Distributed Biomass Power Systems for Independent Power Production in Remote Locations

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ABSTRACT

Energy is a large contributor to our cost of living and can take an even greater portion of income from those living in remote areas. Communities not on the electrical power grid require isolated diesel generators. Operation and maintenance of power systems is relatively more expensive due to the smaller scale of the business unit. Transportation and distribution costs add to the cost of fuel. Various ways of subsidizing diesel generation are used by crown utilities and governments to ensure affordable power for remote off-grid communities. Although these subsidies do mitigate high consumer costs, diesel remains an expensive power generation method, has high maintenance costs, contributes significant pollution, and is more sensitive to fuel price variations in remote locations.

Alternate sources of energy for remote power application include wind, small hydroelectric and biomass. Of these three it can be argued that biomass is the most “on-demand” available, storable, and transportable. Many communities have abundant renewable energy forest resource. Biomass is a fully renewable energy source, is considered greenhouse gas (CO₂) neutral and thus can reduce the greenhouse gas emissions associated with power and heat used by communities. Crown utilities are mandated to supply power to communities and can find this difficult to do within acceptable pricing structures. Distributed biomass energy initiatives meet the utility’s desire to reduce greenhouse gas emissions and make more power available to citizens.

Practical bioenergy technologies are needed, where biomass is available, to replace remote diesel generation and heating oil use. The ability to produce distributed heat and power requires a technology that is cost effective (capital cost comparable to large-scale facilities on a $/kW basis), is small in size, requires minimum operator presence and qualification, and has high conversion efficiency. In addition it is preferred that the technology used provide high quality heat to reduce fossil fuel used for space heating. It is therefore important to analyze small biopower technologies in terms of energy efficiency, operating simplicity, and convenience of the end product: useable heat and electricity.

In remote areas it is not feasible to promote traditional small-scale power generating systems using steam due to the complexity and expense of even the simplest steam system. As a result remote communities are not able to take advantage of their local, sustainable energy resources. Instead they are constrained to buy and install diesel generators and continually import fossil fuels to run them. Other possible technologies include bio-oil systems, Organic Rankine Cycle, and a new system using the Entropic Cycle. This paper will compare alternate biopower conversion systems. To ensure consistency in analysis, comparison between these technologies for the 0.25 to 4 MWe power generation range will be discussed by using a common feedstock: 50% moisture content wood with a heating value of 20.5 MJ/BDkg fuel which can be shipped and trucked to remote locations or collected by the community.
INTRODUCTION
Remote Canadian communities that are not connected to the wider electrical distribution grid have a special issue with respect to power production. Typically diesel generators are used to power a local distribution system at the inflated costs of operation, maintenance, fuel supply and environmental impact. Many of these communities are located near or within forest lands that offer a source of renewable energy for the residents’ needs. Clearly a cost-effective biopower conversion system could serve both the local society and the environment.

Forest resources hold several advantages over alternate renewable energy sources of wind, solar and river energy. Bioenergy has a high energy density which allows for smaller equipment, it can be harvested and stored, transported and used on-demand. However biomass is a still distributed resource such that avoiding large transportation costs suggests small-scale systems. On the other hand, the small population of remote communities allows a small-scale combined heat and power (CHP) system to match the available fuel to the local need. What is required is a practical technology that can fulfill this opportunity.

TRADITIONAL SYSTEMS
Large steam boiler systems as shown in Figure 1 have been the traditional approach to power production from biomass. These systems have typically been implemented by corporations using the large quantities of biomass waste produced by their operations. In some instances independent power systems have been developed where sufficient biomass is concentrated by several industries in a region. What is notable is the size of such systems. Typically these systems become economically viable at power levels exceeding 20 MWe and become excessive in size when approaching 100 MWe. Often such systems operate where there is a “host” application for process steam. This offers both co-generation operating benefits and economic justification for large investment.

A typical capital cost for a condensing steam, biomass power plant can be evaluated from the reported numbers for constructing Williams Lake Power [1]. The 60 MWe plant was completed in 1993 for $150,000,000 (Cdn) giving a unit cost of $2500/kWe. This level of investment clearly requires major investor consortiums. Due to economies of scale it can be anticipated that smaller sized biomass steam plants would be a greater unit cost. Pulp mills are a special situation where large quantities of wood waste is concentrated, a large steam host is present in the pulping process which makes co-generation viable and large consumption of power is required. Many pulping operations and large sawmill communities have the opportunity to increase utilization of biomass for power on the traditional scale.

Steam systems are based on the Rankine cycle which has limited efficiency opportunity. The advantage of the Rankine cycle is that it compresses its working fluid in liquid form. This greatly reduces the parasitic power required. However this benefit is mitigated in that almost all of the latent heat of the working fluid is rejected in the cycle. To maximize efficiency, steam systems are operated at the highest practical temperature and pressure requiring high alloy materials. Moreover reheat, recuperation, economizer and combustion air heater systems are typically employed to maximize conversion efficiency. Williams Lake Power is reported to have overall efficiency in the order of 29% [1] using fuel with about 38% moisture content although that figure has been disputed by some as being high. Traditional biomass steam systems are relatively complex power plants.
SMALL-SCALE BIOPower

Even though there are still many opportunities for utilization of biomass in large-scale, there are even greater opportunities for small-scale systems. However much of this potential is unrecognized due to our historical biases. Since biomass is a distributed resource it often remains unnoticed until it has been collected into central regions for reasons other than energy production. Transport costs are generally too high to justify collecting biomass for energy purposes only but are easily justified when high value products (lumber, pulp, etc) are the intent. Unfortunately even when accumulated, there is often still too little quantity to justify a traditional steam power system.

Relatively small quantities of biomass are available from many sources. When looking at forest resources alone, these sources include:
- Waste products from sawmills and other forest product companies
- 46% of every harvested tree that remains in the forest
- Underbrush clearing for wildfire protection
- Utilization of bug-killed or fire-killed trees
- Selected logging for renewable energy
- Imported and stored biomass from distant operations

There is a tremendous potential for using this material constructively to reduce dependency on fossil fuels and to enhance the living standards of residents in remote regions.

An example of the opportunity in remote regions can be found by reviewing communities in the Canadian Northwest Territories. More than two dozen communities are listed by the Northwest Territories Power Corporation [2] with electrical rates ranging from $12.13 to $266.60 / MWhr. The picture in Figure 2 shows an aerial photograph of the community of Nahanni Butte [3]. This community has three diesel generators with a total installed capacity of 250 kWe to meet a peak demand of 129 kWe [4]. Power costs are listed at $95.73 / MWhr and are subsidized by the territorial government. However, as the picture shows, the local forest resources are vast. In northern areas the slow growth rates may not always support logging activities for export, but they will support a sustainable energy harvesting for the community. Using forest resources to displace diesel power and heating oil would see a large reduction in greenhouse gas and other polluting emissions. Figure 3 shows the greenhouse gases displacement for remote communities in Northern Canada for a 2 MWe Turbion™ CHP system.

Fig 2: Remote Community

ALTERNATE BIOENERGY TECHNOLOGIES

There are a number of technologies that have been proposed for small-scale power production from biomass resources. Some of these technologies also lend themselves to CHP applications. Whenever CHP can be implemented, the overall efficiency is greatly enhanced. A list of the alternate technologies being proposed includes:
- Small-scale condensing steam turbine system
- Small-scale CHP steam with back-pressure turbine
- Bio-oil production and engine/turbine conversion to power
- Gasification to syngas and engine/turbine conversion to power
• Air turbine (indirect Brayton cycle)
• Organic Rankine Cycle (ORC)
• Entropic Power Cycle (Turbion™)

Currently none of these systems appear to meet commercial viability. Those that are sufficiently proven technically appear to be too costly and complex for general acceptance. Other systems are still in development or demonstration but some predict a more acceptable cost level. When compared to very large steam systems, small-scale technologies show much reduced electrical conversion efficiencies. But in CHP applications the efficiencies rise to respectable levels. Comparison of the above technologies is shown in Table 1 [1]. To establish a direct comparison all systems were evaluated using green biomass fuel at 50% moisture content.

SMALL-SCALE CONDENSING STEAM: There are both technical and practical reasons that steam systems lose efficiency at small scale. Without the economy of scale, high alloy materials cannot be cost-justified in small systems. This requires them to operate at lower temperature (400°C) and pressure (4700 kPa) which reduces the thermal conversion efficiency. Scaling laws result in reduced thermal conversion efficiency through the steam turbine at low mass flows of small systems. System complexity cannot be cost-justified so recuperation and reheat cannot be justified. A small-scale steam system will have overall conversion efficiency in the order of 10%.

SMALL-SCALE CHP STEAM: Re-applying the small-scale steam system to make use of thermal energy in the steam will greatly enhance the overall efficiency of the system. However the electrical conversion efficiency will be reduced since more energy must be left in the steam to make it useful as a heat source. The technical and practical limitations noted for small condensing systems still apply. It should also be noted that although steam can be a good heat carrier, it has distribution limitations. In particular steam is not readily pumpable and must be produced at a pressure sufficient to serve the delivery needs. A small-scale CHP steam system can have overall conversion efficiency in the order of 55% with 6% representing the electrical conversion portion [5].

BIO-OIL PRODUCTION: Systems to produce bio-oil from biomass feedstock are being promoted for energy recovery systems. These systems have the benefit of concentrating the biomass energy into a liquid fuel which can be more easily transported. Bio-oil processes also create a char byproduct that has not been shown to have market value and is in a carbon form that can self-ignite. Most bio-oil...
production systems use a fluidized bed reactor which introduces large parasitic power draws, makeup sand requirements, fuel drying and sizing, and operation complexity. A system that doesn’t use fluidized bed technology and uses the char within its process could find a niche market apart from the focus of this paper provided it can operate in off-grid areas. Bio-oil must be converted through an engine or turbine to produce usable power. It is estimated that the overall conversion efficiency of the bio-oil pathway to power is in the order of 6% with little practical opportunity for CHP [5].

Table 1: Technical Comparison for 50% Moisture Content Wood Feedstock

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<tr>
<td>Technical Complexity</td>
<td>low 1..2..3..4..5 high</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>3</td>
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<td></td>
<td>less 1..2..3..4..5 more</td>
<td>5</td>
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<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>2</td>
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<tr>
<td>Fuel Preparation</td>
<td>less 1..2..3..4..5 more</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Operator Qualification</td>
<td>low 1..2..3..4..5 high</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
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<td>5</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Optimum System Size</td>
<td>60 MW</td>
<td>&gt; 5 MW</td>
<td>&lt; 2 MW</td>
<td>&lt;1/2 MW</td>
<td>&lt; 5 MW</td>
<td>&lt; 5 MW</td>
<td>&lt; 2 MW</td>
<td>&lt; 2 MW</td>
</tr>
<tr>
<td>Power Efficiency - biomass to elect.</td>
<td>29.2%</td>
<td>6.4%</td>
<td>7.75%</td>
<td>7.4%</td>
<td>9.9%</td>
<td>5.7%</td>
<td>10.2%</td>
<td>12.0%</td>
</tr>
<tr>
<td>Secondary Products - usefulness</td>
<td>- char</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>115°C steam</td>
<td>80°C liquid</td>
<td>90°C liquid</td>
<td></td>
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<tr>
<td>Overall Cogeneration Efficiency</td>
<td>yes 1..2..3..4..5 none</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
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<tr>
<td></td>
<td>29.2%</td>
<td>6.4%</td>
<td>7.75%</td>
<td>7.4%</td>
<td>9.9%</td>
<td>53.9%</td>
<td>54.5%</td>
<td>67.7%</td>
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**SYNGAS PRODUCTION:** Gasification of biomass can be used to produce a syngas that in turn can be used in an engine or turbine to produce power. This approach is usually taken in an attempt to increase conversion efficiency and to reduce cost of electrical conversion systems. However practical problems exist with losses due to fuel moisture content, gas cleaning requirements and engine operation. Syngas production from biomass is not yet a commercially proven approach. Theoretical analysis shows that this method of power production results in an overall conversion efficiency in the order of 8% and little practical opportunity for CHP [5] except for the heat contained in the engine coolant.

**INDIRECT BRAYTON CYCLE:** Development work is progressing by several groups aimed at creating an indirectly heated air turbine system. The benefit would be its simplicity and its inherent safety since it would not use a boiler. One difficulty with the indirect Brayton cycle is its balance between cycle efficiency and overall efficiency. Increasing the cycle efficiency by increasing the operating temperature reduces the heat recovery of the indirect heat exchanger. An indirect Brayton cycle using its optimum temperature and pressure will result in overall conversion efficiency in the order of 7½% [5]. CHP benefits can be added by using the hot air although this heat cannot be readily distributed over distances.
**Organic Rankine Cycle (ORC):** The Rankine cycle used with the traditional steam system can also be implemented using an organic working fluid in place of water. The primary advantage comes from changing the temperature and pressure regime to operate under pressure in the low temperature portion of the cycle. This reduces the volume flow and the size of equipment in this area. Mitigating this effect is the lower enthalpy as compared to water which requires greater mass flow for the same power. These systems often introduce a hot oil circuit to recover heat without boiling within the flue gas zone and to reduce the risk of volatile working fluid leaking into the hot regime. To maximize CHP the coolant from the condenser will sometimes be further heated by exhaust flue gas before being sent to a district heat system. An ORC system can have overall conversion efficiency in the order of 55% with 10% representing the electrical conversion portion [5]. Although commercialized ORC systems are available, it appears that the cost is still very high.

**Entropic Power Cycle (Turbion™):** The Entropic power cycle is currently under development in a 250 kWe demonstration system. This proprietary power cycle uses the low compression energy of the Rankine cycle to minimize parasitic losses. It uses the vapour heating advantages of the Brayton cycle to negate the need for a boiler operator. It uses the pressure regime of the Organic Rankine cycle to minimize equipment size. It also inherently produces a hot coolant at district heat levels to offer CHP functionality. The packaged design of the Turbion™ system achieves a remarkable reduction in size. Although the Turbion™ system promises to be cost-comparative to a large-scale steam system, it is not yet available commercially. This system can have overall conversion efficiency in the order of 68% with 12% representing the electrical conversion portion [5].

**Conclusion**
Power production from local biomass resources can be a great benefit to remote communities. Imported diesel fuel for power and heating oil for buildings is very expensive. Even with subsidies, there is effectively an economic rationing of energy. New services, expanded business ventures and personal lifestyles are all limited by the high cost of energy and the limits to subsidies. Diesel generation contributes to greenhouse gas emissions, has associated smells and is noisy. Local forest resources can be used to displace fossil fuels if a suitable power system can be obtained. Small-scale biopower is required to meet the needs of the user and match the availability of the fuel. To meet this opportunity, a suitable system must be commercially available at an affordable price. Presently there are a number of technologies that can functionally address the opportunity. However at this time there doesn’t appear to be a system that is both cost-effective and commercially ready.

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**References**