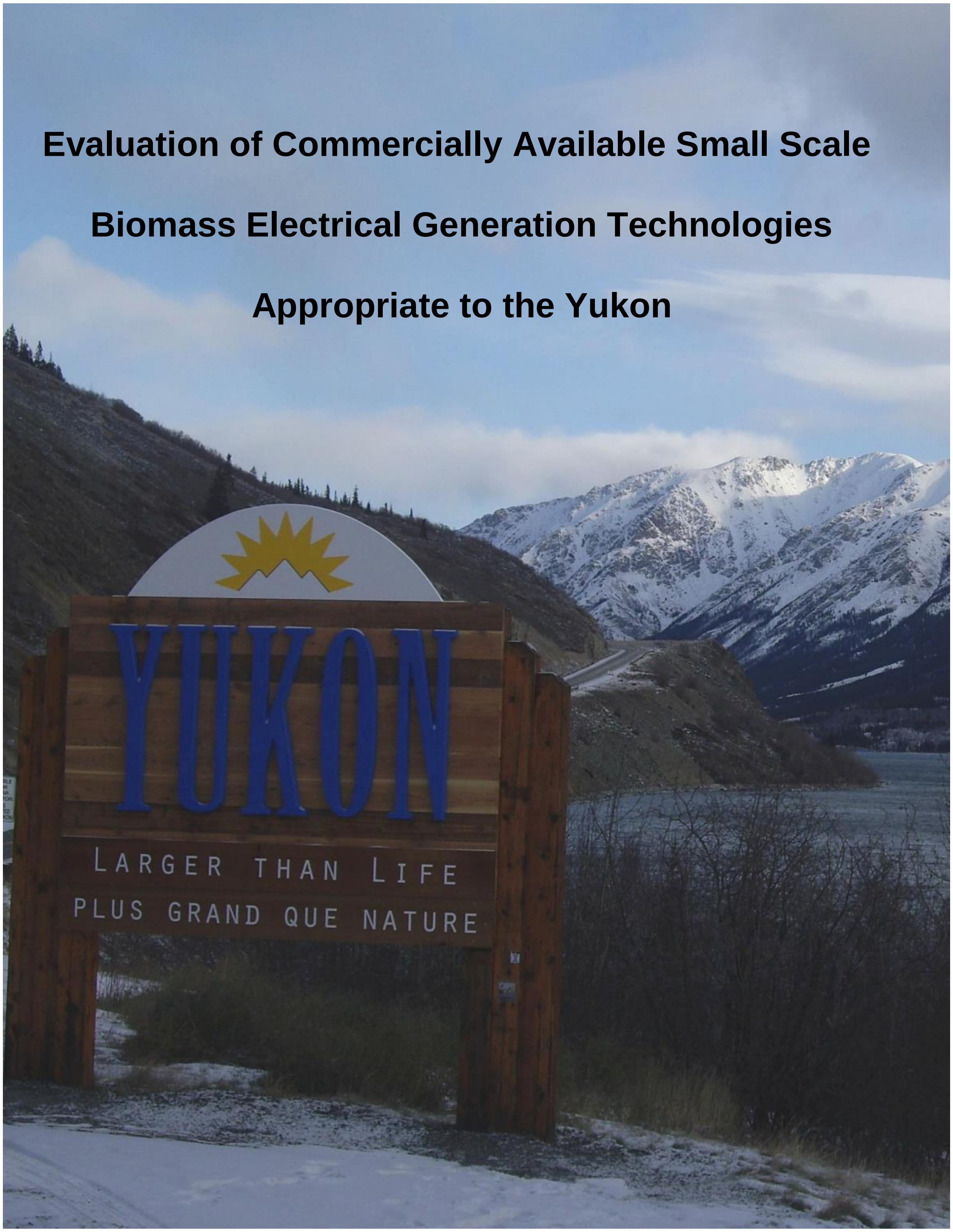
Evaluation of Commercially Available Small Scale Biomass Electrical Generation Technologies Appropriate to the Yukon



Evaluation of Commercially Available Small Scale Biomass Electrical Generation Technologies Appropriate to the Yukon

Prepared for Energy Mines & Resources, Government of Yukon

by

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EXECUTIVE SUMMARY

The Yukon Territory has substantial biomass resources and the potential to use them for space heating and power generation, preferably in one system generating combined heat and power (CHP). The technologies on offer for biomass CHP are numerous and varied which makes selection very difficult for community leaders, even for those with an engineering background. This report presents an evaluation of small scale biomass electrical generation technologies "on offer" and includes the following technology areas and companies: Gasification (Community Power Corporation, Spanner Re2 GMBH/Borealis Wood Power, Ankur, Babcock Vølund Biomass Canada Ltd, Nexterra, PRM Energy Systems, Proton Power, Xylowatt, Zeropoint Clean Tech Inc); Organic Rankine Cycle (Infinity Turbine, Adoratec, Triogen, Turboden, Electratherm); Brayton Cycle (AgriPower Inc, Entropic Energy, Talbott's Biomass Energy Systems); Stirling Engine (Stirling Power, Stirling DK).

The evaluation includes a brief description of the technologies and companies and their track records. To this multitude of companies a relatively simple criteria was applied: A company may be considered "viable" for further consideration if they have at least five units currently in operation. Having a number of installed and operating units greater than five does not automatically mean that the technology is "turnkey ready", especially in remote communities where local support may be minimal, but this is a good starting point.

The following small-scale biomass-fired electrical generation technologies are considered "viable" for further evaluation, at this time:

<u>Gasification:</u>
Community Power Corporation
Borealis Wood Power (Spanner Re2 GMBH)

<u>Organic Rankine Cycle:</u>
Infinity Turbine
Adoratec
Turboden

At present no suitable Brayton cycle, Stirling cycle are available that would be suitable for installation at Haines Junction or at any other community in the Yukon

Gasification systems, although the most active field in terms of research and development do not have a strong track record. The strongest candidate at the current time is a 45 kWe Spanner system, represented in Canada by Borealis Wood Power. Spanner has over 150 operating units operating in Europe and as long as the limitations of the technology are respected it seems to perform well. Europe is also the primary location for operating ORC systems. Of the three systems considered "viable" only one company, Turboden, is actively pursuing the North American market. Turboden's North American offerings have been limited, to date, to their larger systems (1-2 MWe) which may be too large for many remote communities.

As a first step in economic analyses, a “ball-park” estimate of the capital cost of gasification and ORC installations is shown below (figures are in thousands of dollars):

Plant Size (kWe)	Gasification Equipment Only, $k	Gasification Total Facility, $k	ORC Equipment Only, $k	ORC Total Facility, $k
50	400	1,250	NA	NA
100	800	2,500	NA	NA
500	4,000	8,500	2,000	6,000
1000	8,000	20,000	3,500	11,500

These figures are generic and do not represent any specific product. Graphs are included in the report covering a wider range of sizes. The total facility costs are approximate and based on new buildings and plant infrastructure. The ORC total facility includes the cost of a boiler which can be equal to the cost of the ORC alone. Future evaluations should include not only economics and a proven track record but also appropriate sizing (for both heat and electricity) for the target community and ability to follow load variations. Special consideration should also be given to feedstock requirements and compatibility with local supply and resources to maintain that supply.

Given the significant costs associated with the systems, which are unproven in remote northern communities, a key requirement is to ensure that the capacity is available to host these technologies. Community capacity is a critical ingredient to the sustained success of any energy project and it is therefore recommended that further action include development of this capacity as an inherent component. With this in mind, future consideration should be given to:

- Establishing experience with wood fuel (especially chips) supply infrastructure – the best bet is to try this with an advanced, low emissions heat-only system.

- Once experience is proven with a wood chip heating system expand the system to CHP by adding on an ORC, e.g., Turboden. The heating system would have to be planned so as to be suitable for addition of an ORC without major problems.

- The lowest cost option would be to install a small gasifier (< 100 kWe) and tie the installation to an extensive community capacity building program.

To accelerate the development of small scale biomass electrical generation technologies, governments can play a role by ensuring that there are clear rules and regulations for emissions, efficiency and power purchase by utilities. Governments should also establish clear policies on small-scale CHP which will encourage new developments.

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1.0 INTRODUCTION

In remote areas with an abundance of biomass and expensive fossil fuels, the use of local biomass for generation of heat and electricity would seem an attractive proposition. If one is to believe potential equipment suppliers, conversion technologies are readily available in ranges from 1 kWe to 2 MWe to suit most remote communities. The Yukon Territory has substantial biomass resources and the potential to use them for space heating and power generation, preferably in one system generating combined heat and power (CHP). The technologies on offer for biomass CHP are numerous and varied which makes selection very difficult for community leaders, even for those with an engineering background. Many of the technologies being offered are based on systems designed for fossil fuels for which standards and classifications exist. In some case these systems have been modified for "biomass" without consideration being given to the wide variation in properties of biomass and a lack of standards for biomass fuels. These types of systems are further disadvantaged by the low energy density of biomass fuels which then require substantially more storage and handling and led to sub-optimal performance of the technologies themselves. A final hurdle is the definition of "commercially" available/viable/feasible. A system is not viable merely on a supplier's claims. Technical and financial evaluations are required and then in order to allow the proper choice to be made, the scope of the evaluation must be carefully laid out to take into account, at a minimum, all of the factors mentioned here.

The objectives of this report are to summarize the current small scale biomass electrical generation technologies that are available and appropriate for the Yukon. This includes a brief description of the technologies and companies and their track records, capital cost estimates evaluation of technology viability for a relatively remote northern community such as Haines Junction.

2.0 BIOMASS CHP TECHNOLOGIES

A completely commercial and reliable technology exists for using biomass for combined heat and power. It is used in large-scale plants and is based on the steam-driven Rankine cycle with biomass energy used to make steam to run a turbine generator. Unfortunately, for small community systems, steam-based biomass CHP generation in North America is only economical at large-scale facilities generating in excess of 10 MWe. There is a variety of reasons for the large-scale limitation, the principal one being boiler/steam (these types of plants utilize high temperature, high pressure steam) legislation that requires an on-site power engineer at all times resulting in unacceptably high labour costs for smaller facilities.

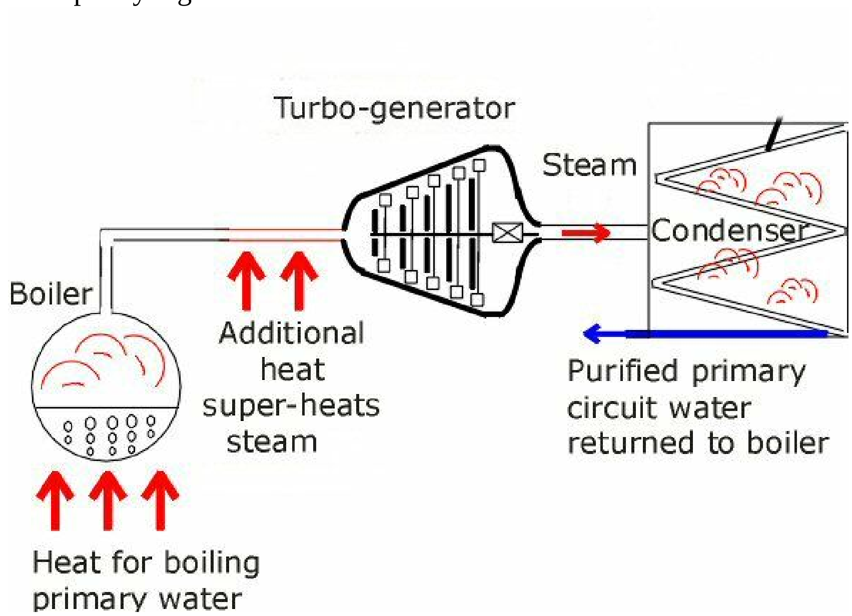

Figure 1 - Rankine Cycle for Power Generation

There is a potential market for small-scale systems, especially CHP whereby revenue can be generated from both power production and heat utilization. In Canada, a commonly used guideline is that there are at least 300 communities not connected to a major electricity grid and there are also numerous industrial sites (e.g. sawmills) that produce enough biomass residues to warrant on-site power generation. The potential for small-scale biomass CHP is highlighted by several initiatives to support development of plants, including a BC Bioenergy Network supported initiative in Kwadacha, BC and the Manitoba Hydro Biomass Optimization Program supported by NRCan. However, at the current stages of development, the challenges of deploying largely unproven small-scale systems in remote communities seem insurmountable.

One has to consider that for remote communities reliability and dependability are critical and technical support is not usually readily available. Furthermore, the viability of relatively "new" small-scale power generation technologies cannot be determined based solely on the claims of the technology suppliers. Some sort of criteria is necessary to establish viability, i.e., a proven track record. The other factor which comes into play is economics. It is difficult to carry out a financial assessment for a new CHP project while it is essentially still under development as the costs of new technology demonstrations are much higher than for proven systems. How does one decide if a system is proven? What is the "number of operating units" required in order to establish true reliability and costs? This is open to interpretation, however the author suggests that this number should be at least FIVE (5) units (an additional precaution should be that at least one unit is operating in Canada), i.e., if a technology provider has five units operating in a reliable manner then there should be sufficient data to provide some confidence and also sufficient cost data to allow preparation of a proper financial analysis. In this report this will be the criteria used to assess whether a technology can be considered commercially viable for application in remote communities. This does not mean that other technologies are not feasible, rather only that they are not "commercially proven" for that application. In some instances technologies which do not meet this criterion may be selected, and there may be good reasons for doing so, i.e. being at the leading edge of a technology can result in significant benefits, however the project should then be considered a pilot or demonstration project and will likely incur significant development costs and require considerable engineering/research support from the supplier. This is acceptable if advancing the technology is the stated objective of the project but if the objective is to provide heat and power at the lowest possible cost then screening criteria as discussed here are necessary. Finally, having a number of installed and operating units greater than five does not automatically mean that the technology is "turnkey ready", especially in remote communities where local support may be minimal. Any assessment of suitability must include consideration of the requirements for normal operation of the "proven", i.e. maintenance and parts replacement schedules, feedstock restrictions etc.

There are numerous small-scale biomass CHP technologies under development and the most promising are reviewed here on the basis of the criteria set in the previous section, those with over five operating units in a reliable manner are deemed "Yukon viable" whereas those below this guideline are deemed "under development". Technologies without at least one operating system (even at laboratory scale) are not considered.

Four basic technology types are considered in this report: Gasification and Internal Combustion Engine; Organic Rankine Cycle; Brayton Cycle and Stirling Engine. A fifth, Fast Pyrolysis for production of bio-oil followed by combustion in an Internal Combustion or Turbine Engine, is not included as this concept has not been reliably demonstrated. Canada is home to the leading companies in the area of Fast Pyrolysis: Ensyn Technologies, ABRI Tech, Agritherm and Pyrovac. Ensyn has worked with Manitoba Hydro and CanmetENERGY to demonstrate bio-oil combustion as a replacement for fuel oil in furnaces but this has not yet resulted in a demonstration of engine-based combustion. Overseas, BTG Group PV in the Netherlands, Pytec and KIT in Germany and VTT/Metso/UPM are the leading groups in attempts at commercializing fast pyrolysis. Some testing has taken place with combustion in gensets, however it has generally used heavily fractionated or solvent-diluted bio-oil and cannot be considered commercial at the current time.

The following is a listing of the leading suppliers of small-scale CHP grouped according to technology. Companies which can be considered "Yukon-viable" based on the above described criteria are shown in bold. Note that not all of those shown in bold are necessarily recommended as there are other criteria which must also be included in the assessment.

Gasification And Internal Combustion Engine:

Community Power Corporation
Spanner Re2 GMBH/Borealis Wood Power
Ankur
Babcock Vølund
Biomass Canada Ltd

Nexterra
PRM Energy Systems
Proton Power
Xylowatt
Zeropoint Clean Tech Inc

<u>Organic Rankine Cycle:</u>
Infinity Turbine
Adoratec
Triogen
Turboden
Electratherm

<u>Brayton Cycle:</u>
AgriPower Inc
Entropic Energy
Talbott's Biomass Energy Systems

<u>Stirling Engine:</u>
Stirling Power
Stirling DK

In the following sections, the overall status of each of these technology areas is described along with some commentary on each of the companies and their technologies under development.

2.1 Gasification And Internal Combustion Engine

Internal combustion (IC) engines, particularly gasoline and diesel-fuelled engines are readily available for small-scale electricity generation. They have low capital cost, have a high uptime (>95%), and qualified maintenance personnel are readily available. In terms of heat recovery (i.e. for CHP application) heat can be recovered from the engine oil, jacket water (~30%) and exhaust (up to 50%). The ready availability of IC engines makes them an appealing basis for biomass CHP. Add to this the fact that gasification and combustion of syngas has been around for over a century; cars were run on gasifiers as recently as the Second World War. The inclination is to think that it must be simple to build a gasifier and an engine and start producing power and heat.

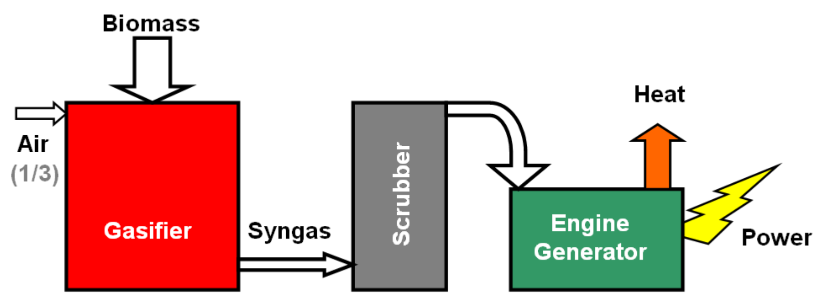

Figure 2 - Simplification of CHP via Biomass Gasification

Biomass gasification is achieved through the partial oxidation of the biomass feedstock (i.e., partial combustion whereby only about one third of the air normally required for full combustion is used). The untreated gas exiting the gasification chamber is known as producer gas. Producer gas contains (in addition to the nitrogen already in the air) primarily carbon monoxide (CO), and hydrogen (H2), with smaller amounts of methane (CH4) and carbon dioxide (CO2), a small fraction of CH4, traces of other hydrocarbons (C2+C3), tars, particulates and other undesirable species such as NH3, HCN, H2S and SO2. Producer gas is a low quality gas with a heating value of 4-6 MJ/Nm3 or just over one tenth the energy content of natural gas at 40 MJ/Nm3. Producer gas can be burned directly in a boiler to generate heat, although the cost of gasification followed by direct combustion will generally be much higher than just burning the biomass feedstock directly. The low energy content of producer gas is a challenge, but not insurmountable, for IC engines. Much more significant is the presence of heavy organic tars in the produced gas that condense and adhere to the conduits and internal components of the engine causing fouling and unacceptable engine wear.

Gasification can be carried out with oxygen and steam, however for purposes of this report only air driven gasification is considered as this is the basis for most small-scale CHP systems. Air-based biomass gasification efficiency, defined as how much of the energy in the original feedstock ends up in the producer gas is typically around 75%.

In order to allow producer gas to be used directly for power generation (i.e., combusted in an engine/generator set) or catalytically modified to produce chemical products such as methane, methanol, dimethyl ether or diesel-type oils it must be cleaned of tars and other contaminants. Once producer gas is cleaned, it is generally referred to as syngas, i.e. a synthetic gas. In common usage, “syngas” has become the term for gas produced in a gasification system and is used to refer to both producer gas and syngas.

Tars produced during biomass gasification can have significant negative effects on system operation as condensation and deposition of tars at temperatures below 350˚C can lead to fouling and potential blockage of downstream equipment and piping. Typical tar contents in producer gas can range from 0.5 to 100 g/m3. For internal combustion engines these tar levels must be reduced to below 0.1 g/m3. The tar limit drops significantly for gas turbines (0.005 g/m3) and even further for chemical synthesis applications (0.0005 mg/m3). For chemical synthesis processes, sulphur and ammonia compounds can lead to catalyst destruction and the limits for NH3, HCN, H2S are below one part per million. Tar production varies by gasifier design. A downdraft gasifier produces less tar than a fluidized bed or updraft gasifier.

Reactor Type	Advantages	Disadvantages
Fixed bed, updraft	Simple, inexpensive process Exit gas temperature about 250°C Operates satisfactorily under pressure High carbon conversion efficiency Low dust levels in gas High thermal efficiency	Large tar production Potential channeling Potential bridging Small feed size Potential clinkering
Fixed bed, down draft	Simple process Only traces of tar in product gas	Minimum feed size Limited ash content allowable Limits to scale up capacity Potential for bridging and clinkering
Fluidized bed, circulating	Flexible process Up to 850°C operating temperature	Corrosion and attrition problems Poor operational control using biomass
Fluidized Bed, bubbling	Flexible feed rate and composition High ash fuels acceptable Able to pressurize High CH_4 in product gas High volumetric capacity Easy temperature control	Operating temperature limited by ash clinkering High product gas temperature High tar and fines content in gas Possibility of high C content in fly ash

Figure 3 - Characteristics of Different Gasification Technologies (Ref: Yukon Energy FEED Study)

Several methods exist for the reduction of gasification tars. Common methods for tar removal in small-scale CHP systems are based on mechanical separation using cyclones, scrubbers and filters. Thermal cracking in which the tar molecules are “cracked” apart by high temperatures can also be used (e.g., Nexterra). Cracking of the tar molecules by use of catalysts can be very effective but must usually be done in combination with other techniques to avoid catalyst destruction. Mechanical methods can be effective in capturing both tars and particulate matter from the producer gas stream. The most common approach in CHP application is to use a bed of hot charcoal (usually within the gasifier vessel) to reduce the tar followed by cooling and a filter to remove most of the remaining tar and particulates. Tar concentrations in the output gas can thus be reduced to as low as 0.05 g/Nm3. For improved tar reduction, scrubber systems and electrostatic precipitators can be used. These are however more expensive options and furthermore, water-based systems generate a significant amount of contaminated water which then needs to be treated. Tar reduction is really a matter of cost. Technologies exist (e.g. cryogenic conditioning) to completely eliminate tar. The real challenge is to carry out the required tar reduction in a cost effective manner without creating additional problems. This is the principal reason that there are few suppliers of commercial small-scale gasifier-based CHP systems. In addition to proper gasification and syngas cleaning technology, maintaining steady-state conditions and a homogeneous feedstock are critical for long term trouble-free operation.

Community Power Corporation

Community Power Corporation (CPC), based in Littleton, Colorado, offers 25 kWe and 100 kWe units designated "BioMax". BioMax units comprise a downdraft gasifier with dry syngas filtering with overall electrical efficiency >20%. CPC claims unit availability (uptime) of around 80%. CPC claims 33 installations handling a variety of biomass feedstocks. In Canada, Alberta Innovates and Manitoba Hydro have purchased BioMax50 and BioMax100 systems respectively. Operators of these units claim that even though the units ship in standard containers (5 containers for the BioMax100) assembly and operation of the biomass handling system requires considerable attention. The units are also reported to require considerable attention for any significant variation in fuel properties. Further assessment is required as even though a significant number of units have been deployed, most of them have been supported by the US government. With these caveats the BioMax units are deserving of consideration for the Yukon.

http://www.gocpc.com/

The Yukon Energy Haines Junction FEED, prepared by Stantec Consulting Ltd., summarized some issues identified by CPC on an installation in the Yukon:

- *"Long-term bioenergy system reliability and availability (downtime) have not yet been*
- *confirmed in a remote, cold climate community. Impact of cold climate is not yet known on system performance*
- *Operation and maintenance costs need to be verified*
- *Sustainable biomass harvesting plan needs to be confirmed*
- *Impact of biomass variability on system performance needs to be confirmed (biomass*
- *type, heating value, cleanliness, moisture content, etc.)*
- *Requirements for and impact of permitting and environmental performance requirements*
- *are not fully understood*
- *Availability of local operators with appropriate maintenance skills"*

Spanner Re2 GMBH/Borealis Wood Power

In 2004 Spanner Group, an automotive parts manufacturer in Germany, acquired a gasifier technology and created a subsidiary, Spanner Re2, to develop and market a small gasification-based CHP system. The CHP system is based on a small fixed bed downdraft gasifier with syngas cooling, tar reforming and a fabric filter. Feedstock uniformity is emphasized in this system with limits for moisture content (<20%) and a fines removal system as part of the feed system. In 2013 the company had over 150 units in operation in the 30 to 45 kWe range (+70-120 kWth heat). Spanner Re2 reports over 25,000 hours of engine time (GM 5.7 L V8) for the initial units installed in 2009. The units are installed mainly in Germany, with some in northern Italy and Austria. Units are installed in small businesses e.g., farms, sawmills, agricultural industries with single owner-operators who sell power to the grid and have a requirement for heat. Spanner Re2 does not sell the units as an "off-the-shelf" commodity but evaluates the application with the client and ensures that there is a fit and that the client will "look after" the system. Clients are not required to have technical expertise and are mostly dedicated to ensure proper feedstock properties and perform some clean-out, typically once a week for a couple of hours. Spanner has concluded a licensing agreement with Borealis Wood Power of Burlington, Ontario who will sell the CHP units in North America. In 2013 Spanner shipped the first unit to Borealis for installation at their facilities in Burlington.

http://www.holz-kraft.de/
http://www.borealiswoodpower.com/

Note: During the week of Sept 9/2013, the author visited Spanner warehouse, assembly plant and six operating installations in Bavaria, Germany. Comments are given below:

- Site visits included assembly and meeting with company engineers – Spanner is expanding production and expects to achieve manufacturing capability of 1 unit per day sometime in 2013
- The unit operates on wood chips, NOT pellets and not bark or dirty fuel; there is a small screen in the conduit bringing the fuel into the unit feed system which removes fines. The gasifier design and operation is based on having specific fuel properties for moisture and voidage (amount of empty space between fuel particles) in order to generate a consistent producer gas. Too many fines reduce the voidage; too much dirt causes ash problems and pellets change the fuel density in the bed. The latter could probably be overcome by changes in the design but then that design would be limited to pellets
- Too many fines and too much moisture causes an increase in tar production
- The technology works well because it is operated in a narrow regime of conditions with specific fuel requirement
- Spanner does not sell units "off the shelf" as a commodity, each application is evaluated and Spanner ensures that there is a requirement for heat (power is usually sold by the client to a utility at preferred rate; heat value in Germany is based on natural gas price and at time of visit was equivalent to 10 cents per kWh); the client is educated on the monitoring of the unit and especially on the absolute necessity to dry chips to 20% moisture – in one case of a business owned by a married couple, Spanner would not sell the unit to the husband until the wife agreed that it was the right thing to do – Spanner insists on full buy-in from an educated customer
- The author visited units operating on farms, sawmill, garden center, woodworking shop, hops processing and drying plant – in each case the owner-operator was interviewed and asked about performance of the system – all were content with system and support from Spanner – one farmer on being asked about his longest shutdown due to equipment failure replied "one day" – most operators keep an eye on the system and check in a couple of times per day, mostly to check on feed system but equipment is mostly unattended – char/ash in heat exchanger has to be cleaned out every couple of weeks and this usually takes less than two hours – at one site the room where the unit is located was a little loud so the operator just flipped a switch and turned it off, everything stopped within 10 seconds, after a 20 minute period he flipped the switch on again and the unit started operating and was back at full capacity within a couple of minutes.
- One operator has had to change the IC engine twice in three years. The failures were traced due to faults with the engine itself rather than the application. In any event, for this

design this is not considered a serious issue as the engines are standard GM V8 engines with relatively low cost ~$10k.

- Spanner has a requirement for air changes per hour in unit room to prevent build-up of noxious gases
- No emissions or ash disposal issues (chips have little ash)
- Chip drying is accomplished by very low level heat – in most cases operator vents room air from where room is located into the bottom of a trailer which has been equipped with a slotted base plate – the warm air goes up thru the load of chips
- Visits highlighted the need to have a "champion" operator who has "ownership" of the system – this is the approach which needs to be followed if Yukon is to install one unit – it is doubtful that government buying a unit and dropping it into a community as a demonstration will work – fuel feed and condition is such a critical issue that someone who "cares" must monitor this aspect and make sure it is done correctly, this is not onerous and require a lot of time but it must be done correctly.

Ankur

Ankur (India) is a supplier of downdraft gasifier systems in the range of 5-850 kWe, with custom-built units up to 2.2 MWe available. Ankur has over 50 installations worldwide, mostly in third world countries. Ankur's syngas cleaning system includes a cyclone, a Venturi water scrubber and various levels of particulate filters (wood chips, sawdust and a fabric filter). The cleaning is rudimentary and the systems typically have high labour costs due to frequent engine teardowns. Treatment of contaminated water from the scrubber unit also requires considerable attention. Given the level of attention required, even though the system is commercially demonstrated worldwide it has not been installed in Canada and the unit is not recommended for remote communities in the Yukon. The system is available in Canada through Aboriginal Ankur Corporation.

http://aboriginalankur.com/

Babcock Vølund

Babcock Vølund (Denmark) developed a fixed bed updraft gasifier system starting in 1996 in Harboøre, Denmark (with substantial government subsidy). The Harboøre gasifier was operated on heat-only mode (6.5 MWth for district heating) for four years until the syngas was deemed clean enough for the 1.5 MWe Jenbacher engine which since then has operated for over 75,000 hours. The technology is now licensed to JF Engineering Corp. of Japan and they are planning units in the 2-3 MWe range.

Biomass Canada Ltd

Biomass Canada Ltd. is an Edmonton-based developer of a catalytic (a fixed bed of Ni-Co balls is part of thee bed) downdraft gasification system. During operation the catalyst bed acts as a tar cracker with temperatures in the 2000 C range. The company has received funding from the Alberta Government for a 2MWe demonstration unit which at this writing is not yet complete.

Nexterra

Nexterra is a Vancouver-based supplier of modular updraft gasifier systems and has to date sold eight commercial systems to supply up to 3 MWth of heat per module. In 2012, Nexterra completed the installation of a 2MWe CHP demonstration at the University of British Columbia.

Nexterra's system uses a high temperature oxidizer to thermally crack tars in the syngas and maintains high efficiency by recovering syngas heat for the air streams. The Jenbacher engine on the system has operated intermittently as the system works through its teething problems. Nexterra is planning units in the 2-15 MWe range which is beyond the scale being considered in the Yukon.

PRM Energy Systems

PRM Energy Systems, based in Arkansas, has eight CHP installations to date, based on an updraft multi-zone gasifier for straw (rice husks). The syngas is then burned in a heat recovery steam generator and electricity is generated using the Rankine cycle. The scale of installations has ranged from 225 kWe to 12 MWe and they offer models that require 20-2000 tonnes per day. PRM does have one project (1MWe) with the gasifier using an IC engine that was commissioned in 2006, however this is the first of this kind for this company. Given that their focus has been on agricultural residues and that most of their experience is with steam-based power system they are not included in the recommended list for the Yukon.

Proton Power

Proton Power, based in Tennessee, claims to operate an auger-type gasification system under anaerobic conditions. Feedstocks are saturated in water which enhances production of hydrogen in the syngas and offers the possibility of multiple uses for the syngas, e.g. chemical synthesis. The company also claims tar-free syngas due to high temperature gasification. Proton Power is at the demonstration stage of development, with a project planned for Tennessee and another, in collaboration with the BC Bioenergy Network, for the remote BC community of Kwadacha (35 kWe).

Xylowatt

Xylowatt, based in Belgium, offers a downdraft gasifier with three distinct regions within the gasifier including a distinct "char" zone for tar reduction. The design is claimed to have very low tar levels in the syngas (the designated design name is NOTAR). Gas conditioning includes a cyclone, a water-injection Venturi scrubber, and two heat exchangers to cool the syngas (10°C) and condense any remaining tars. Xylowatt has two 300 kWe CHP installations operating in Belgium.

Zeropoint Clean Tech Inc

Zeropoint Clean Tech is based in Potsdam NY and supplies a downdraft gasifier based system to produce two products: syngas and biochar. The company is operating one plant in Germany, is constructing a second 3 MWe plant in Ireland and has formed a partnership with Envirotherm GmbH to produce systems in the 2-20 MWe range.

2.2 Organic Rankine Cycle

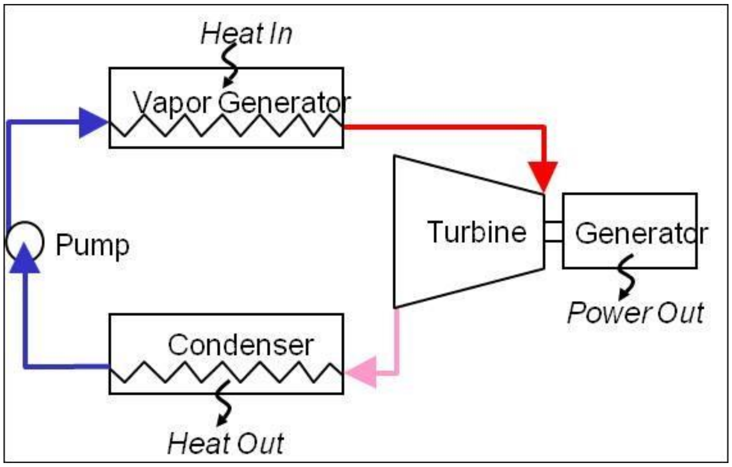

Figure 4 - Schematic of Organic Rankine Cycle

Organic Rankine cycle (ORC) engines are closed systems which operate on an external source of heat. The heat may come from a conventional source including established biomass combustion systems. ORC differs from Rankine cycle in that the working fluid is sealed within the system and depending on the fluid used as a heat source can operate at low temperatures. The heat source vaporizes the working fluid that then is passed through a turbine attached to a generator for electricity generation. Refrigerants, such as R245fa and R134a, are used for waste heat and low temperature heat sources from 80-140°C. Hydrocarbons fluids are used for temperatures of 150-250°C, while silicon-based siloxanes are used for temperatures of 250-350°C. The efficiency of ORC units depends on temperature and ranges from 7.5% for low temperature (<100°C) heat sources to >23% for high temperature (>350°C) heat sources. ORC systems can have very high uptime (>97%) and turndown ratios of 10:1.

One limitation of ORC systems is the high per-unit capital cost, mostly due to low electrical efficiency. Energy pricing is the principal reason that whereas these units are well established in Europe, they are just beginning to make inroads in North America. The high cost factor can be mitigated by going to higher temperature systems such as provided by biomass combustion or by using waste heat which has no further value. Since biomass combustion is the expected heat source for remote communities, a more economical approach may be to consider combining a relatively inexpensive biomass furnace with ORC systems using siloxane-type working fluid at 250-350 C. The other approach may be to turn the CHP concept on its head by setting up a system to provide heat first and then use the low temperature waste heat to run a low temperature ORC system. Obviously each application is different and both options would have to be part of an economic analysis to determine the cost effective approach. For these reasons both low and high temperature ORC systems should be considered.

An important consideration for ORC is the level of support and integration provided by the ORC equipment supplier. Many ORC systems are NOT supplied "turnkey". The client (community) is expected to specify, procure and install the boiler and/or heat exchangers and integrate these with the ORC system. All of these requirements can add substantially to the cost of ORC systems.

Infinity Turbine

Infinity Turbine produces ORC units with ratings from 10-500 kWe from any heat source with a minimum of 55 C temperature differential between the heat source and cool liquid flow heat sink. Infinity Turbine units can use either R245fa or R134a refrigerants depending upon the temperature of the heat source. When the input temperature is between 80°C and 95°C, R134a is the preferred working fluid, while R245fa is used for temperatures between 95°C and 140°C. Infinity Turbine produces modular designs in which the unit is bolted together and can be disassembled in a few minutes depending on site. ITxr modules can be assembled to drive 20 kWe or 60 kWe generators. These units have built-in magnetic couplings which allow the user to magnetically "attach" a coil on the outside of unit, or "magnetically" couple to the shaft of an external generator or other rotary equipment. The entire unit is sealed and has one moving part.

http://www.infinityturbine.com/ORC/ORC_Waste_Heat_Turbine.html

Adoratec

Adoratec, a subsidiary of Maxxtec (Germany) makes turnkey ORC modules up to an electrical output of 500 kW pre-assembled on a skid. All main equipment parts of the turbo generator e.g. heat exchanger, feed pump, turbine, generator piping, instruments/wiring and other auxiliary equipment are pre installed and allow cost effective transport and installation to site. Adoratec has 22 ORC installations in Europe with unit capacities ranging from 250 kWe to 1.5 MWe. The unit design is based on using a thermal transfer fluid to transfer heat (~300 C) to the ORC working fluid.

http://www.adoratec.com/

Triogen

Triogen, based in the Netherlands, has 20 ORC units (~150 kWe) operating in Europe. Their units typically use toluene as the working fluid which requires a heat source with a temperature greater than 350°C but does offer higher electrical efficiency than other systems. The use of toluene as the working fluid makes it possible to use the flue gas of combustion directly. This eliminates the need for a heat transfer thermal oil system. The use of toluene has created issues in Canada with regards to certification and these units are currently not available here. There may be an opportunity for a Canadian company here as Triogen's principal technology is a unique High-speed Turbo Generator (HTG) – wherein all the components are placed on one shaft, which means that the turbine drives the generator and the pump. No gears are used; the rotational speed of the generator and pump is equal to the rotational speed of the turbine. The housing is a hermetically sealed unit. Triogen has developed the Triogen HTG in-house, all other components for the ORC are developed in conjunction with Triogen's preferred suppliers.

http://www.triogen.nl/

Turboden

Turboden, originally started in Italy but is now owned by Mitsubishi Heavy Industries (Japan) [this is a positive development as a large multinational such as MHI can make the significant investments that may be required to achieve success], is the largest supplier of biomass heat ORC systems. Turboden offers CHP units ranging from 300 kWe to 2200 kWe. Turboden units have net electrical efficiencies of 17-19% but this does not include parasitic electrical demands, which normally reduce the overall efficiency by a further 2-3%. Worldwide, there are currently over 250 Turboden ORC units installed with the majority of the units driven by biomass combustion. Turboden uses silicon-based siloxanes as their working fluid requiring thermal input temperature of ~ 300 C. However, because this organic fluid is vaporized and under pressure within the ORC engine, even though it is still sealed some jurisdictions impose the same restrictions as for high pressure steam (e.g. Rankine cycle). Regulations in Yukon need to be examined to determine whether this will be an issue. Turboden's system has been selected by Nechako Lumber to generate power at its biomass heat recovery plant in Vanderhoof, B.C.

http://www.turboden.eu/en/home/index.php

ElectraTherm

Electratherm is based in Reno, Nevada and offers a single ORC model – the 20-65 kWe Green Machine – using refrigerant R245fa as the working fluid with temperature input from 77°C to 116°C and electrical efficiency range of 5.0-7.5%. The unit is designed around a twin screw expander allowing it to produce electricity at slow speed relative to turbines and operate with the working fluid in vapour, mixed phase, or wet flow. The Green Machine uses an induction generator for electricity production. This requires a connection to the grid or another operating system (e.g., diesel generator) for generation and is therefore not suitable as a stand-alone system in an isolated community.

2.3 Brayton Cycle

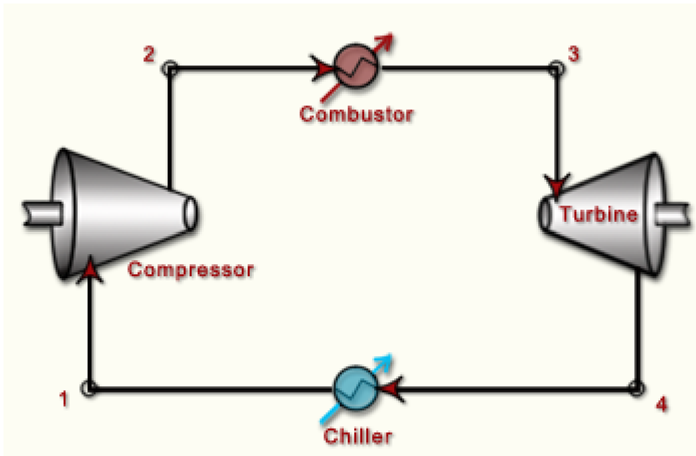

Figure 5 - Basics of the Brayton Cycle

The Brayton cycle uses an external heat source, such as biomass combustion, to heat compressed air in an indirect air/air heat exchanger. This compressed, heated air (or other gas) is then expanded through a turbine connected to a generator. The use of an indirect heat exchanger means that the turbine is exposed only to air and hence avoids corrosion or erosion problems. The crux of these systems is that in order to achieve efficiencies in the 16–19% range very high air temperatures are required and heat exchanger-metal temperatures exceeding 1,100 C are required. The heat-exchanger design and its durability are thus critical factors for these types of systems and account for the relatively scarce projects in this area. In general, the technology is not considered to be well-proven. On the positive side, because the turbine is not subject to any flue gas interactions any type of biomass fuel is suitable, subject of course to furnace design.

AgriPower Inc

AgriPower has developed a single 125 kWe external Brayton cycle engine that produces 125 kWe gross. This system is being deployed in New York and the company is operating a 250 kWe test unit in California. Since the unit is based on external combustion with no water or working fluid beyond air, engines are expected to meet safety regulations without major challenges.

Entropic Energy

Entropic Energy, based in Port Coquitlam, BC is developing two engines, an entropic cycle engine based on a modified ORC with a heat recuperator and a hybrid Brayton cycle engine that uses high humidity air as the working fluid to increase specific heat in the working fluid. Neither system has reached the commercial stage. Entropic Energy is pursuing demonstration units for both designs in the 100 kWe range.

Talbott’s Biomass Energy Systems

Talbott’s is one of the UK’s largest producers (>4500 units sold) of biomass furnaces and boilers ranging from 10 kWth to 10 MWth. They have developed a micro-turbine based Brayton cycle system rated at 100 kWe which they had been offering for sale at ~C$900k. One unit was installed and operated in the UK in 2007 and was claimed to have an electrical efficiency of ~15%. It now appears that problems have developed in this technology and it is no longer being offered for sale.

2.4 Stirling Engine

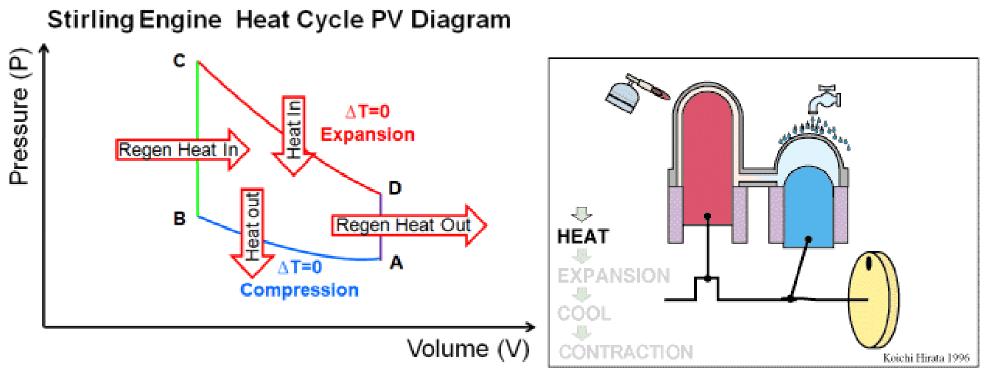

Figure 6 - Stirling Cycle and Schematic

Stirling and Ericsson engines have been in existence since the mid-19th century (invented in 1816 by Robert Stirling) and while thousands were deployed commercially to provide pumping power to farms, they have seen limited commercial deployment in modern biomass CHP projects. Stirling engines are heat engines that utilize a temperature differential to create mechanical motion. They operate on a closed regenerative thermodynamic cycle whereby a fixed amount of gas is contained within a sealed engine. Continuous expansion and contraction of the gas and the associated pressure change drives pistons and turn a shaft connected to a generator. Heat transfer between the working fluid and the heating and cooling sources is through the cylinder wall and the efficiency of this heat transfer is the limiting performance factor. The greater the temperature differential between the heating and cooling sources the greater the electrical production.

Stirling Power

STM Power was a Stirling engine maker based in Michigan with over 25 years of experience and had been developing a 25 kWe PowerUnit when the company failed in 2007. Its technology was acquired by Stirling Biopower which is now proposing to produce a single design unit capable of up to 45 kWe at a claimed efficiency exceeding 25%. This engine is still under development.

Stirling DK

The market leader in commercial deployment of biomass compatible CHP Stirling engines is Stirling DK. Stirling DK, based in Denmark, installed sixteen engines throughout Europe with a rating of 35 kWe and 140 kWth. The Stirling DK system was based on using a downdraft gasifier to produce syngas which was burned "raw" in a boiler produce flue gas at temperatures of ~1100-1200 C. The heat exchanger for the Stirling engine sat inside the boiler for maximum heat transfer. This approach allowed a wide latitude in fuel quality with minimal fouling on the heat exchanger due to the use of relatively clean syngas as the actual "engine". Stirling DK used helium as the fluid inside the sealed engine at pressures of 4.5 MPa. All Stirling DK systems were essentially custom manufactured in their facility in Denmark and the economics were sufficiently poor that the company is no longer in business.

2.5 Capital Cost Estimates

Given the current state of CHP technologies as described in the preceding sections, i.e., very few proven "reliable" are available, there is really insufficient cost data to allow preparation of a proper financial analysis. In the case of Stirling engines and Brayton cycle systems there are no reliable technologies available. There are a few pilot units in operations but the costs of these small demonstrations cannot be extrapolated to provide any reasonable capital cost estimates. Estimates and quotes are available (from suppliers and feasibility studies for remote communities, e.g., Yukon Energy Haines Junction FEED Study) for some of the gasification and ORC technologies although some of these have to be "taken with a grain of salt" due to the number of units in operation and absence of any units in remote communities. This report will therefore necessarily limit itself to expected ranges of capital cost for ORC and gasification units.

A proper feasibility study for evaluating the economic viability of remote community biomass power projects would have to take into account not only capital cost but also detailed information on the actual site, transportation logistics, the community electricity consumption and load growth rates, heat loads for a local heating network, feedstock availability and costs, operating costs and energy purchase prices.

Figure 7 presents a normalized view of the capital cost for gasification equipment. The x-axis shows the size of unit and the y-axis then gives the cost of the unit per kilowatt (electric) of power generation capacity. This graph is based on actual vendor estimates, although in some cases vendor quotes for an identical unit delivered to two different sites within the same year varied by over 50% of the lower price – an indication of the uncertainty in this field. Another example, not included in the graph, was the estimate by Proton Power which came in at ~$4,000/kWe, less than half of all the other estimates. Given that at the time of the estimate the company's only operating equipment was in a laboratory, the validity of this estimate must be questioned.

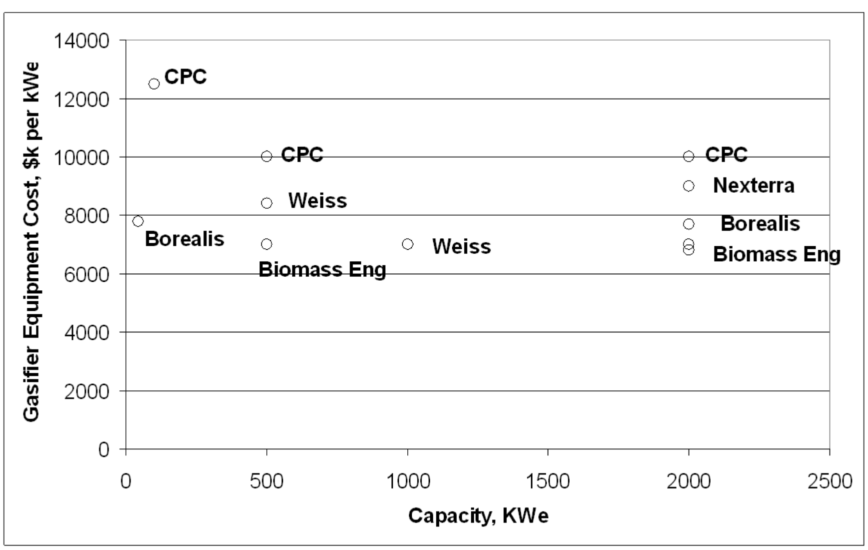

Figure 7 - Capital Cost (per kilowatt) of Gasifier Equipment

Based on Figure 7, the median capital cost for a gasification system of up to 2 MWe is $8,000/kWe. Based on this, one can estimate that a 50 kWe system should cost $400,000 and a 2 MWe system should cost $16M. This is the cost of the gasification CHP system only and does not include the building to house the plant or fuel handling and storage.

There is a discrepancy in Figure 7 at the low end of the scale. The unit from CPC (100 kWe) appears to be much more expensive than the one from Borealis (45 kWe). The reason for this is that CPC provides their system in a series of containers and already includes some fuel handling capability. In recent discussions, Borealis has indicated that they are also considering a container-based installation option. Based on these considerations, i.e., that total capital cost should include infrastructure as well as, data was reviewed for complete systems and Figure 8 was prepared. Figure 8 shows estimates of the total facility cost for a gasification CHP system. This figure provides

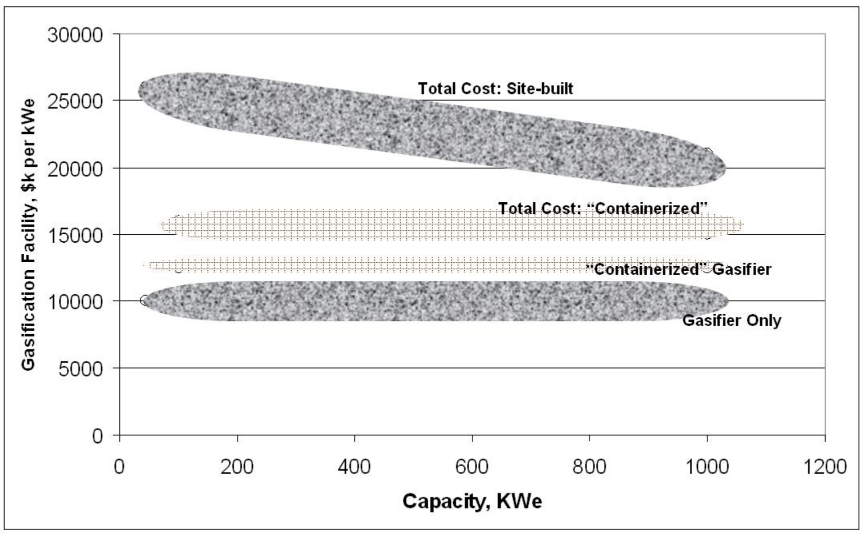

Figure 8 - Total cost (per kWe) of a Gasification-based CHP Facility

Ranges rather than specific values as these numbers depend on a number of local factors as noted earlier. Figure 8 also shows expected costs for a container-based approach vs a build-on-site facility. For example a custom built 50 kWe plant should cost ~$1.2M whereas a container-based 100 kWe system should cost about ~$3.2M. This reconciles well the discrepancies noted in Figure 7. Based on Figure 8, a 1000 kWe facility with buildings including storage can be expected to cost up to $20M.

Organic Rankine Cycle (ORC) systems present a slightly more complex situation. Normally ORC systems are NOT supplied "turnkey". The client (or community) is expected to specify, procure and install the boiler and/or heat exchangers and integrate these with the ORC system. There will usually be additional costs associated with hiring an "integrator". However, if a suitable boiler or heat source is already available/installed then considerable savings can be achieved.

Figure 9 presents estimates of expected capital cost for an ORC system using the same per kWe basis as the previous figures. It is immediately apparent that the capital cost drops as the size increases as opposed to gasification where size seems to be immaterial. Perhaps this is an indication of a more mature/established technology. ORC systems are already well established in Europe owing to higher energy prices there. More competition? Unfortunately the lack of demand in Canada has meant that there are fewer options available. For example, Turdboden markets units with a production capacity as low as 345 kWe in Europe but only markets systems larger than 1 MWe in North America. This may change in future but for the time being restricts the consideration of ORC in remote communities.

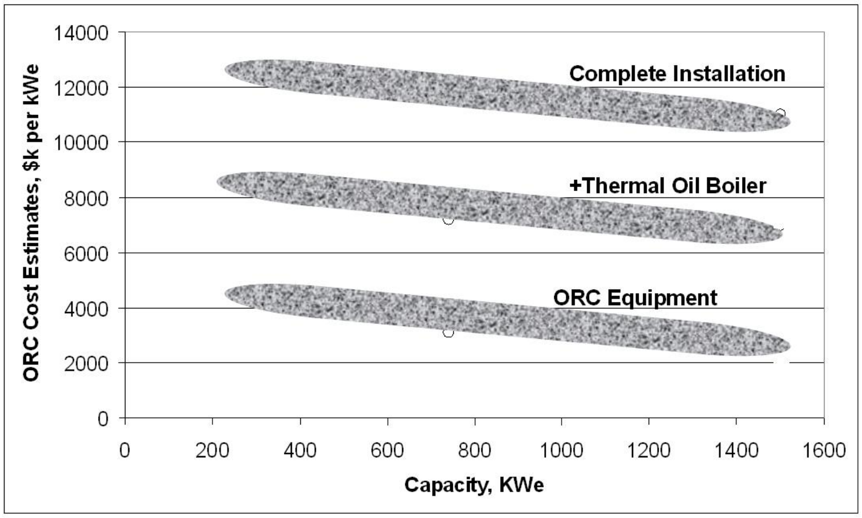

Figure 9 – Costs (per kWe) for ROC-based CHP Facility

Figure 9 presents three bands of costs. The lower band is the cost of the ORC itself, the middle band adds the cost of a thermal oil boiler (biomass-fired system using thermal oil as the heat transfer fluid) and the top band is the complete cost including structure and installation. On this basis even though a 1000 kWe ORC could be expected to cost under $4M, the total cost of an installation could be ~$12M.

Capital cost data has been presented for CHP systems based on gasification or ORC technologies. The costs have been presented in a normalized manner, i.e., capital cost per kWe of generating capacity and should be accurate enough for pre-feasibility evaluatons of CHP in remote communities.

3.0 BIOMASS CHP IMPLEMENTATION CONSIDERATIONS

Currently there is a poor business environment for use of biomass fuels for district heating and small scale cogeneration. Small businesses can be the champions for implementation of small CHP systems, given the right drivers. The question becomes: How do you kick-start an industry where one does not exist? How do you go from zero supply and zero demand to the threshold where a bioenergy industry can operate economically? Governments can play a role by ensuring that there are clear rules and regulations for emissions, efficiency and power purchase by utilities. Beyond that governments also need to develop clear policies on small-scale CHP which will encourage new developments.

Consider events over the last six years in the Northwest Territories where a local entrepreneur proposed a pellet heating system that could offer heat at 70 per cent the cost of fossil (diesel) oil. The proposal was to install a pellet boiler in a local correctional facility. After some convincing the government jumped on board and the rest as they say is now history. Today, Yellowknife considers itself the pellet boiler capital of Canada. Concerns over emissions from wood-burning have dissipated. Brand new EPA-approved pellet burners are over 1,000 times cleaner (particulate matter) than generic woodstoves from the 1970s. The Northwest Territories government has provided $60 million in support and incentives to businesses and homeowners to convert to pellet burners. Wood pellet consumption now exceeds 20,000 tonnes/year and a wood pellet plant for the Northwest Territories has been proposed by Aurora Wood Pellets who in March 2014 signed an MOU for fibre supply from Fort Resolution.

Governments can play a significant role in creating the right business climate for increased utilization of biomass fuels. There are significant benefits to biomass utilization including:

- Biomass is an abundant and renewable source of energy.
- Using biomass for energy diversifies the energy supply and reduces dependency on fossil fuels (fuel oil, propane, and natural gas).
- Burning biomass in efficient boiler systems produces less air pollution than woodstoves, beehive burners, burning slash piles, prescribed burning and catastrophic wildfires.
- Sustainably produced biomass is a local renewable energy source. The money spent on biomass keeps energy dollars circulating in the local economy and supports jobs in the community.
- Biomass utilization can also subsidize the costs of forest fire reduction projects, improving safety for rural communities.
- Biomass projects can serve as an impetus for a community to increase its capacity for planning and managing other community projects
- Communities who have invested in biomass energy systems and have replaced individual wood stoves with district heating systems have generally noted “One of the biggest

> benefits of the biomass district heating system has been a dramatic decrease in house fires"

While every biomass project must be economically feasible, there are many other benefits that can help justify the commitment of time and energy to learning about bioenergy. Because of these additional benefits, government policies and support should be implemented to help people conquer the learning curve and develop the infrastructure to support economical biomass utilization into the future. In the case of forest management practices, using the residues for energy provides opportunities to offset the costs of these operations. By making new use of forest byproducts for fuel, biomass energy also strengthens the whole regional forest-products industry, giving it new local markets and improving the forest resource, along with creating jobs.

Burning wood for energy has a positive impact in moderating global climate change. Carbon dioxide (CO_2) buildup in the atmosphere is a significant cause of global climate change. Fossil fuel combustion takes carbon that was locked away underground (as crude oil and gas) and transfers it to the atmosphere as CO_2. When wood is burned, however, it recycles carbon that was already in the natural carbon cycle. Consequently, the net effect of burning wood fuel is that no new CO_2 is added to the atmosphere.

Aside from a good business climate there are a number of other factors which determine success or failure for biomass CHP systems. The principal of these are selecting a reliable technology (as reviewed in the previous chapter), the correct feedstock and most importantly, the people who put it all together and keep it going. The key to having the people is to build community capacity.

3.1 Community Capacity

Community capacity is a critical ingredient to the sustained success of an energy project. Locating, developing and maintaining skills to lead, manage, finance and run projects of this type is paramount and can lead to smaller projects acting as incubators for larger, more complex projects. Acquiring these skills involves capacity-building and community involvement throughout the entire project:

- developing appropriate governance mechanisms
- strategies to maximize project economic development and job creation
- information gathering on how other remote communities have developed clean energy projects with partners
- hands-on training of clean energy project development and management
- ongoing consultation with financial, legal and technical (engineering) advisors during the project development process and project site selection
- outreach and communications systems to engage the community during the project development

- mechanisms to train and equip local people for clean-energy jobs including educational and apprenticeship opportunities. One of the key determining factors for success in existing biomass systems has been getting “buy-in” from the future operators and managers right from the start of a project.

There is a need to gain experience and confidence on biomass heating systems with chips (and pellets) in order to minimize environmental and health impacts and increase public awareness. Wood plants require both maintenance and operation beyond what would be required for an oil- or gas-burning plant. Wood pellets are more difficult to feed into the combustion chamber than either oil or gas. Wood chips are more difficult to feed than are wood pellets, and require that quality-control measures be put in place by the plant operator, as opposed to the pellet-fuel vendor. Feeding cordwood requires the most intervention by an operator, but the least equipment.

3.2 Feedstock Issues

Wood can be burned clean, on a level with the emissions from a natural gas plant. If cord wood or chips are being fed, the emissions can be as clean as from a pellet plant, provided that the quality-control issues have been addressed. Wood contains virtually no sulphur or chlorine, both of which can create noxious chemicals in a plant’s exhaust.
Storage of oil and gas requires considerable planning, permitting and expense. Wood fuel is innocuous and simple to store or to clean up after a spill.

Feedstock quality and homogeneity are much more important for internal combustion systems – in particular gasification-based facilities – than for external combustion systems employing heat engines. Feedstocks for gasification and IC engine/microturbine systems typically require drying and bark removal in order to limit tar production. A uniform particle size is also important for efficient operation of the system, to limit bridging (blockage) of the fuel, and to minimize production of tar. Preprocessing, including debarking, sizing, and drying of the fuel is necessary for gasification but can increase capital and operating costs and reduce the net electrical and heat output due to parasitic loads.

Available feedstock characteristics will play a much larger role in the decision-making process for implementation and operation of a gasification system than ORC or Stirling engines. Educating project developers and project stakeholders on the appropriate feedstocks for specific technologies is important for managing performance expectations and increasing technology-deployment success.

One major factor in the move to increased use of biomass for energy is a need for appreciation and development of specifications for biomass fuels. There is a common misconception that “biomass is biomass”. Biomass properties can vary substantially and one person’s wood chips are different from someone else’s idea of what they will be (this was clearly illustrated in the problems with operation of the Yukon College Gasifier). Specifications need to be firmed up and adhered to but this is where experience is useful and necessary.

Wood chips are the most commonly used bioenergy feedstock and have been used extensively for heating large facilities and for process heat applications such as drying lumber. Chips are produced as a by-product in sawmills and can also be made by chipping scrap wood or whole trees. While relatively inexpensive compared to more processed forms of biomass, chip consistency and quality can vary substantially. The ideal chip is dry, uniform in size and free of dirt and other debris. Each combustion system will have a preferred fuel specification. Some systems can handle variable consistency, lower-quality chips, but these systems also require more maintenance; therefore it is very important to match your system to the available fuel source. Over the long run it may be cheaper to buy a more expensive chip than feed your system with poor-quality fuel. Ensuring a reliable supply of wood chips has been a challenge for most of the community-based bioenergy systems in Canada.

Wood pellets are a wood product that is processed to reduce the water content and increase density, producing a fuel stock that is easier to handle, store and transport compared to cordwood and wood chips. This uniformity allows pellet systems to burn more efficiently. Because the pellets are easier to store and handle, pellet systems tend to be simpler, smaller, less expensive and quicker to install than wood chip systems. The tradeoff is higher cost per unit energy compared to other less-refined fuel stocks - about twice the cost of wood chips for the same energy content. Pellet systems may be more economical for small-and medium-sized applications.

A reason for choosing a wood chip boiler may be the desire to use a local supplier. A pellet-fired boiler would generally depend on pellet factories outside of the community. Wood chip-fired systems require an indoor storage area and handling equipment to move the chips from the bin to the boiler. Consequently, they can be more time-consuming to design and install. Depending on scale, these costs may be offset by the lower cost per unit energy over wood pellets.

Wood pellets are a cost-effective means of providing heat to residential and small commercial buildings. Once a market for wood pellet fuel of approximately 10,000 tonnes per year can be established, a local pellet manufacturing plant could be commercially viable, providing both economic opportunities, reduced economic leakage and the potential to further develop the pellet market into distributed cogeneration opportunities. The Yukon government’s new microgeneration policy provides the opportunity to sell any excess renewable electricity to the grid at 21 cents per kilowatt-hour. At this time small wood-fired microgeneration equipment is still in the development stages but may be market-ready in the foreseeable future.

4.0 RECOMMENDATIONS

An evaluation of “available” small-scale biomass-fired electrical generation technologies appropriate to the Yukon shows that there are few technologies which can be considered to be proven reliable and commercially viable. Four technology areas were considered: Gasification coupled with an Internal Combustion Engine; Organic Rankine Cycle (ORC); Brayton Cycle and Stirling Engine. Based on the criteria that a commercially reliable system should have at least five units operating at customer sites, only two gasification companies and three ORC suppliers were considered sufficiently advanced to warrant more detailed evaluation. Future evaluations should include not only economics and a proven track record but also appropriate sizing (for both heat and electricity) for the target community and ability to follow load variations. Special consideration should also be given to feedstock requirements and compatibility with local supply and resources to maintain that supply.

The following small-scale biomass-fired electrical generation technologies are considered “viable” for further evaluation, at this time:

Gasification:
Community Power Corporation
Borealis Wood Power (Spanner Re2 GMBH)

Organic Rankine Cycle:
Infinity Turbine
Adoratec
Turboden

At present no suitable Brayton cycle, Stirling cycle or Fast Pyrolysis-based units are available that would be suitable for installation at Haines Junction or at any other community in the Yukon.

Gasification systems, although the most active field in terms of research and development do not have a strong track record. Both the Spanner system, represented in Canada by Borealis Wood Power and Community Power Corporation have only one system at the “demonstration” stage in Canada. Spanner has over 150 operating in Europe and as long as the limitations of the technology are respected could be a strong contender for operation in a remote community. Community Power Corporation has a few units operating in the US although most of these are government-backed “demonstrations” and there are still some economic and technology issues to be addressed.

ORC systems are well established in Europe but have yet to make significant inroads in North America. Of the three systems considered “viable” only one company, Turboden, is actively pursuing the North American market. Turboden’s offerings have been limited, to date, to their larger systems (1-2 MWe) which may be too large for many remote communities.

As a first step in economic analyses, a “ball-park” estimate of the capital cost of gasification and ORC installations has been prepared (figures are in thousands of dollars):

Plant Size (kWe)	Gasification Equipment Only, $k	Gasification Total Facility, $k	ORC Equipment Only, $k	ORC Total Facility, $k
50	400	1,250	NA	NA
100	800	2,500	NA	NA
500	4,000	8,500	2,000	6,000
1000	8,000	20,000	3,500	11,500

The total facility costs are approximate and based on new buildings and plant infrastructure. The ORC total facility includes the cost of a boiler which can be equal to the cost of the ORC alone.

Given the significant costs associated with the systems, which are unproven in a remote northern region, a key requirement is to ensure that the capacity is available to host these technologies. Community capacity is a critical ingredient to the sustained success of any energy project and it is therefore recommended that further action include development of this capacity as an inherent component. Locating, developing and maintaining skills to lead, manage, finance and run projects of this type is paramount and can lead to smaller projects acting as incubators for larger, more complex projects. With this in mind, future consideration should be given to:

- Establishing experience with wood fuel (especially chips) supply infrastructure – the best bet is to try this with an advanced, low emissions heat-only system.

- Once experience is proven with a wood chip heating system expand the system to CHP by adding on an ORC, e.g., Turboden. The heating system would have to be planned so as to be suitable for addition of an ORC without major problems.

- The lowest cost option would be to install a small gasifier (< 100 kWe) and tie the installation to an extensive community capacity building program.

5.0 GLOSSARY

Backup system: An alternate fuel combustion system used to provide heat when the primary system is out of service or unable to meet the full heat load.

Baghouse: A type of particulate removal device used with very large biomass heating plants.

Bio-gas: A gas usually produced from anaerobic digestion of biomass, whose principal constituent is methane. Can be used as a combustion fuel.

Biomass: Any organic matter that can be burned for energy. Here used as synonymous with wood in its various forms.

Boiler: A heat exchanger used to extract heat from hot combustion gases and transfer the heat to water. The boiler output can be either hot water or, if the water is allowed to boil, steam.

Calorific value: The energy content of a fuel, expressed in units such as MJ/kg or Btu per pound.

Capital Cost - fixed, one-time expenses incurred on the purchase of land, buildings, construction, and equipment

Carbon burn-out: The end of the combustion process in which all uncombined gaseous and solid carbon is oxidized to carbon dioxide.

Char: Carbon-rich combustible solids that result from pyrolysis of wood in the early stages of combustion. Char can be converted to combustible gases under certain conditions, or burned directly on the grates.

Chipper: A large device that reduces logs, whole trees, slab wood, or lumber to chips of more or less uniform-size. Stationary chippers are used in sawmills, while trailer-mounted whole-tree chippers are used in the woods.

CHP: The acronym for 'combined heat and power.' CHP is the simultaneous production of heat and electrical power from a single fuel.

Cogeneration: The simultaneous production of heat and electrical power from a single fuel. A term used in industrial settings, now being displaced by the more descriptive term CHP.

Combined heat and power (CHP): The simultaneous production of heat and electrical power from a single fuel.

Combustion efficiency: The efficiency of converting available chemical energy in the fuel to heat, typically in excess of 99% in biomass burners. Efficiencies of conversion to usable heat are much lower.

Combustor: A freestanding primary combustion furnace, usually located adjacent to the boiler or heat exchanger. Exhaust gases from the combustor pass into and through the boiler before exiting to the stack.

Commissioning: The process of verifying that a new heating plant meets the performance specifications called for in the installation contract.

Complete combustion: Combustion in which all carbon and hydrogen in the fuel have been thoroughly reacted with oxygen, producing carbon dioxide and water vapor.

Cyclone separator: A flue gas particulate removal device, which creates a vortex that separates solid particles from the hot gas stream.

Design/build: A design and contracting process under which the contractor bears ultimate responsibility for the design and function of the equipment or system installed.

Design specifications: For mechanical systems, specifications (and drawings) produced by the owner's mechanical or design engineer. Design specifications become part of the contract for the installation. The designer bears ultimate responsibility for the design and function of the system.

District heating: The use of a single boiler plant to provide hot water or steam for heating a number of buildings in a locality.

Excess air: The amount of combustion air supplied to the fire that exceeds the theoretical air requirement to give complete combustion. Expressed as a percentage.

Fly ash: Airborne ash carried through the combustion chamber by the hot exhaust gases, and typically deposited in the passages of the boiler heat exchanger.

Furnace: The primary combustion chamber of a biomass burner. The term also refers to warm-air heating appliances.

Gasification: partial combustion/oxidation whereby only about one third of the air normally required for full combustion is used. The untreated gas exiting the gasification chamber is a combustible gas known as producer gas or syngas.

Gasify: To convert solid biomass into combustible gas.

Grates (or combustion grates): Slotted or pinhole grates that support the burning fuel and allow air to pass up through the fuel bed from below.

Heat exchanger: A device that transfers heat from one fluid stream to another. The most common heat exchanger in biomass combustion systems is the boiler, which transfers heat from the hot combustion gases to boiler water.

Heat load: The demand for heat of a building at any one time, typically expressed in MegaWatts (MW) or MegaWatt Hours MWh. Peak heat load refers to the maximum annual demand for heat, and is used in sizing heating plants.

Heat transfer medium: A fluid (either water, steam, or air) that carries heat from the combustion system to the point of use.

Hogged fuel: Biomass fuel produced by grinding up various forms of wood and bark, possibly mixed with sawdust. Often refers to a variable low-quality fuel. If produced from clean, high-quality dry scrap, can be a very high-quality fuel.

Hog: Shorthand for hog mill, a device used to grind up various forms of biomass into chip-sized pieces.

Hogged or Hog fuel: Biomass fuel produced by grinding up various forms of wood and bark, possibly mixed with sawdust. Often refers to a variable low-quality fuel. If produced from clean, high-quality dry scrap, can be a very high-quality fuel.

Hydronic: Refers to a water-based heat distribution system that uses either hot water or steam.

Induced draft fan: A fan mounted at the discharge of the boiler, before the stack, to keep furnace pressure at the correct level and assure proper movement of flue gases up the chimney. Also called the ID fan.

Injection auger: The final fuel auger that moves the solid fuel into the combustion zone. In particular, an auger that forces fuel through an aperture onto the grates.

kW - kiloWatt: a standard unit of energy equal to 1,000 watts (one watt = one joule per second) of energy transfer. When discussing combined heat and power, the subscripts denote the electrical energy (kWe) produced and the thermal energy produced (kWth) in the system, respectively.

kWh - kiloWatt Hour : a standard unit of power equal to the energy in kW multiplied by the hours of energy production.

MMBH: A unit that characterizes the size or peak output of a boiler, equal to one million Btus per hour.

MMBtu: A unit of energy equal to one million Btu (each M represents 1,000). In boiler or system sizing, also represents 1 MMBtu per hour.

MW - MegaWatt: a standard unit of energy equal to 1,000,000 watts (one watt = one joule per second) of energy transfer. When discussing combined heat and power, the subscripts denote the the electrical energy (MWe) produced and the thermal energy produced (MWth) in the system, respectively.

MWh - MegaWatt Hour : a standard unit of power equal to the energy in MW multiplied by the hours of energy production.

Metering bin: A small bin in the fuel feed stream, just upstream of the combustion device. Allows a precise feed rate, or metering, of the fuel to the fire.

Multi-clone (or multi-cyclone): A particulate removal device that includes a number of cyclone separators.

NOx: Oxides of nitrogen. Air pollutants that can be released from various types of combustion processes, including biomass combustion.

Particulates: Very small solid airborne particles. A source of air pollution that can result from biomass combustion.

Producer gas: A mixture of flammable gases (principally carbon monoxide and hydrogen) and nonflammable gases (mainly nitrogen and carbon dioxide) made by the gasification of carbonaceous substances, e.g., biomass

Pyrolysis: The oxidation process by which solid wood is converted to intermediate combustible gases and combustible solids through a variety of thermo-chemical reactions.

Refractory: A material resistant to high temperatures that is used to line combustion chambers in order to reflect heat back to the fire and to keep furnace temperatures steady.

Rotary airlock: A device used to pass solids such as incoming fuel or fly ash from a multi-cyclone without passing air. Can be used to prevent burnback or the introduction of boiler room air into the exhaust gases through a multi-cyclone.

Simple payback: A method of economic analysis in which cost effectiveness is based on installed cost and first-year savings. Also refers to the number of years it takes an improvement to pay back the investment, computed by dividing the installed cost by the first-year energy savings.

Sizing: The process of specifying the size (measured in kW or MW) of a heating plant.

SOx: Oxides of sulfur. Air pollutants implicated in acid rain caused by combustion of fossil fuels. Modern wood systems have 1/6 the sulfur dioxide emissions of fuel oil.

Stack: The chimney of a combustion system.

Stack emissions: The components of the hot combustion gases (including particulates) exiting from the stack.

Stoker: An auger or other device for feeding solid fuel into the combustion zone.

Syngas – a synthetic, combustible gas produced from gasification composed mainly of carbon monoxide, hydrogen and methane. Syngas is sometimes used interchangeably to denote producer gas.

Tar - a dark, thick, flammable liquid consisting of a mixture of hydrocarbons, resins, alcohols, and other compounds. Tars are produced during biomass gasification as vapours but can have significant negative effects on system operation as condensation and deposition of tars at temperatures below 350˚C can lead to fouling and potential blockage of downstream equipment and piping.

Thermal efficiency: The ratio of output energy to input energy when the combustion system is running under design conditions

Turn-down ratio: An index of the range over which efficient combustion can be achieved by a biomass burner. Calculated by dividing the maximum system output by the minimum output at which efficient, smoke-free combustion can be sustained (for example, with a maximum of 2.0 MW and a minimum of .5 MW, the turn-down ratio is 4:1).

Turnkey: For mechanical systems, a contracting process under which the contractor has full responsibility for design and for the complete installed package of work. The owner accepts the completed system once the contractor has demonstrated that the system meets the performance specifications.

Ultimate analysis: Laboratory analysis that tells the percentage components of the elemental constituents of a fuel, including water and ash.

Under-fire air: Combustion air added under the grates. Serves the function of evaporating water, cooling the grates, and supplying oxygen for the pyrolysis/combustion reactions.

Uptime: the portion of time during which a piece of equipment or system is operating

Venturi scrubber: A flue gas particulate removal device that uses a reduction in pipe inlet and water spray to capture and remove small, gas-entrained solid particles.

Volatiles: Fuel constituents capable of being converted to gases at fairly low temperatures.

Wet scrubber: A flue gas particulate removal device that uses a water spray to capture and remove small, gas-entrained solid particles. Used only in very large biomass burners.

Woodchips: Small rectangular pieces of wood (approximately 2 cm x 5 cm x 1cm) produced by either a mill chipper or a whole-tree chipper.