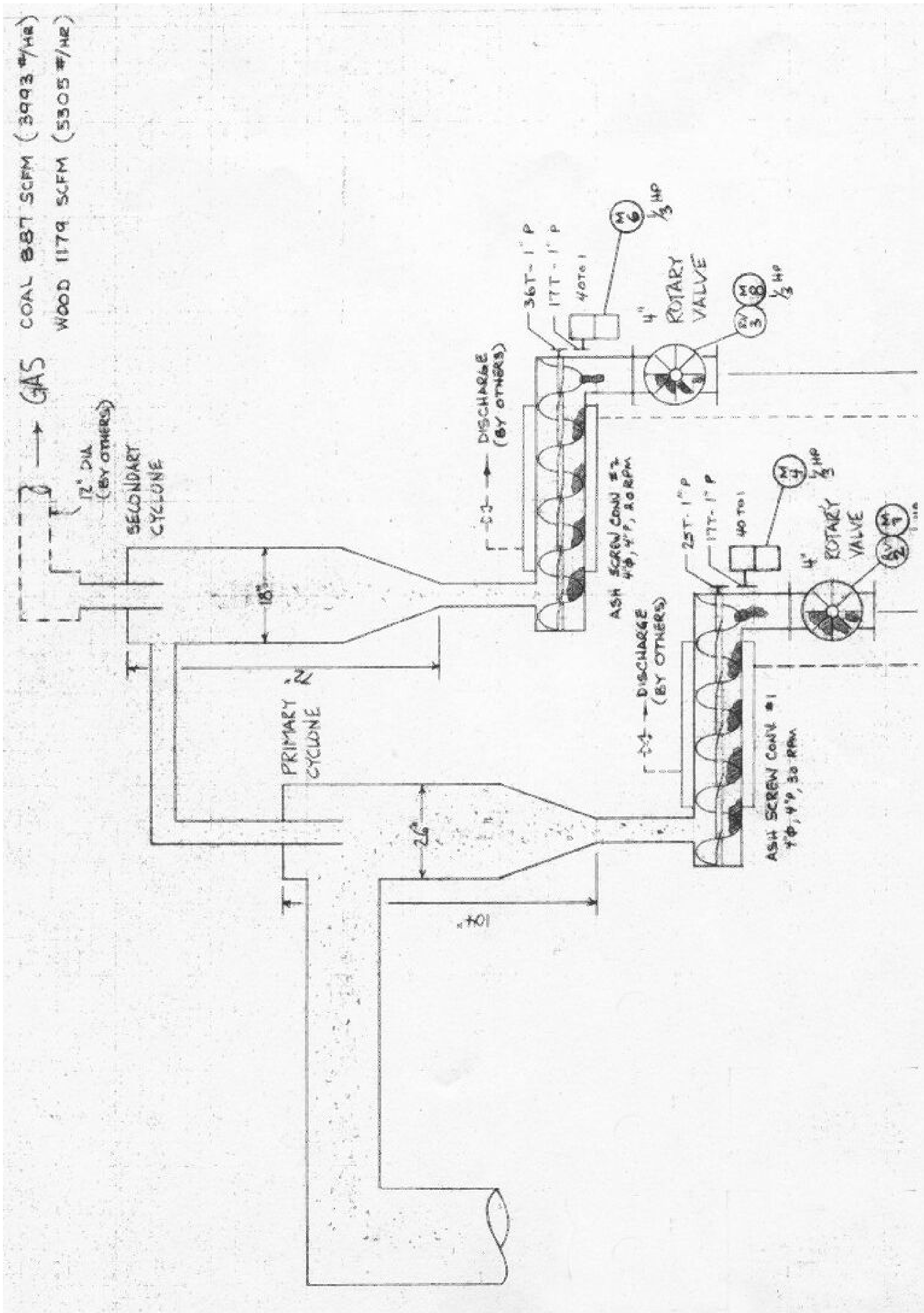
APPENDIX A - Original Gasifier Drawings



17
19
20
18
16
7
8
9
10
15
22
21
14
4
3
11
2
12
5
6
1
13
16"
(407)
32"(813)
195' (4955)
98" (2489)
73 1/4" (1860)
33 (840)
9 3/4" (248)
(1118)
44" I.D.
162 1/2"
92 3/8" (2346)


PLAN
FEEDER OPENING
44" I.D. x 20" I.D.
120" (3048)
85 5/8" (2175)
57 5/8" (1465)
30 1/2" (775)
92 3/8" (2346)
94 1/2" (2400)
42" (1067)
42" (1067)
34 1/2" (877)
48 3/8" (1229)
11 5/8" (294)
43 3/8" (1100)


WOOD 2379 #/HR
25% H2O
1.32 FT³/MIN.
FEEDER
TWO 9"Ø PITCH SCREWS
1 TO 5 RPM
14"x18" ROTARY VALVE
AIRLOCK
FLUIDIZED BED
1250° - 1450°F
1200°F
STARTING BURNER
50 SCFM
20 SCFM
20 HP
8"
3"


GAS
COAL 887 SCFM (3993 #/HR)
WOOD 1179 SCFM (5305 #/HR)
SECONDARY CYCLONE
PRIMARY CYCLONE
DISCHARGE (BY OTHERS)
DISCHARGE (BY OTHERS)
4" ROTARY VALVE
4" ROTARY VALVE

APPENDIX B - Instrumentation & Control Notes

YUKON COLLEGE Gasifier I&C Notes

Equipment Tags

BF-01	Motorized butterfly valve	Preheater combustion air
BF-02	Butterfly valve	Fluidizing air to fuel feed auger
BF-03	Butterfly valve	Fluidizing air to fuel feed airlock
BV-01	Ball valve	Preheater main oil manual shutoff valve
BV-02	Ball valve	Preheater pilot oil manual shutoff valve
M-01	600VAC Motor	Preheater combustion air FD blower
M-02	600VAC Motor	Fuel feed auger
M-03	600VAC Motor	Fuel feed airlock
M-04	600VAC Motor	Primary ash auger
M-05	600VAC Motor	Coolant pump
M-06	600VAC Motor	Secondary ash auger
M-07	600VAC Motor	Primary ash airlock
M-08	600VAC Motor	Secondary ash airlock
M-09	DC Motor	Feed hopper auger
PSH-01	Pressure switch	Preheater oil high limit
PSL-01	Pressure switch	Preheater oil low limit
PSL-02	Pressure switch	Preheater combustion air low limit
SV-01	Solenoid Valve	Preheater main oil automatic shutoff valve
SV-02	Solenoid Valve	Preheater pilot oil automatic shutoff valve
TC-01	Temperature Controller	Gasifier temperature controller (combustion air)
TC-02	Temperature Controller	Burner controller (Hi/Lo fire)
TC-04	Temperature Controller	Reactor Hi Hi limit ('West' controller)
TE-01	K-Type T/C	Bed temperature
TE-02	K-Type T/C	Preheater outlet temperature
TE-03	K-Type T/C	Reactor outlet temperature
TE-04	K-Type T/C	Bed temperature
TSH-01	Temperature Switch	Reactor Hi limit

Equipment Interlocks

01. ID fan
02. Emergency shutdown button
03. Reactor Hi Hi temperature limit
04. Reactor Hi temperature limit
05. Reactor Lo temperature limit
06. Ash System (primary and secondary augers, primary and secondary airlocks)
07. Preaheater flame failure
08. Combustion chamber flame failure
09. Fuel feed airlock / feed hopper auger

I & C REQUIRED CHANGES

I. .New control system w/ datalogging capabilities
. Independent burner management system for preheater (BMS)
. Complete overhaul of safety interlocks (burner, ash system, feed system)
. Modulating control of ID fan
. At least 4 pressure ports (preheater outlet, reactor at nozzle level, reactor outlet, boiler outlet)

I.More temperature ports in the reactor as well as Boiler inlet and outlet

II.Boiler control system needs updating (not replacement)

III.Reactor Should be interlocked to boiler when in normal gasifying operation

YUKON COMMUNITY COLLEGE GASIFIER
Potential Control System

National Instruments Fieldpoint RT System	**$4,395.00**

Module	Price	Quantity	Total
FP - 2000	$1,425.00	1	$1,425.00
FP - TC - 120	$505.00	1	$505.00
FP - AI - 110	$505.00	1	$505.00
FP - AO - 200	$565.00	1	$565.00
FP - DI - 301	$255.00	1	$255.00
FP - DO - 401	$325.00	1	$325.00
FP - TB - 1	$140.00	4	$560.00
FP - TB - 3	$255.00	1	$255.00

Control Software	**$9,280.00**

LabVIEW Professional Edition	$5,000.00
Real Time Module	$2,855.00
PID Control Toolkit	$1,425.00

Instrumentation (pricing may vary)	**$17,900.00**

Description	Price	Quantity	Total
K-Type T/C	$300.00	8	$2,400.00
Pressure Tx	$1,000.00	4	$4,000.00
Flow Tx (Comb Air)	$5,000.00	1	$5,000.00
Flow TX (Purges) *	$5,000.00	1	$5,000.00
* This is a ball park dependant on the number of pressure ports			
Frequency Drive	$1,500.00	1	$1,500.00

Control Panel (pricing may vary)	**$15,000.00**

Panel & Components	$10,000.00
Burner Management System	$5,000.00

Subtotal	$46,575.00
Taxes	$6,986.25
TOTAL COST FOR HARDWARE	**$53,561.25**

Pressure, Level, and Temperature switches may also be required.
The above does not include field wiring or labour costs.

APPENDIX C - Modified Operating Procedure

Modified Operating Procedure

1) Set limits.

2) Verify proper shaft operation on all drives.

3) Start fuel oil pump. Open inlet valve on oil supply line (110psig).

4) Start cooling water to ash cooling conveyor.

5) Verify settings:
   Power Switch--off
   Gasifier Switch--off
   Preheater Switch--off
   Cooling Water Switch --off
   Feed Control --local
   Gasifier Feed Rate Pot--stop/off
   Manual Air Gate Valve--full open
   Auger/Radar Air Valves set at --small=1/2
   -- large=1/8

6) Turn Power Switch to ON (Silence Alarm)
   (All controllers/limits power up, 3" valve opens)

7) Turn Gasifier Switch to ON

8) Turn Green Start button to ON
   - initiates blower and control circuitry
   - "pressure blower" and "bed feed auger" illuminate

9) Turn Preheater Switch to ON
   -preheat on light illuminates shortly
   - "preheat ignition on"
   -"preheat pilot on" illuminates
   Then control of the burner set through "preheat temperature control"
   instrument yellow main oil on" light will indicate temperature control
   switching Hi/Lo firing rate

10) Verify oil flame operation (visually)

11) Allow preheater to control until the temperature control lower switch setting has been achieved and burner is de-energized (this lower switch setting is a deviation sand setting approx 300 F below set point which should be 1300 F (700 C) ie.1000 F)

12) The following will come "ON"

   --#1 ash cooler conveyor

--#2 ash cooler conveyor
--#1 rotary ash valve
--#2 rotary ash valve
-- rotary feed valve
-- D.C. drive feeder

13) Turn "cooling water" switch to ON

- blue "coolant pump" and "cooling water" lights on.

14) Fuel Storage Control Panel

- Disconnect ON
- Control Power ON
- Light ON
- Pit Heat ON
- Hi Left Auger ON
- Pit Conveyor ON
- Centre Pit Feed ON
- Manual Feed OFF
- Hydraulic Pump ON

15) Make sure that gasifier is preheated evenly

- at about 425 C the bed fluidizes and gets uniform temperature

16) Set feed rate at less than 1.5 to combustor.

- Let temperature rise to 1300 F (704 C) then shut off the feed
- Let temperature drop to 1100 F(600 C) the feed to 1.5.

Comments: 3 is the recommended feed for full operation.

Recommended: If the temperature doesn't hold shut off feed and wait for it to stabilize.

GENERAL NOTE:

In running the gasifier the following are recommended approaches:

- approach the desired gasification temperature from the low side (i.e. increase temperature toward the target)
- run with low fuel setting
- increase fuel to target but drop air simultaneously
- increase air to target setting and control to maintain temperature

APPENDIX D - Test Run Data - March 27, 2004

Yukon Gasifier Testing March 27, 2004

Time	TEMPERATURES Gasifier Exit T1	In-bed T2	Preheat T3	Boiler Out T4	Boiler IN T5	Stack Tstack	PRESSURES Preheat psi P1	Bed P2	Top P3	B1 Inlet PB	Stack (in H20) P4	COMMENTS
930	283	394	635	92	156	86	2.5	13.87	0.5		2.25	P2 zero is 13.25
945	300	412	678	92	170	86	2.6	0.6	0.5		2.25	
1000	317	433	656	91	186	86	2.6	13.9	0.5		2.5	
1015	329	444	660	91	198	86	2.6	13.8	0.5		2.5	P above B1 burner
1030	337	449	662	91	206	86	2.7	13.9	0.6		2.5	+25"
1045	345	460	657	100	215	110	2.7	13.9	0.6		2	
Shut off pre-heat to gasifier, fire B1 on oil only (low/mod fire)												
1050	286	459	478	127	194	133.6					2.4	
1055	250	459	422	134	183	138.5					2.4	
1100	238	460	390	150	180	141.4					2.4	
1105	228	459	363	156	176	143.9					2.4	
1110	220	459	342	158	174	145.8					2.4	
1115	214	459	321	160	171	146.9					2.4	
Switch to oil burner to high fire												
1120	208	461	313	175	168	167.9					1.7	
1126	202	458	301	179	166	169					1.8	
1130	201	458	293	178	165	167.4					1.9	
1135	197	459	280	178	163	168.5					1.9	
1140	193	458	269	178	162	169.8					1.9	
1145	190	456	263	183	162	175					1.9	
1150	188	455	255	186	161	176.6					1.9	
Switched ID fan off, draft on 1\2 cm wc, lots of smoke, 02 <0, CO>5000, Cannot fire hi-fire without ID fan. Back to low-fire												
1206	176	455	259	135.6	172	118.6					0.3	
1210	174	452	261	132	173	115.1					0.3	
1215	171	451	260	126	176	111.3					0.3	
1230	166	445	253	127	181	109.3					0.3	

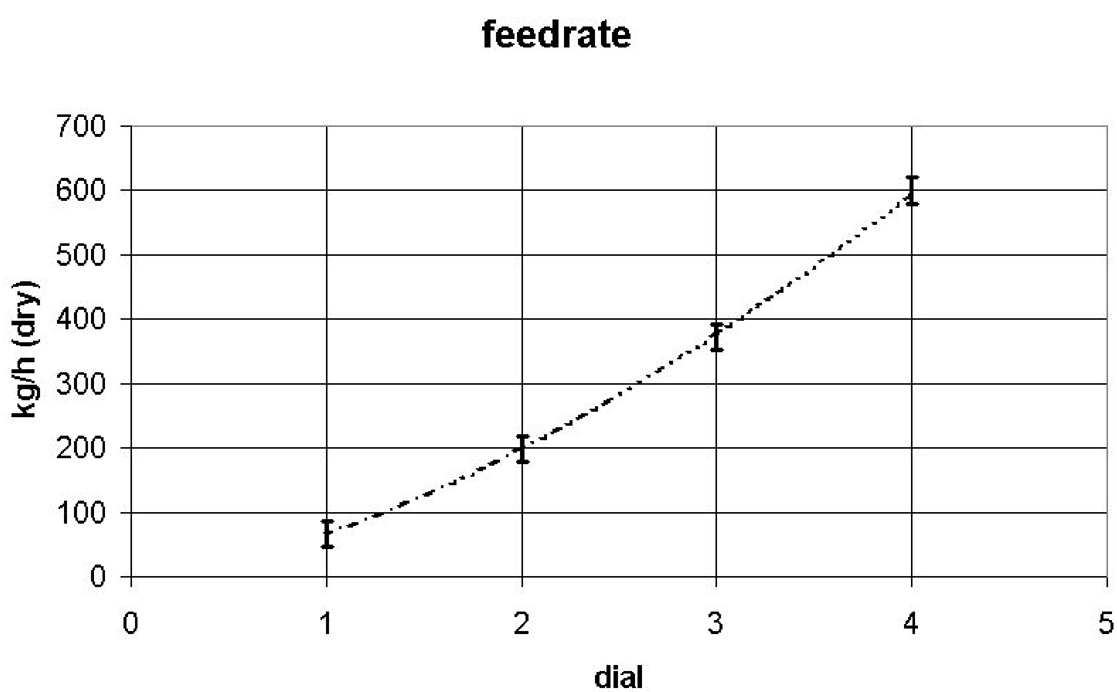
Time	Gasifier Exit	In-bed	Preheat	Boiler Out	Boiler IN	Stack	Preheat psi	Bed	Top	B1 Inlet	Stack (in H20)
	T1	T2	T3	T4	T5	Tstack	P1	P2	P3	PB	P4
	1:55pm Restart Pre-Heat										
1345	Blower tripped out by controls >900C, restarted with fuel shut off. Cooled to 820-Fuel restarted at 0.5										
1400	285	421	649	95	159	88.1	2.7	14.2	0.8	20.5	1.8
1450	345	470	687	82	213	78.3	2.7	14.3	0.9	21	1.75
1455	Oil burner B1 on low fire										
1505	353	482	698	141	221	148.8	2.6	14.3	0.9	18.4	1.5
1513	Wood chip feed at 1.0										
1520	554	646	155	168	259	160.9	2.6	14.5	1	19.2	1.5
	MGV 3 turns open setpoint 900 C										
1535						167.5	2.6	14.6	1.3	28	1.5
1539	681	888	91.6	174	313						
1600	579	690	74.5	177	324	176	2.6	14.5	1.1	27.3	1.5
	MGV 3 turns open/ECV fully open.Fuel turned to 3/4(0.75)										
1630	577	671	62.8	178	347	178.3				29.2	1.5
1645	615	710	60	178	363	179.3				30.1	1.5
1700	618	725	58	179	378	180	2.6	14.6	1.2	31	1.5
1720	637	750	56	179	393	180				30	1.4
1730	663	756	55	179	400	181					
1810	688	818	55	183	419	181				30	1.5
	MGV 2 1\2 turns open. Setpoint 700, EVC closed										
1815	679	841	53	182	416	181	1.8	14.1	0.7	20	1.4
1817	Fuel set to zero										
1825	Fuel set to 2.0, Setpoint 720										
1830	Manual valve one turn back (1 1/2 open)										
1831	Fuel to 3.O, Temperature excursion to >950C										
	ECV doesn't control properly, will attempt to run my closing ECV and running MGV only										
	3 turns open, 0.5 fuel ~stable										
1952	673	753	50	182	421	183	1.7	14.2	0.7	18.5	1.25
2010	Air open 5 turns, (try to aim for ~600C), (then turn air 2 turns, to ~3.0), (and fuel to 6.0kg/min)										
1811	652	685	49	182	440						
2015	Six turns open										
2030	Shut down to clean glass										
2040	Air- 2 turns, feed 0.5										
2040	599	656	46	182	430	183	1.1	14	0.6	14.8	1.5
2045	Air to 2--Feed to 3										
2049	Air to 3										
2055	Air to 5						205.3				
2057	Air to 4										
2100	Air to 3, bucket of sand to cool bed										
2103	Air to 4										

Yukon Gasifier Testing March 27, 2004 - Flue Gas Analysis

		NO (ppm)	S02 (ppm)	CO (ppm)	CO2 (%)	O2(%)
Time						
1040		0	2	310	0.46	20
		Shut off preheat				
1050		45	2	6	7.82	10.65
1100		49	2	4	7.85	10.58
1105		52	2	4	7.84	10.57
1110		53	2	4	7.85	10.6
1115		60	2	3	8.02	10.38
1120		79	9	16	11.27	6.3
1130		66	214	51	14.32	2.83
1135		109	286	109	14.55	2.5
1140		152	252	312	14.66	2.21
1145		215	166	10	13.32	3.72
1150		226	120	9	13.32	3.82
1206		99	26	38	15.42	1.52
1211		102	28	24	15.33	1.69
		There is some variation in air				
1215		90	45	1864	16.23	0.48
				adjusted air		
1220		97	60	273	15.91	1
1230		124	91	25	15.35	1.64
1405		1	6	216	0.24	20.13
		0	2	207	0.2	20.35
1508		39	13	873	7.88	10.13
1522		50	13	666	10.41	7.84
		46	12	606	10.81	7.56
		Air B1opened a bit, to fuel 0.5				
1600		51	7	546	6.82	11.25
1630		52	7	572	7.2	11.36
1645		53	7	546	7.38	10.97
1700		54	8	604	7.8	10.7
1720		54	6	485	7.37	11.03
1730		54	6	511	7.33	11.14
1810		46	5	509	8.42	10.14
1815		53	5	404	7.82	10.53
		49	4	590	7.34	11.13
2040		50	7	492	6.77	11.64
2055		129	14	over	17.6	1.19
2110		56	2	351	8.12	10.2
Boiler Cofire at end					5.92	12.54

APPENDIX E - Wood Chip Feed Calibration

dial	kg/h	m3/h
1	66	0.32
2	198	0.95
3	372	1.79
4	600	2.89



APPENDIX F - Regulations on Unattended Boilers/Boiler Plants

Regulations on Unattended Boilers/Boiler Plants

Ontario Regulations

Fire Tube, Water Tube Design Steam Boilers		
Type	**Ratings**	**Requirements**
Low Pressure Steam < 15 psig	< 294 kW (30 bhp, 10 TH)	Unregistered
	> 294 kW (30 bhp, 10 TH) < 1471 kW (150 bhp, 50 TH)	Registered, Guarded Controls, Maintenance Program
High Pressure Steam > 15 psig	< 147 kW (15 bhp, 5 TH)	Unregistered
	> 147 kW (15 bhp, 5 TH) < 490 kW (50 bhp, 17 TH)	Registered, Guarded Controls, Maintenance Program

Low Water Volume (LV) Water Tube Steam Boilers			
Type	**Criteria**	**Ratings**	**Requirements**
II. Low Pressure Steam < 15 psig IV.	Boiler water content < 150 Gal. (682 L) Boiler & system water content < 750 Gal. (3410 L)	< 294 kW (30 bhp, 10 TH)	Unregistered
		> 294 kW (30 bhp, 10 TH) < 24524 kW (2500 bhp, 836 TH)	Registered, Guarded Controls, Maintenance Program
II. High Pressure Steam > 15 psig IV.	Boiler water content < 75 Gal. (341 L) Boiler & system water content < 250 Gal. (1136 L)	< 147 kW (15 bhp, 5 TH)	Unregistered
		> 147 kW (15 bhp, 5 TH) < 14715 kW (1500 bhp, 502 TH)	Registered, Guarded Controls, Maintenance Program

Hot Water Boilers			
Hot water boilers operating at temperatures less than 212°F (100°C) have no requirements			
Type	**Criteria**	**Ratings**	**Requirements**
Low Temperature Boilers operating at water temperature > 212°F (100°C) ≤ 250°F (121°C)	II. Flooded Volume boiler water content < 150 Gal. (682 L) IV. Boiler & system < 750 Gal. (3410 L)	< 294 kW (30 bhp, 10 TH)	Unregistered
		> 294 kW (30 bhp, 10 TH) < 1962 kW (200 bhp, 67 TH)	Registered, Guarded Controls, Maintenance Program
	II. Flooded Volume boiler water content > 150 Gal. (682 L) IV. Boiler & system < 750 Gal. (3410 L)	< 294 kW (30 bhp, 10 TH)	Unregistered
		> 294 kW (30 bhp, 10 TH) < 1471 kW (150 bhp, 50 TH)	Registered, Guarded Controls, Maintenance Program
High Temperature Boilers operating at water temperature > 250°F (121°C)	II. Flooded Volume boiler water content < 75 Gal. (341 L) Boiler & system < 250 Gal. (1136 L)	< 147 kW (15 bhp, 5 TH)	Unregistered
		> 147 kW (15 bhp, 5 TH) < 736 kW (75 bhp, 25 TH)	Registered, Guarded Controls, Maintenance Program
	II. Flooded Volume boiler water content > 75 Gal. (341 L) Boiler & system > 250 Gal. (1136 L)	< 147 kW (15 bhp, 5 TH)	Unregistered
		> 147 kW (15 bhp, 5 TH) < 490 kW (50 bhp, 17 TH)	Registered, Guarded Controls, Maintenance Program

Quebec Regulations

STATIONARY ENGINES		Maximum installation power rating (in kW)			
Installation type		Conditional Surveillance	Periodic Surveillance	Interrupted Surveillance	Continuous Surveillance
High Pressure Boilers (Steam or Hot Water)	Smoke tubes	300	6000	12000	12000 +
	Water tubes	450	9000	18000	18000 +
	Coil type	600	12000	24000	24000 +
	Electric	600	12000	24000	24 000 +
Low Pressure Steam Boilers	Smoke tubes	600	12000	24000	24000 +
	Water tubes	900	18000	36000	36000 +
	Coil type	1200	24000	48000	48000 +
	Electric	1200	24000	48000	48000 +
Low pressure hot water boilers		2000	30000	120000	120000 +
Thermal liquid boilers		2000	30000	120000	120000 +
High pressure steam generators		10000	60000	240000	240000 +
High pressure refrigeration equipment (Group 2 or 3)		50	300	600	600 +
High pressure refrigeration equipment (Group 1 - volumetric)		300	600	1200	1200 +
High pressure refrigeration equipment (Group 1 - centrifugal)		400	1200	1200 +	
Low pressure refrigeration equipment (Group 1)		400	1200	1200 +	
Steam engines or turbines		250	250 +		

Province	Regulations	Comments
British Columbia	power plant, or a high pressure organic or thermal fluid plant, not exceeding 10 m^2 of boiler capacity . low pressure steam plant not exceeding 30 m^2 of boiler capacity . low pressure hot water plant not exceeding 150 m^2 of boiler capacity . low pressure organic or thermal fluid plant not exceeding 150 m^2 of boiler capacity . low pressure hot water plant that operates at a temperature not exceeding 100˚ C and at a maximum allowable working pressure of 206 kPa, and does not exceed 300 m^2 of boiler capacity . unfired plant not exceeding 150 m^2 of boiler capacity	A power engineer's or boiler operator's certificate is not required to operate any of the following plants
Alberta	. a boiler having a boiler rating of 10 kilowatts or less in capacity that forms the whole or part of a power plant . a boiler having a boiler rating of 20 kilowatts or less in capacity, installed in a heating plant . a boiler that is intended to be used in connection with a hot water heating system and that has no valves or other obstructions to prevent circulation between the boiler and the expansion tank but only if the expansion tank is fully vented to the atmosphere . a pressure vessel of 152 millimetres or less in internal diameter . a pressure vessel that is used for the storage of hot water and has an internal diameter of 610 millimetres or less . a pressure vessel or pressure piping system operating at and with relief valves set at 103 kilopascals or less . a boiler or pressure vessel subject to the jurisdiction of the Canadian Transport Commission or a boiler or pressure vessel subject to the Canada Shipping Act (Canada) . a pressure vessel intended to be installed in a closed hot water heating system having a working pressure of 207 kilopascals or less and having an internal diameter of 610 millimetres or less . any pressure piping system and machinery and equipment ancillary to it by which refrigerants are vaporized, compressed and liquefied in the refrigerating cycle and that has a capacity of 10.5 kilowatts or less . a pipeline, as defined in the Pipeline Act, unless the pipeline forms the whole or part of a boiler, pressure vessel, pressure plant, power plant or heating plant that forms the whole or any part of an installation, as defined in the Pipeline Act . a pressure vessel that is subject to the Transportation of Dangerous Goods Act, 1992 (Canada).	The Safety Codes Act and the regulations made pursuant to the Act and any code, standard or body of rules declared to be in force pursuant to the Act do not apply to

Manitoba	. a steam plant of 50 kW (five boiler horsepower) capacity or less, operated subject to a pressure of 103 kPa (15 psi) or more, or a steam plant subject to a pressure of less than 103 kPa (15 psi), and that has a capacity of 500 kW (50 boiler horsepower) or less; . a hot water heating boiler operating at a (15 lb/po); pressure not exceeding 1100 kPa (160 psi) or a temperature not exceeding 120 degrees Celsius (250 degrees Fahrenheit), or both, at or near boiler outlet; . an air pressure plant, other than reciprocating type, of not more than 5000 kW (500 boiler horsepower) equivalent capacity; . an air pressure plant of the reciprocating type, of not more than 1500 kW (150 boiler horsepower) equivalent capacity; . a steam plant or pressure plant used on a single family farm for farming purposes only; . a plant subject to Part II of the *Canada Labour Code*; . a low volume boiler plant, whether or not the boilers are connected together, provided that; . the plant is equipped with a full set of automatic safety controls, . the plant or any of its boilers are not connected to, or used in conjunction with, other boilers that require supervision under the Act or regulations, and . the owner of the plant . certifies in writing to the minister that the plant will be serviced annually by a person holding a valid commercial and industrial gas fitter's licence under *The Gas and Oil Burner Act*, and . provides evidence to the minister on an annual basis that such servicing has been completed	**Power Engineers Regulation** The Act and this regulation do not apply
	. steam plant operating at a pressure of 103 kPa (15 psi) or greater but not over 1030 kPa (150 psi), with a capacity in excess of 50 kW (five boiler horsepower) but not over 500 kW (50 boiler horsepower), and installed in a building in which no person resides, is equipped with a full set of automatic safety controls and the owner of the plant certifies in writing to the minister that the plant and each safety device is tested every day of operation by a power engineer of the class required under this regulation and is maintained in good working order, and particulars of the tests and the results are recorded in a log, the minister may in writing authorize the operation of the plant without constant supervision	**Power Engineers Regulation**

New Brunswick	. heating and power plants under the jurisdiction of the Canadian Transport Commission; . low pressure heating plants having a rating of fifty therm-hour or less; . high pressure heating plants having a rating of twenty therm-hour or less	Act does not apply to
	A power engineer is not required to be in attendance where a heating plant or power plant is comprised of one or more coil tube boilers and where . each boiler contains steam at a pressure of more than fifteen pounds per square inch (one hundred and three kilopascals) or water at a temperature of more than two hundred and fifty degrees Fahrenheit (one hundred and twenty degrees Celsius) and the combined total water content of the boilers does not exceed two hundred and fifty Imperial gallons (one thousand one hundred and twenty-five litres), or . each boiler contains steam at a pressure of fifteen pounds per square inch (one hundred and three kilopascals) or less or water at a temperature of two hundred and fifty degrees Fahrenheit (one hundred and twenty degrees Celsius) or less and the combined total water content of the boilers does not exceed seven hundred and fifty Imperial gallons (three thousand three hundred and seventy-five litres).	**NEW BRUNSWICK REGULATION 84-175** under the **BOILER AND PRESSURE VESSEL ACT**
	The owner of a low pressure heating plant having a capacity not exceeding a rating of one hundred and forty therm-hour or of a high pressure heating plant having a capacity not exceeding a rating of seventy therm-hour may make arrangements for the boilers to be left unattended and in operation if: . the heating plant is guarded in accordance with section 6; . a Fourth Class Power Engineer has charge of the heating plant; . the safety controls are checked daily and entries made in a log book noting the time of the check; and . the installation is inspected periodically and approved by a boiler inspector.	

Nova Scotia	**(1)** Minimum supervision may be authorized pursuant to Section 12 for any of the following plants: **(a)** a power boiler plant with a power rating of 1000 kW or less; **(b)** a heating boiler plant with a power rating of 2000 kW or less; **(c)** a refrigeration plant that uses a Group A2, A3, B1, B2 or B3 refrigerant as classified in CSA B52-99 Mechanical Refrigeration Code, as amended from time to time, and has a power rating of 150 kW or less; **(d)** a refrigeration plant that uses a Group A1 refrigerant as classified in CSA B52-99 Mechanical Refrigeration Code, as amended from time to time, and has a power rating of 350 kW or less; **(e)** a compressor plant that compresses oxygen or a flammable or toxic gas that has a power rating of 150 kW or less; or **(f)** an air, or a non-flammable or non-toxic gas compressor plant that has a power rating of 750 kW or less. **(2)** Where a plant is operating under minimum supervision, no power engineer or operator shall leave the plant site without ensuring that the plant is **(a)** operating under automatic control safely and in accordance with the manufacturer's specifications; and **(b)** guarded. **(3)** The power engineer or operator for every plant that is operating under minimum supervision shall visit the plant at least once during every 24-hour period to ensure that the requirements of Sections 17 to 22 respecting control, alarm and safety devices and systems and guarded controls are complied with.	Crane Operators and Power Engineers Act **Power Engineers Regulation**
Newfoundland	. A power engineer is not required to be in attendance at a plant that is comprised solely of coil tube boilers and either . each boiler contains steam at a pressure of more than 103 kilopascals or water at a temperature of more than 121˚ C and the total output does not exceed 3,600 kilowatts or the total water content does not exceed 1,125 litres; or . each boiler contains steam at a pressure of 103 kilopascals or less or water at a temperature of 121˚ C or less and the total output does not exceed 12,000 kilowatts or the total water content does not exceed 3,375 litres.	**Boiler, Pressure Vessel and Compressed Gas Regulations**

Northwest Territories **and** **Nunavut**	. a boiler . that develops less than 30 kW of power, or . that is used for heating private residences that house less than three families; . a pressure vessel . of less than 0.043 m_ in volume, . that is operated at a pressure of less than 103 kPa, . that is required to be inspected under the Explosives Act (Canada), or . that is a diesel engine; . a boiler or pressure vessel . that is part of the equipment of railways under the Railway Act (Canada), or . that is subject to inspection under the Canada Shipping Act (Canada); and . a refrigeration plant having a capacity of 11 kW or less of refrigeration in 24 hours.	**BOILERS AND PRESSURE VESSELS ACT** This Act does not apply
Yukon	. a boiler having a boiler rating of 10 kilowatts or less in capacity which forms all or part of a power plant; . a boiler having a boiler rating of 20 kilowatts or less in capacity, installed in a heating plant; . a boiler that is intended to be used in connection with a hot water heating system and that has no valves or other obstructions to prevent circulation between the boiler and an expansion tank which is fully vented to the atmosphere; . a pressure vessel of 152 millimetres or less in internal diameter; . a pressure vessel which is used for the storage of hot water and has an internal diameter of 610 millimetres or less; . a pressure vessel or pressure piping system operating at and with relief valves set at 103 kilopascals or less; . a pressure vessel intended to be installed in a closed hot water heating system having a working pressure of 207 kilopascals or less and having an internal diameter of 610 millimetres or less; . any pressure piping system and machinery and equipment ancillary thereto by which refrigerants are vapourized, compressed and liquified in the refrigerating cycle and that has a capacity of 10.5 kilowatts or less;	**BOILER AND PRESSURE VESSELS ACT** This Act or any regulation made under this Act does not apply

American Regulations (Exemption criteria for Acts and Regulations)

Regulation	State	Comment
Pressure vessels that do not exceed:		
A volume of 15 cubic feet and 250 psig when not located in a place of public assembly.	Illinois Kansas Mississippi Oklahoma	Not located in public Air receiving tanks
A volume of 5 cubic feet and 250 psig when located in a place of public assembly.	Alaska Illinois Minnesota Mississippi Nebraska Nevada New Hampshire New Mexico Pennsylvania	No limit Located in public 100 psig limit
A volume of 1-1/2 cubic feet or an inside diameter of 6 inches with no limitation on pressure.	Alaska Kansas Maine Mississippi New Hampshire Pennsylvania	6 inches only 1-1/2 - 600 psig limit 6 inches only 600 psig limit 3000 psig limit 3000 psig limit
Pressure vessels operated at a pressure not exceeding 15 psig with no limitations on size	Alaska Illinois Kansas Kentucky Maine Pennsylvania Minnesota Mississippi New Hampshire Oklahoma	Not located in public Safety devices
Automatic utility hot water heaters that are used for space heating using the potable system, if the hot water heater is equipped with a safety relief valve and operational controls required by the latest Boiler Construction Code published by the American Society of Mechanical Engineers that has been adopted by the Department of Labor and Workforce Development under AS 18.60.180 ; . contains only water; . does not exceed 120 gallons in capacity, a water temperature of 210 degrees Fahrenheit, a pressure of 150 pounds of square inch gauge pressure, or a heat input of more than 200,000 BTU an hour; and . contains a tempering valve that will regulate the outlet domestic water temperature at not more than 140 degrees Fahrenheit.	Alaska Minnesota New Mexico	 Only c) 500000 BTU, 160 psig Only c) 160 psig, 250 degree Fahrenheit

Hot water supply boilers which are directly fired with oil, gas or electricity when none of the following limitations are exceeded: . Heat input of 200,000 BTU per hour. . Water temperature of 200 degrees Fahrenheit. . Nominal water containing capacity of 120 U.S. gallons.	Illinois Kansas Kentucky Maine Nebraska Pennsylvania	 Pressure and Temp. relief valves 210 degrees Fahrenheit 210 degrees Fahrenheit
Unfired pressure vessels operating entirely full of water, and hot water supply boilers or domestic water heaters, if none of the following limitations is exceeded: . a heat input of 200,000 British thermal units per hour (57,143 watts); . a water temperature of 210 degrees Fahrenheit (99 degrees centigrade); . a maximum water-containing capacity of 120 gallons (454.2 liters)	Alaska Kentucky Nevada Oklahoma Ohio	
Boilers and unfired pressure vessels located on farms and used solely for agricultural purposes	Alaska Kansas Kentucky Maine Pennsylvania Michigan Minnesota Nebraska	
Steam and hot water heating boilers, used exclusively for heating purposes, that are located in private residences or in apartment houses of fewer than six families	Alaska Minnesota Mississippi Oklahoma	
Boilers and pressure vessels, located in private residences or in multi-family buildings having fewer than 6 dwelling units, that are within any of the following categories: . Steam heating boilers operated at not more than 15 psig. . Hot water heating boilers operated at not more than 30 psig. . Hot water boilers operated at not more than 160 psig or 250 degrees Fahrenheit. . Pressure vessels containing only water under pressure for domestic supply purposes, including those containing air, the compression of which serves only a cushion or airlift pumping function	Illinois Kentucky Maine Pennsylvania Michigan Montana Ohio	 A and B, no limit on units B and C Not B Not B B and C 50 not 160 psig Not B
Heating boilers and pressure vessels which are located in private residences or in apartment houses of less than five family units	Kansas Nebraska	 15-30 psig limit with safety devices
Coil type hot water boilers where the water can flash into steam when released directly to the atmosphere through a manually operated nozzle provided the following conditions are met: 2) There is no drum, headers or other steam space. 4) No steam is generated within the coil. 6) Outside diameter of tubing does not exceed 1 inch. 8) Pipe size does not exceed 3/4 inch NPS. 10) Water capacity of unit does not exceed 6 U.S. gallons. 12) Water temperature does not exceed 350 degrees Fahrenheit.	Alaska Illinois Kentucky Nevada	No condition 3 No condition 3
Hot water heating and other hot liquid boilers not exceeding a heat input of 750,000 BTU per hour	Minnesota	
Pressure vessels for containing water or other nonflammable liquids under pressure, including those containing air, the	Kansas Maine	

compression of which serves only as a cushion, when neither of the following limitations is exceeded: . A design pressure of 300 psig; or . a design temperature of 210˚ Fahrenheit	Minnesota Nevada New Hamshire Oklahoma	No limitations 125 psig limitation only 120 gallon limitation
Pressure vessels operated full of water or other liquid not materially more hazardous than water, if the vessel's contents' temperature does not exceed 140 degrees Fahrenheit or a pressure of 200 p.s.i.g.	Minnesota Oklahoma	

New Zealand Regulations

-Some excerpts from ***Approved Code of Practice for the Design, Safe Operation, Maintenance and Servicing of Boilers***

4.1 GENERAL
4.1.1 Under 15 hp boilers are not required to be operated by a qualified boiler operator; however, they are not classified as unattended boilers.
4.1.2 In terms of power output, this class of boiler is seen as being under 1.2 MW and/or having a steam output from and at 100°C not exceeding 1814 kg of steam per hour.
4.1.3 All new boilers in this category shall comply in full with the requirements relating to clauses 4.2 and 4.3, limited-attendance boilers or unattended boilers as specified in this code of practice.
4.1.4 Under 15 hp boilers may be upgraded to limited-attendance or unattended boilers provided they meet the requirements of this code of practice.

5.2 CONTROLS AND MOUNTINGS
In addition to the safety valves, water level gauges, pressure gauges, blowdown valve(s) and combustion chamber thermal alarm required in Part 1, unattended boilers shall have at least the following control mountings, which shall comply with BS 759:
(a) First low water cut out and alarm.
(b) Second, independent low-water cut out and alarm, self-checking, internally mounted, of special design.
(c) Feedwater availability indicator and alarm.
(d) Feedwater low-pressure alarm, or low flow alarm.
(e) Steam temperature and pressure controls.
(f) Superheater and reheater temperature controls and alarms (for boilers with superheaters or reheaters).
(g) Continuous automatic blowdown control (TDS control).
(h) Flame detector(s) or ionisation rod flame monitoring to supervise both pilot and main flames (for every burner where necessary in multiburner furnaces).

Where there is a risk of condensate contamination by oil or grease:
(i) Condensate oil and turbidity detector and alarm, and condensate diversion system.

Where there is the risk of hardness penetration into condensate returns, or feedwater streams (e.g. by water softening plant unsupervised for depletion):
(j) Feedwater monitoring alarm (e.g. conductivity) and diversion).

Especially where there is a risk to steam mains, or damage to equipment such as turbines may occur:
(k) A high-level control to prevent overfilling of the boiler is strongly recommended.
(l) A steam limiting valve is strongly recommended in installations where there is a heavily fluctuating steam demand.
NOTE: In (a) above, the first low-water alarm and cut out may be self-monitoring, internally mounted, of special design. In this case, the test period in 5.15.2 may be extended to one month.

APPENDIX G - Chemical Analyses

Wood Chips and Bark

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Client Name	: Fernando Preto	Group Number	: 3120
Project Code	: 440100	Job Number	: N/A
Submission Date	: 2004-03-04	Submitted by	: R Dureau
Due Date	: 2004-03-18	Index Date	: 2004-03-04
Project Title	**: General**		
Project Info	**: Biomass**		

****
* RESULTS FOR SAMPLE **Wood Chips** / ACT040144 *
****

PROXIMATE ANALYSIS (wt%)

	As Analyzed		
Moisture	0.67		
Ash	0.67	0.67	
Volatile	83.72	84.28	84.86
Fixed Carbon	14.94	15.05	15.14

ULTIMATE ANALYSIS (wt%)

	As Analyzed	Dry@105˚C	
Carbon	49.51	50.53	
Hydrogen	5.95	6.07	
Nitrogen	0.10	0.10	
Sulphur	0.25	0.26	
Oxygen (Diff)	42.18	43.04	0.00

CALORIFIC ANALYSIS

	As Analyzed	Dry@105˚C
Cal/g	4667	4763
MJ/KG	19.54	19.94
BTU/LB	8401	8573

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RESULTS FOR SAMPLE **Wood Chips** / ACT040144 continued
TEST RESULTS

Protocol Name	Test Name	Value
Majors, Minors & Trace	SiO2	12.53 wt %
"	Al2O3	4.28 wt %
"	Fe2O3	9.91 wt %
"	TiO2	0.44 wt %
"	P2O5	3.38 wt %
"	CaO	50.39 wt %
"	MgO	4.57 wt %
"	SO3	3.93 wt %
"	Na2O	3.35 wt %
"	K2O	3.61 wt %
"	Barium	4125 ppm
"	Strontium	2211 ppm
"	Vanadium	57 ppm
"	Nickel	288 ppm
"	Manganese	2555 ppm
"	Chromium	434 ppm
"	Copper	1024 ppm
"	Zinc	3874 ppm
"	Loss on Fusion	2.15 wt %
"	Sum	100.00 wt %

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****
* RESULTS FOR SAMPLE **Yukon Bark** / ACT040145 *
****

PROXIMATE ANALYSIS (wt%)

	As Analyzed
Moisture	4.21

ULTIMATE ANALYSIS (wt%)

	As Analyzed	Dry@105˚C	
Carbon	50.34	52.55	
Hydrogen	5.54	5.78	
Nitrogen	0.31	0.32	
Sulphur	0.13	0.14	
Oxygen (Diff)	39.47	41.21	0.00

CALORIFIC ANALYSIS

	As Analyzed	Dry@105˚C
Cal/g	4769	4979
MJ/KG	19.97	20.84
BTU/LB	8584	8961

TEST RESULTS

Protocol Name	Test Name	Value
Majors, Minors & Trace	SiO2	7.30 wt %
"	Al2O3	2.22 wt %
"	Fe2O3	0.91 wt %
"	TiO2	0.14 wt %
"	P2O5	3.98 wt %
"	CaO	67.66 wt %
"	MgO	4.49 wt %
"	SO3	1.25 wt %
"	Na2O	0.43 wt %
"	K2O	7.17 wt %
"	Barium	4973 ppm
"	Strontium	1897 ppm
"	Vanadium	<111 ppm
"	Nickel	53 ppm
"	Manganese	5345 ppm
"	Chromium	<52 ppm
"	Copper	176 ppm
"	Zinc	3591 ppm
"	Loss on Fusion	2.84 wt %
"	Sum	99.99 wt %

Signature: ______________________________________ 2004-03-23

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Halogen Analyses

Report of Analysis ACT

File Name: FP-REP-H2604

Concentrations on the Dry Basis

Date: MAR. 26/04

Job # / Project #

Client Name:

Reported By: Rob Dureau

Reference File Name: FP-REQ-H0404 / FP-HAL-H2604

#	Sample Type	% H2O	Hg (ug/g) AVERAGE	Br (ug/g)	F (ug/g)	Cl (ug/g)
1	Yukon Bark			< 14	19	94
2	Wood Chips			< 24	< 20	56

Gasifier Sand

Yukon Gasifier sand characterization

1. True density: 2751.4 kg/m^3
2. Bulk density: 1501.6 kg/m^3 ±5%
3. Size distribution:

Size, mm	Weight fraction, wt%
>2.0	0.13
1.4—2.0	8.19
0.85—1.4	66.22
0.30—0.85	24.35
0.075—0.30	1.05
<0.30	0.06

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4.
Elemental analysis

Submission Date : 2004-03-30 Submitted by : Robert Dureau
Due Date : 2004-04-13 Index Date : 2004-03-30
Project Title : General
Project Info : Sand

****
* RESULTS FOR SAMPLE **LJ-H2904-1** / ACT040214 *
****

TEST RESULTS

Protocol Name	Test Name	Value
Density @ ambient temperature	Density @ ambient temperature	2751.4 Kg/m3
"	Ambient temperature	28.5˚C
Majors, Minors & Trace	SiO_2	52.28 wt %
"	Al_2O_3	42.57 wt %
"	Fe_2O_3	0.66 wt %
"	TiO_2	2.26 wt %
"	P_2O_5	0.12 wt %
"	CaO	0.81 wt %
"	MgO	<0.19 wt %
"	SO_3	<0.46 wt %
"	Na_2O	<0.20 wt %
"	K_2O	0.67 wt %
"	Barium	<263 ppm
"	Strontium	79 ppm
"	Vanadium	214 ppm
"	Nickel	70 ppm
"	Manganese	181 ppm
"	Chromium	176 ppm
"	Copper	72 ppm
"	Zinc	68 ppm
"	Loss on Fusion	0.26 wt %
"	Sum	99.72 wt %

Signature: ______________________________ 2004-04-13