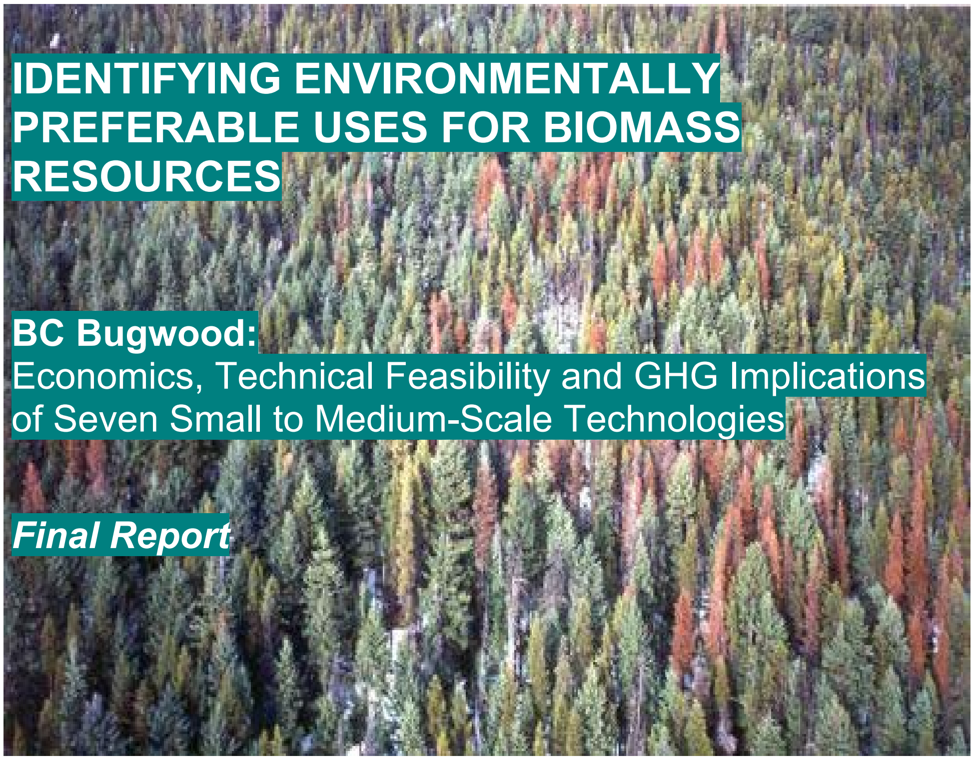

IDENTIFYING ENVIRONMENTALLY PREFERABLE USES FOR BIOMASS RESOURCES

BC Bugwood:
Economics, Technical Feasibility and GHG Implications of Seven Small to Medium-Scale Technologies

Final Report

Prepared for:

BC Ministry of Forests and Range
BC Ministry of Energy, Mines & Petroleum Resources

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The contents of this report reflect the research and opinions of the consultants only. They are not necessarily the opinions of the Government of British Columbia. Any errors or misrepresentations are the responsibility of the authors.

The selection of technologies covered in this report is not exhaustive. Both the choice of technologies and the depth to which they could be covered were dependent on budgetary limitations, the information available, and proprietary interests. The recommendations are therefore only applicable to the technologies examined and are not meant to imply that other technologies should not be used to manage pine beetle wood. The comparisons made between technologies in this report should be used cautiously as they cover a very broad range of applications which yield very varied products, and in practice additional aspects may weigh in on the ultimate choice of technology.

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EXECUTIVE SUMMARY

This study examines the technical and economic feasibility of converting the biomass resource in pine-beetle killed trees (bugwood) into energy products. Seven different technological approaches were examined: the Lignol process to make ethanol, small-scale CHP (combined heat and power), bio-liquid, cellulignin briquettes, gasification to make methanol, pipeline quality synthetic natural gas (SNG), and pelletizing. Of these processes only pelletizing is currently considered commercial in BC. The results of the overall analysis are given in **Table ES-1.**

Table ES-1 Feasibility of Bugwood-to-Energy Technologies

Technology	Cost-effective	Comments
Pellets	Some scenarios work, but not at high feedstock costs.	**Commercial.** Limited domestic market due to concerns about particulate emissions. Potential in UK at high prices, but un-quantified. Coal plant may want to buy pellets for image reasons; biomass is competitive with natural gas as a fuel
Cellulignin Briquettes	Local use works at lower feedstock cost	**Commercial in Brazil.** Depends on whether CL can be accepted as a substitute to natural gas in industrial and residential applications, and on natural gas prices.
CHP	Yes: off-grid, under 2 MW	**Pre-commercial.** Costing depends on technology; small CHP reviewed is a new BC technology.
	On-grid: Yes, at lower feedstock cost; only marginal at $40/m^3$	Depends on emission credits and RPP Incentive, as well as power sales price.
Bio-Liquid	No	**Pre-commercial.** High harvesting costs negate ROI; Bio-liquid market needs to be developed.
Ethanol	Yes, at lower feedstock cost	**Pre-commercial.** High uncertainty with respect to production cost and value of co-products; first demonstration plant in BC expected by 2007.
Methanol	Yes, with H_2 addition	**Conceptual.**
SNG	No	**Conceptual**; requires higher natural gas price to break even.

In this study it was determined that the economic feasibility of most of the technologies is very dependent on the harvesting (feedstock) costs. Our investigations determined that current harvesting costs are in the range of $40/m^3, however earlier work by the BIOCAP Foundation assumed a harvesting cost of $26/m$^{3.}$ To allow comparison with the earlier BIOCAP work and provide some sensitivity analyses, both harvesting costs were used in the evaluation of the various technologies in this report.

At the higher harvesting cost only niche applications of CHP off-grid and methanol production can yield a return on investment of at least 10%. To offset the high cost of harvesting, mixing bugwood with other, low-cost feedstocks such as hog fuel may provide enough cost reduction to make some of the technologies examined more economically viable. Similarly, directing some of the bugwood harvesting costs (e.g. silviculture, road and camp building) away from the conversion operations may be justified to encourage bugwood removal. How the bugwood harvesting costs are allocated between the forest industry, the provincial government and the technology proponent is one of the key issues to be resolved if bugwood is to be successfully utilized as a biomass resource. A successful program for using bugwood could act as a catalyst to “kick start” an expansion of a general biomass utilization industry in BC.

Other results that follow from this study are:

- Although some of the technologies appear to yield high returns at current product prices a detailed market analyses for the biomass products such as methanol, cellulignin etc. has not been conducted as part of this study. The ultimate success of these technologies will therefore depend on the future size of these markets, and prices that can be achieved for the products made from bugwood.
- Assuming that enough bugwood can be found at an average distance of 150 km from the processing plant, transport costs do not constitute more than 20-25% of delivered feedstock costs. On-site processing using mobile equipment may not result in cost advantages when compared to stationary processing.
- Transport costs for energy products made from bugwood are lower than for logs. For example, a tonne of methanol can be transported for about one-third of the cost of wood. However, life-cycle costs do not necessarily decrease due to lower transport costs, as processing costs can be substantial. The main reason for converting wood to other forms of energy, such as ethanol or methanol, is therefore not a cost reduction, but the opening of new markets for wood products.
- An additional benefit of developing a bugwood biomass infrastructure, is the possibility that it could be integrated with biomass that is currently flowing to landfills, and non-energy recovery wood waste (beehive) burners. Inclusion of these “waste” woods and even non-stem wood as feedstock could reduce the combined biomass feedstock costs and extend the life of the biomass facilities beyond that of the bugwood supply.
- More complex technologies with higher capital costs, such as the Lignol process or methanol production can yield higher returns than less costly technologies, such as bio-liquid production or pelletization. Whether a process yields the desired returns mainly depends on the market value of its products.
- The greenhouse gas emission reductions achieved by various energy uses of bugwood vary by a factor of three, between 0.5 and 1.5 tonnes of CO_2 per tonne of feedstock, between the various technologies. Higher emission displacements are achieved whenever high-carbon fuels, such as coal or automotive fuels, are displaced, and combined with a high conversion efficiency from wood to other fuels or energy types.

To encourage the development of an industry that uses bugwood and wood residues in BC, it is recommended that support be given to the further development of technologies which are close to being commercial. Likewise, mechanisms to encourage the harvest of bugwood should be investigated and implemented. Options may include reduced cut block license fees, or reallocating bugwood – good wood harvesting costs, so that it is still economic for the forestry businesses to remove all of the wood, even though they may not be able to use the low-value bugwood for their primary operations. This is already happening in BC with low-cost cut licenses granted to bugwood users that also include significant amounts of merchantable wood. In addition the “shelf life” of bugwood should be more accurately quantified to define how many years standing dead trees can be used as sawlogs, pulp logs, or even biomass.

This study further recommends the creation of a comprehensive bugwood-for-energy strategy for BC based on additional studies to identify markets, biomass energy facility locations, and coordination of the different approaches to bugwood utilization. The goal would be to use the bugwood resource; to enable accelerated rejuvenation of affected forests and to create new biomass energy industries that can source other forestry energy feedstocks to continue to function after the bugwood is no longer available.

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1 INTRODUCTION

In recent years, a mountain pine beetle infestation of unprecedented size and intensity has killed a large number of pine trees in the interior of BC. If the epidemic continues at its current rate there will be a large quantity of dead pine that will be unusable for traditional forestry products (called "bugwood" in this report).

While recently killed trees can best be used for higher-end uses in wood products manufacturing and the pulp & paper sectors, the quantity is overwhelming. It is expected that 400 to 500 million m^3 will remain unharvested by 2024 [Eng 2005], which is equivalent to the energy in 500 million barrels of oil (based on calorific value). The large amount of infested wood and the increasing amount that is too deteriorated for conversion to quality products suggests alternative treatments be considered. The authors believe that energy applications for bugwood may present a good way to utilize wood that cannot be used in higher-end applications. Energy solutions can offer social benefits, such as employment creation, and at the same time, contribute to BC's greenhouse gas emission reduction targets. Energy recovery from bugwood can mitigate the costs of bugwood management and forest rehabilitation, and prevent wildfires, even offering a net profit in some situations.

Previous work completed for the BIOCAP Foundation [BIOCAP 2005] focused on a very large-scale biomass plant (300 MW) to produce electricity in the BC Interior. This present report studies a range of decentralised options to address the bugwood problem. The technologies all focus on energy uses of the wood and were selected in cooperation with the BC Government. The technologies examined convert bugwood to:

- pellets (for energy use in industrial or residential applications);
- briquettes (with pre-hydrolysis);
- combined heat and power in distributed, small-scale facilities;
- bio-liquid;
- ethanol;
- methanol; and,
- wood gas, which is purified to natural gas pipeline specifications.

Combinations of the above technologies are possible. Care was taken during the analysis to determine the influence of pre-treatment of the wood on transportation costs. For example, a concentration of energy in the form of bio-liquid or briquettes will reduce the volumes to be transported.

Each technology is examined with respect to its commercial availability, its suitability for decentralised, mobile or semi-mobile applications (taking into account electricity and fuel autonomy and water or other process requirements), the economics and the markets for the main product and potential co-products. The analysis also addresses long-term financial viability issues by assessing the chances of securing feedstock for each plant mid-term using the bugwood resource and long-term from other forest and alternative biomass feedstocks.

Recent applications, pilot projects and research related to each technology are referenced in the report. For each technology, a greenhouse gas (GHG) analysis was undertaken that provides an initial quantification of emission reductions flowing from each process. Potential revenues from the sale of carbon offsets were included in the financial analysis.

Locations and potentials for each technology are derived as a function of the aforementioned parameters. Based on the findings, recommendations are made as to which technologies are most promising, and should therefore be favoured in a policy and R&D strategy to deal with the bugwood problem in BC.

Electricity grid emissions: A marginal emissions factor, as determined by ICF Consulting for each Canadian province, was used to calculate life-cycle CO_2 emissions from the processing plants discussed below. This factor (0.24 t/MWh) is an annual average of the marginal power production emissions in BC and reflects both hydropower and natural gas emissions.

Carbon credits: It was assumed that carbon credits could be gained from any of the technologies discussed. The future market value of these credits is unknown, but a value of $15 per tonne of CO_2 was used in the return on investment calculations if the end product was used in Canada. Only net life-cycle emission reductions were accounted for in the calculations. Additional carbon credits could be created for accelerated regrowth of trees after the bugwood is harvested, but this was not accounted for in this study.

Stumpage fees: This study assumes low stumpage fees, as the cost of harvesting wood is very high for any energy application. As energy is seen as a low-value use of bugwood, a high stumpage fee does not seem warranted. However, harvesting costs do include all ancillary costs, like road and camp construction, overhead, etc.

Electricity: BC Hydro's tariff for large industrial users, such as sawmills, is 2.73 ¢/kWh (January 2006). To account for the service charge, this was increased to 3.4 ¢/kWh for the calculations in this study. For power sales, a value of 6 ¢/kWh was assumed. This reflects past BC Hydro contracts with renewable energy providers, but more recent bidding rules may lead to slightly higher pricing. The avoided cost based on new natural gas combined cycle plants is likely to be higher than 6 ¢/kWh.

Natural gas: Terasen's industrial tariff for natural gas for 2006 is $10.10 per GJ, for the BC Interior, including delivery and administrative charges. This rate was used in this study to account for the price of natural gas.

Return on investment: The return on investment (ROI) was calculated using the Excel IRR function (Internal Rate of Return). The IRR only reflects overall plant economics. In reality, capital for a new plant is likely to come from different sources (i.e., equity, bank loans, etc.). A practical investment strategy of equity share investment with the balance being loan financed will produce a more attractive internal rate of return (IRR) than an overall ROI of 10% indicates. Capital was assumed to be available and was amortized over 10 years at a 10% annual interest rate.

Currency conversions: One Canadian dollar was deemed equivalent to US$1.20 and €1.40.

2 BUGWOOD AVAILABILITY AND DISTRIBUTION IN BRITISH COLUMBIA

2.1 Size of the Resource and Its Availability Over Time

The opportunity offered by bugwood in BC is a temporary one. As **Figure 2.1.1** shows, annual tree losses are expected to peak at about 90 million m³ in 2007, after which the epidemic is expected to slowly abate over time. The availability of bugwood over time will have major impacts both on the existing forest products industry, as well as on any solutions implemented to use the surplus wood made available through the pine beetle infestation.

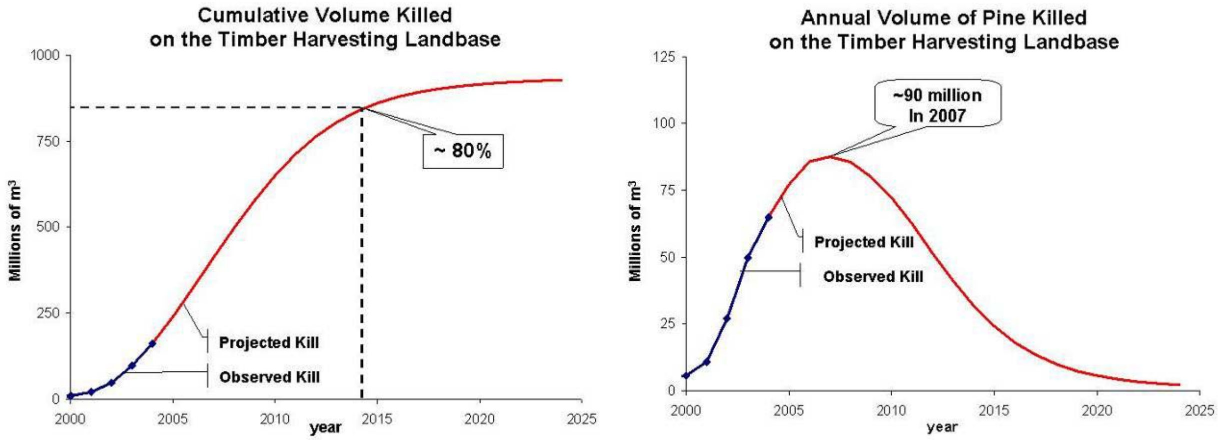

Figure 2.1.1 Cumulative and Annual Volumes of Bugwood [BCFS 2005]

Figure 2.1.2 shows that after a few years, dead trees dry out and decay sets in so that the wood is no longer suitable for higher-end uses, such as construction wood or furniture-making. It can, however, still be useful up to 15 years for the pulp & paper sector [BCFS 2005, p.21, reference scenario], and beyond for energy uses. Wood decays faster in moist zones (i.e., the shelf life across BC will vary from area to area), depending on the climate. Even where higher end uses are maintained, the relative waste production is likely to increase which may also pose problems.

Trees killed by pine beetles are not expected to be useful for sawmills after about five years – an assumption that still needs to be confirmed in the field. Older trees can still be used for pulp and paper (up to about 15 years) or energy purposes.

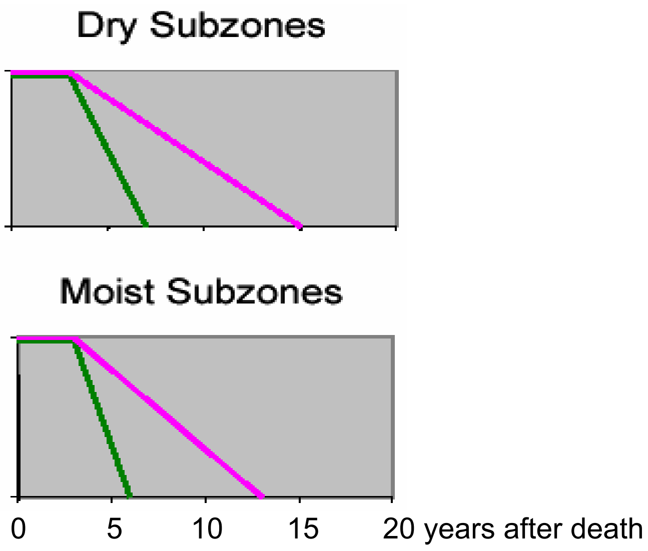

Figure 2.1.2 Shelf Life of Bugwood [BCFS 2005]

Not only is the phenomenon of bugwood, at this scale, a temporary one, but the limited "shelf life" of the wood once a tree has been killed also poses logistical problems. Note that the actual shelf life of bugwood is not very well established yet and that research is on-going to determine better shelf life parameters. Some trees will still be standing much longer than 15 years (i.e., the assumption that nothing can be harvested after 15 years may be a conservative one). However, additional trees may be lost due to forest fires and windstorms, which will shorten the availability period in addition to the loss of trees that have fallen.

The BC Ministry of Forests has modelled the availability of bugwood over time for the 21 affected Timber Supply Areas, using the following four categories:

1. ***Live Pine:*** merchantable and susceptible pine that has not been killed by mountain pine beetles;
2. ***Sawlogs:*** Dead pine that has been killed recently enough that it is suitable for the manufacture of dimensioned lumber products;
3. ***Chips:*** Pine that has been dead long enough that it is no longer suitable for dimensioned lumber products but is still useable for "alternative" products such as pulp, oriented strand board or bio-fuel; and,
4. ***NRL (Non-recovered loss):*** Pine that has been dead for so long that it is no longer useable even for alternative products.

The last category could still contain material suitable for energy uses but may require technologies that are to be discussed in this report.

In **Figure 2.1.3**, the "Logged NRL" category represents the volume of residue without commercial value that will be logged alongside sawlogs in harvested blocks. This volume must be logged alongside the commercial wood because it will be intermixed with sawlog and chip volume. Likewise, the Logged Chips are considered a by-product of sawlog harvesting, which is assumed to be the primary activity. The harvested sawlogs and chips are harvested within the current Annual Allowable Cut. The dark shaded areas in the graph represent wood that is not harvested under current scenarios, and thus, lost to any commercial use after some time.

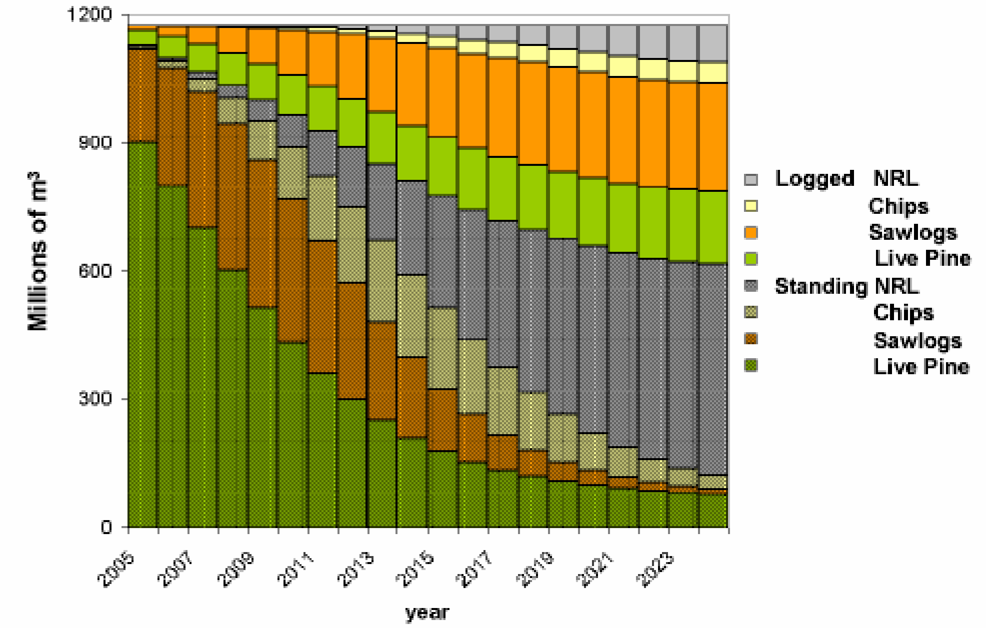

Figure 2.1.3 Predicted Fate of Bugwood on the BC Timber Harvesting Landbase [BCFS 2005]

Within the coming twenty years, the amount of recoverable sawlogs and chips from bugwood stands will be reduced to very small amounts, whereas, the “non-recovered loss” increases to a very large amount (between 400 and 500 million m³ by 2024). However, as mentioned above, the condition of old bugwood stands deteriorates to a degree that harvesting may become more difficult or even impossible after some time. The shelf life for energy related uses of “non-recovered loss” bugwood is therefore determined by the ability to successfully harvest the wood before it becomes too brittle, falls and rots, or is destroyed by wildfire. Safety concerns due to breaking branches during harvesting can also preclude traditional harvesting techniques and commercial use of such low-value bugwood. Increased breakage during harvesting can pose safety risks in some cases, and results in increased handling costs and less recovery, translating into higher costs.

Assuming that, according to **Figure 2.1.4**, bugwood is no longer harvestable after 15 years and that the resource is reduced by 1/11 each year through decay beginning in the fourth year after a tree dies, **Figure 2.1.4** shows the cumulative availability of bugwood expected in the BC Interior. The graph assumes that 35 million m³ of bugwood are harvested between 2005 and 2015, with harvests reduced to pre-epidemic levels by 2016 and further reduced by 19% by 2020. Only the surplus resource (not harvested at current levels) is shown. It becomes obvious that the resource is a very temporary one, peaking in 2011 and then dwindling again to reach fairly low levels by 2020. Initiatives involving new technology or adaptations of existing approaches may require some years to be implemented. This suggests that any approach to utilize the bugwood resource should be gauged to a duration of ten years. However, it is not known whether the pine beetle infestation will continue after 2024. If new pine is being infested after this date, more bugwood will continue to be created, which could continue to be used for sawlogs, chips and energy purposes, albeit in much smaller quantities.

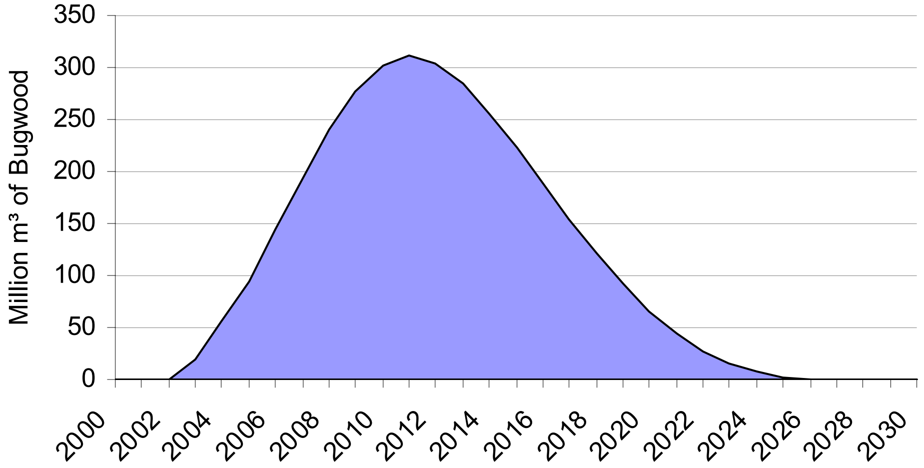

Figure 2.1.4 Cumulative Availability of Still Harvestable Bugwood Not Expected to Be Harvested at Current and Future Harvest Levels (assuming trees can no longer be harvested 15 years after they die)

To manage the bugwood problem, the BC Forest Service has increased the Annual Allowable Cut (AAC) by so-called “uplifts” defined for several Beetle Management Units. Even with the recent uplifts, it is expected that much more bugwood will remain unharvested unless other uses can be found.

The Emergency Bark Beetle Management Area is determined on an annual basis using aerial overview information. Ministry surveys indicated the mountain pine beetle affected about seven million hectares of the province in 2004 [BCFS 2005]. Of this total, about two million hectares showed trace amounts of attack, meaning that less than one per cent of the trees in a mapped area have been killed recently. The other five million hectares represented light-to-severe levels of attack (anything greater than one per cent). This means that there will be areas with very high concentrations of bugwood, and others with low concentrations, suggesting the use of mobile installations to process the wood in various locations in order to recover its energy. Box 1 identifies some issues with using bugwood instead of “green” wood from healthy trees in sawmills – although the ability to use bugwood in sawmills will vary based on the end product being manufactured and the degree of deterioration of the log. Conventional uses of the wood are working at full capacity at the elevated cut level [CFS 2004]. It would also be an unsustainable strategy to let this industry grow in the short term, seeing that the bugwood resource is finite and job losses are likely to ensue in the future, once the resource is used up: Current estimates of timber supply are that after 15 years (2020) the AAC will drop 4.5 million m³ below pre-outbreak levels [*ibid*.].

Box 1 Problems with Using Bugwood in Sawmills

It has been noted that mill workers change their sawing practices when processing beetle-killed pine. The sawyer intentionally slabs heavier than normal to remove the outer sapwood, and edging methods are altered. Grade recovery and lumber yield are thus substantially reduced. Walters and Weldon (1982a) reported that trees dead for 90 days in east Texas yielded 75 to 79 percent as much lumber as green sawlogs. Trees dead for 180 to 360 days did not appear economical to utilize.

The lower initial moisture content of veneer from beetle-killed timber in combination with the increased permeability (due to effects of blue-stain fungi) results in overdried veneer when dried at normal green veneer schedules. Glue-line quality tests indicate that normal drying schedules, adhesives, and gluing practices may require modification to process beetle-killed timber. Best results could be achieved if veneer from bugwood could be segregated and processed separately. This special handling would be justified if a sufficient volume of bugwood were processed.

Source: www.barkbeetles.org/spb/UBKSP/UBKSPSVP.html

Realizing this context, on April 14, 2004, the BC Government issued a request for expressions of interest to utilise the bugwood in the Quesnel, Vanderhoof and Burns Lake areas. It was estimated that an additional 40 million cubic metres could be available in these areas over the next ten years. Following this call, C.H. Andersen was granted a license in 2005 to harvest 10.5 million m³ of bugwood in the Prince George and Quesnel timber supply areas, over a period of ten years. The company intends to build up to four pellet plants in the BC Interior, and ship the pellets by train to Squamish for export to Europe. Two other 15-year forest licences, totalling 21 million m³, were awarded to Ainsworth Lumber for the production of oriented fibreboard.[1] This represents about 50% of the 4.7 million m³ uplift (annual) in the Quesnel/Vanderhoof area.

2.2 Harvesting of Bugwood

Pine stands are usually intermingled with other species of trees. This means that any activity to increase the harvest of bugwood will also increase the harvest of other tree species unaffected by the pine beetle epidemic: on average, for every 0.75 m³ of non-recovered losses (bugwood) that are saved by increasing harvest levels, 1.0 m³ of non-pine volume is harvested as an “incidental by-catch”. At current harvesting levels, the Ministry of Forest [BCFS 2005] assumes the harvest in the 21 affected Timber Supply Areas over the next 20 years will consist of:

Non pine:	490 million m³
Live pine:	170 million m³
Sawlog quality dead pine:	250 million m³

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[1] http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/ads.htm

Chip quality dead pine:	50 million m³
Dead pine residue (NRL):	90 million m³

Table 2.2.1 provides an idea of the distribution of pine and non-pine stands in BC. About one-third is predominantly pine (90% and more), and another third is predominantly non-pine, with the remainder being fairly equally mixed. Some of the most affected areas, such as Quesnel, have a very high percentage of areas where pine is predominant, but others are more mixed. Taking these facts into account suggests that any bugwood salvage strategy will have to consider the transportation of both the bugwood or pre-treatment products (e.g., bio-liquid), and more valuable wood from living trees that are harvested along with the bugwood. This may, in some cases, require a dual transportation system.

Table 2.2.1 Percentage of Pine Stands in BC [BCFS 2005]

Percent Pine	Entire Susceptible Area	Arrow TSA	Quesnel TSA
Low (<40%)	33%	69%	14%
Moderate (40 - 89%)	32%	25%	27%
High (90 - 100%)	36%	6%	58%

The Ministry of Forests expects that 80% of susceptible pine will have been killed in BC by 2014. With a (sawlog) shelf life of 3-4 years, none of this wood will be available for sawmills after 2017/18. This again means that harvesting after that date would concentrate on valuable other species (live trees), with low-value bugwood as a “by-catch”. Note also, that under the current Annual Allowable Cut (AAC), only 90 million of the 580 million m³ of “non-recovered loss” (NRL) bugwood is expected to be co-harvested with sawlogs, chip wood and other tree species (based on government projections, see **Figure 2.1.3**). The use of bugwood may therefore remain an add-on to higher-end wood uses, apart from some areas with a combination of very high pine concentrations and high mortalities. This means that, unless ways can be found to increase the AAC, possibly while minimizing the harvest of non-pine species through selective bugwood harvesting, most of the “non-recovered loss” will, after some years, indeed be lost even to energy-based uses.

According to Canfor, a large-scale logging operation will harvest about 8,000 m³ of wood per day [Canfor 2005], with a maximum skidding radius of 300 m [COFI 2005b]. Logging will continue for most of the year in day shifts. The maximum amount of low-quality bugwood harvested in any given day will be less, depending on the local pine cover and the percentage of pine affected by the pine beetle infestation. Logging mainly takes place during the winter months, from June through March, whereas between March and the end of May, little or no logging occurs. In some areas in BC, logging may also be reduced or stalled during the summer months (June to September), depending on local and weather conditions. This means any energy use, based on bugwood that continues throughout the year will require fuel storage, or the use of alternative fuels, for at least two to three months per year. On-site wood processing during the night (in three shifts) could increase accident risks, and may interfere with life at a wood harvesting camp in cases where three-shift harvesting does not take place (e.g., Canfor operations). Many harvesting operations also do not continue during weekends. It is therefore possible, in some cases, that equipment used to pre-process wood on-site can only be used for about 180 day-shifts per year and would have to be run at very low utilization factors.[2] On the

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[2] 180 days x 8 hours = 2,000 hours, (i.e., a 16% capacity factor). Higher utilization factors are often encountered in BC. According to FERIC [FERIC 2006], annual equipment use for harvesting operations is between 2,800 and 3,200 hours per year in BC, which corresponds to a capacity factor of 34%.

other hand, many operations do run two shifts of 10 to 12 hours during peak harvesting time, or even three shifts, which will lead to higher capacity factors.

Table 2.2.2 shows the daily bugwood harvest expected in the 23 pine beetle units (more than 10% of tree cover is pine today) per cutting crew when assuming that 8,000 m³ are harvested per day by one crew. The last column shows the amounts of bugwood expected to be delivered from each harvesting operation, which provides an indication of the size of operation required to process this wood. The year 2011 was chosen as the reference year because in many areas, standing "dead chips" bugwood will peak around 2011. Non-harvested wood will still be in a good enough state to be harvested for energy purposes, and some of the technologies examined in this report are expected to be commercial by this time. Note that some uplifts have been defined for some of these areas, such as Quesnel, such that the total standing dead chips may be somewhat reduced by 2011 over what is shown here based on the October 2004 AAC.

Table 2.2.2 Percentage of Pine Stands in BC and Resulting Daily Harvest* per Cutting Crew in 2011 [based on Eng 2004, using AAC on October 1, 2004]

Beetle Management Unit (BMU)	Percent Pine (live and killed)	Standing NRL + Dead Chips	Average Daily Bugwood Harvest
Vanderhoof	68%	42.5%	3,400 m³
Lakes	61%	27.5%	2,200 m³
Quesnel	67%	46%	3,680 m³
Merritt	57%	5.2%	416 m³
100 Mile House	52%	13.4%	1,072 m³
Williams Lake	54%	19.5%	1,540 m³
Cranbrook	44%	3.4%	275 m³
Boundary	29%	0.7%	54 m³
Morice	37%	4.6%	364 m³
Lillooet	35%	1.5%	121 m³
Ft St James	38%	8.5%	683 m³
Invermere	33%	3.3%	265 m³
Kamloops	23%	4.1%	336 m³
Arrow	13%	3.0%	244 m³
Okanagan	24%	1.6%	127 m³
Mackenzie	39%	0.6%	46 m³
Kootenay Lake	20%	1.8%	145 m³
Bulkley	15%	0.6%	50 m³
Prince George	25%	11%	897 m³
Golden	11%	1.7%	135 m³
Robson Valley	9.4%	0.9%	73 m³
Cranberry	6.6%	0%	0 m³
Dawson Creek	24%	0%	0 m³

* Assuming a total harvest of 8,000 m³ per day, including other species and pine sawlogs.

From the calculations in **Table 2.2.2** it can be seen that the maximum average daily bugwood harvest will be between 3,000 and 4,000 m³. This is based on a typical daily harvest for some paper and large sawmills. On average, BC sawmills will use about 1,300 m³ of wood per day, and there are many smaller operations as well. The numbers show, however, that a small mobile unit processing about 20 bdt of bugwood per day will not be sufficient to deal with the amounts harvested. 3,000 m³ corresponds to 1,140 bdt per day, which reflects a medium to large-scale operation.

2.3 Transportation Options and Infrastructure

Infrastructure requirements to cheaply transport bugwood create special challenges in the BC Interior. There are railways in many areas, such that the maximum distance (straight line) to the nearest railway is no longer than 200 km (see **Figure 2.3.1**), although there are only certain loading points where goods can be transferred from truck to rail. No navigable rivers exist in the BC Interior, although some lakes may be used for the local transportation of wood. The cheapest way of transporting the resource long-distance to other locations would be:

- Rail transport to the Pacific Ocean, which is reachable by rail through Squamish, Vancouver, Kitimat, or Prince Rupert, combined with shipping over the ocean;
- The railway system, which links up with Vancouver and other BC cities, as well as with Alberta and the U.S.; and,
- The natural gas pipeline system, if wood can be gasified and the wood gas purified to pipeline quality standards.

Figure 2.3.1 The BC Railway Network
Extends from Vancouver to the BC Interior and north, also west to the Prince Rupert seaport. It is also connected to Alberta in four places (Source: BC Rail).

Figure 2.3.2 7-Axle Logging Trucks Are Used in BC (left), as well as Chip Trucks (right)

Figure 2.3.3 B-Train (model)

Before biomass feedstocks or bioproducts can be shipped by train, ship or through the pipeline system as wood gas, they need to be taken out of the forest by truck. Five options exist for truck transportation:

1. Transport of harvested logs by logging truck (**Figure 2.3.2**);
2. Transport of wood chips by chip truck (**Figure 2.3.2**);
3. Transport of pellets by pellet truck (**Figure 2.3.3**);
4. Transport of briquettes by truck; or,
5. Transport of bio-liquid, ethanol or methanol by tanker truck.

Table 2.3.1 Truck Transportation Limiting Parameters

Truck type	Max. biomass load	Max. biomass volume	Resulting max. load
Logging truck	(gross wt: 55 t)	50 m³	50 m³/19 bdt
Pellet truck (B-Train)	38 t	170 m³	58 m³/38 t
Fuel tanker (liquids)	42.5 t	53,500 l	42.5 t

With Option 1 being the default option for hauling logged wood, Options 3, 4 and 5 offer reduced transportation costs through a concentration of the energy in the original bugwood feedstock through a variety of pre-treatments. For bugwood, Option 1 may require modification to current trucks due to the fact that older bugwood is often too brittle to transport long stem wood on a conventional logging truck, as some of the stems might break. On-site chipping will remove this problem, but is generally more expensive than chipping at the plant. Chipping will also increase the volume of the wood, which is undesirable due to higher transport costs. Another problem is that 70% of the resource is only accessible through “bush roads”, which are not accessible to tanker or chip trucks – especially the last part of the road which links up with the on-going harvesting operation [COFI 2005b]. It may be possible to use tractors to transport bugwood logs a short-distance in the case of smaller-scale operations.

For biomass energy applications, the maximum truck transport distance is generally considered to be around 70 km [Concawe 2002, p.13]. Adding in any feedstock harvesting costs may mean that it is impossible to economically use bugwood as a biomass energy feedstock. It is one of the objects of this study to examine the relationship between license, harvesting and transport costs, treatment costs and investment, and processing costs in order to determine if any combination of parameters allows for the cost-effective salvage and decentralized use of bugwood.

2.4 Moisture Content and Other Parameters

Another important parameter influencing the ability to process bugwood is its moisture content. Freshly harvested green wood usually has a moisture content of between 45% and 55% (wet basis). Bugwood (i.e., dead trees), are likely to have lower moisture contents as the tree will dry out to a degree once it dies. The average moisture content of bugwood assumed in BIOCAP 2005 was 13% (dry basis). This was considered too low by some reviewers (see Appendix E of BIOCAP 2005) and a correction to up to 30% (year-round average) was suggested. (30% moisture dry basis equates to 23% moisture wet basis.) Based on experience in BC and other regions in the Pacific Northwest, it was determined that the water content of bugwood can drop to under 17% (wet-based) after just one year. However, in PAPRICAN's experience, water content of wood from trees that have been dead for between five and ten years varies between 20 and 25% (wet-based) [BICHO 2005]. Canfor (Vanderhoof) found that four-year old bugwood will have a water content of 19% (wet-based), and possibly less after a longer time period [Canfor 2005]. We have used 20% (wet-based) as the value for water content for bugwood in this study, which seems a good average number based on current knowledge. Such a water content is low in comparison to green wood (45-55%), but may still require pre-drying for some of the biomass processes discussed in this report.

Table 2.4.1 compares several input parameters used here with those used in previous work in order to identify the source of possible discrepancies in the results obtained. Many of the values for this study were obtained from experts in the field, such as COFI, or logging companies.

The higher heating value of Lodgepole Pine Wood was determined assuming that 10% of the wood is bark [BRIGGS 1994, Ch. 7], and with differing higher heating values for bark and inner wood [*ibid*. Ch. 9]. It is possible that age will reduce the heating value of bugwood due to the loss of volatiles. This factor should be quantified and taken into account before the first processing plant is built.

As dead trees are standing, other changes than just reduced water content may occur that affect wood texture and chemical makeup. For example, the amount of volatiles in wood may be reduced, affecting technologies like gasification and pyrolysis that try to extract volatiles from wood. As research projects are still on-going, these effects could not be quantified for this study, but should be considered when a demonstration project is planned. **Table 2.4.2** summarizes the chemical parameters of wood with 20% moisture content.

The energy conversion based on dry weight or volume used for this study is:

$$1 \text{ m}^3 = 0.38 \text{ bdt} = 7.71 \text{ GJ (HHV)}$$

Table 2.4.1 Comparison of Study Input Parameters

Parameter	BIOCAP 2005b	This Report
Capital interest rate	10%	10%
Amortization period	20 years	10 years
Bugwood moisture content (at harvest)	13% (dry basis)	20% (wet basis)
Harvest per hectare	86.2 m³	71.8 m³
Delimbing	excluded	Included
License fee	Not included	Included
Harvesting cost	$68.55 per bdt	a) $68.55/bdt and b) $40/m³ ($105/bdt)
Log hauling cost	$15.4 per bdt (48 km)	$1.96/tonne-hour
Higher Heating value of wood	20 GJ/bdt	Bark: 23.42 GJ/bdt Wood: 19.94 GJ/bdt Average: 20.29 GJ/bdt
Ash in wood	2.5%	Bark: 3.0% Wood: 1.6%
Dry weight of pine wood	0.38 t/m³	0.38 t/m³

Table 2.4.2 Assumptions on Feedstock Composition

Feed Analysis	kg/kmole	Weight		$\text{kmoles/kg}_{\text{feed}}$	Volume
		(dry)	(wet)	0.0790	100%
Carbon C =>	12	50.00%	40.00%	0.0333	42.17%
Hydrogen H_2 =>	2	6.00%	4.80%	0.0240	30.36%
Oxygen O_2 =>	32	42.00%	33.60%	0.0105	13.28%
Nitrogen N_2 =>	28	0.35%	0.28%	0.0001	0.13%
Ash =>		1.65%	1.32%		
Water H_2O =>	18	0.0%	20.00%	0.0111	14.06%
			12.484	$\text{kg/kmole}_{\text{feed}}$	

3 HARVESTING AND TRANSPORT COSTS

3.1 Harvesting Costs

Harvesting costs, including replanting, road and camp construction, overhead and loading, are given by industry as $40 per m³ of wood [COFI 2005b]. **Table 3.1.1** lists the entire harvesting cost, including bidding cost and stumpage fees, as compared to harvesting costs determined in BIOCAP 2005. As low-value bugwood has no value as chips or sawlogs, it is classified as Grade 3 or lower, i.e. the stumpage fee is very low. The bidding cost is modelled on a recent bid by a pellet manufacturer, assuming that it remains low in the interest of finding bidders that can use the resource in order to enable regrowth of new, healthy trees.

Table 3.1.1 Harvesting Costs

Harvesting Cost	Source	$/m³	$/bdt
Felling, Skidding, Delimbing, Silviculture, Road and Camp Construction, Overhead*	COFI 2005a	40	105
Bidding cost**		0.13	0.3
Annual license and stumpage fees	(Grade 3 wood)	0.37	1
TOTAL		**40.50**	**106**
Felling, Skidding, Delimbing, Silviculture, Road and Camp Construction, Overhead	BIOCAP 2005	**26.05**	**68.55**

* Office operations, environmental protection, consultant fees, archaeological surveys engineering etc.

** Based on recent CH Andersen bid

There is a marked difference between the harvesting costs determined in BIOCAP 2005 and the cost determined here based on industry information. The higher harvesting cost seems excessive compared to other types of biomass, but comes from industry practitioners. A forthcoming report from the Pacific Forest Centre [PFC 2005] determines a harvesting cost of $75.44/bdt, which lies in-between the values discussed. The actual harvesting of bugwood logs, and skidding them to the roadside, costs over $16/m³ [PFC 2005] - slightly increased for bugwood due to the use of deckers etc. (see below). Several other circumstances make harvesting more expensive in BC:

- Environmental regulations do not allow harvesting in conditions when the ground is too wet as the vegetation would be destroyed through the harvesting equipment. Such weather conditions occur more and more frequently in BC due to warmer winters, which means the ground does not freeze. Also, as many trees die in an area, water uptake from trees is reduced in the summer, leading to wetter ground conditions between June and September in the BC Interior. Any interruptions in harvesting activity make it more expensive to salvage wood.
- Harvesting costs tend to be slightly higher for bugwood as it cannot always be harvested using conventional methods. For example, a decker (buttn-top log loader) may be required to harvest the trees, instead of a just skidder, increasing equipment costs. On the other hand, increasing the amount of wood harvested by including bugwood may reduce overall road construction and camp costs.
- Transportation costs can also be affected, as wet roads are less stable and the maximum payload for trucks cannot always be achieved.

FERIC has made some initial cost estimates for the delivered cost of bugwood and arrived at $37 to $43 per m³, including transport costs [FERIC 2006]. However, including all overhead costs and the other factors mentioned above may take this to $50 as quoted here. More cost analysis, and especially research to reduce harvesting cost, would be helpful to tackle the bugwood resource.

It is the aim of this study to remain, as much as possible, within the same parameters as the BIOCAP study [BIOCAP 2005] in order to allow comparisons. As harvesting cost has major impacts on plant economics, the BIOCAP cost of $68.55 per bdt is retained for the following chapters. Sensitivity analysis in Chapter 5 models the higher harvesting cost of $40 per bdt. There are some options to influence feedstock harvesting costs, some of which are discussed in Chapter 6. More analysis on this aspect would be beneficial to establish true costs and find alternatives to reduce feedstock costs for energy uses of bugwood.

3.2 Transport Costs

The delivered cost of wood is about $50 per m³, at a distance of 110 km one-way [COFI 2005a]. With a cost of $9.00 per m³ for transportation at this distance, transportation is only 25% of the delivered cost, with the actual harvesting operation accounting for nearly three-quarters of delivered cost (see **Figure 3.2.1**). This means that reducing transport costs may only have a minor effect on overall process economics, depending on the haul distance. Overall, the cost of delivered wood is very high in comparison to other alternatives, such as coal.[3] Note that transport cost may be somewhat higher for rotten bugwood as the maximum volume for a logging truck may be reached earlier than with green wood (i.e., the tonnage transported will be smaller). Each transfer of logs from truck to train etc. will entail further costs of $4 per m³ [*ibid*.].

Table 3.2.1 Transportation Cost for Selected Options

One-way trip distance	Cost
Logging truck	$4/m³ (loading/unloading) + $0.13/t-km
Transfer truck to train	$3.80/m³ or $10.00/bdt [FSBC 2004]
Transfer train to ship	$5.43/m³ or $14.30/t [DRC 2005a]
Pellet truck (B-Train)	$0.093/t-km, incl. loading/unloading [LOMAK 2006]
40-ft container (truck)	$0.044/t-km
Tanker truck	Ethanol/Methanol: $0.04/t-km [BT 2006] Bio-liquid: 0.0635 ¢/t-km + $10/t (loading/unloading) [GE 2006]
Transfer train/ship	Transfer and storage of oil at harbour: $30/tonne [VW 2005]
Rail transport (bulk)	$0.022 – 0.028/t-km [CNR 2005]
Rail transport (logs)	$0.027/t-km [CNR 2005]
Rail transport (liquids)	Methanol/ethanol: $0.045/t-km Bio- liquid: $0.048/t-km [CNR 2005; GATX 2006]
Rail transport (40 ft container)	$0.032/t-km
Ship transport	Pellets: $54/t [GSC 2005] (to EU harbour only) 40-ft container: $60/t (Shanghai); $179/t (Hamburg)

Table 3.2.2 details the costs of various transport options, based on quotes received from CN Rail and freight companies. Train transport can apply to either logs, pellets, briquettes or liquids, such as bio-liquid. CN Rail was not able to identify loading points throughout the Interior, but indicated that there are several privately-owned and CN Rail-owned facilities that could be used to load rail cars. The nearest possible location would have to be determined based on the location of the processing plant. The costs of rail transport assume a load of 170 m³ per rail car (closed wood chip gondolas) for pellets. Ship transport out of Vancouver to Europe will cost

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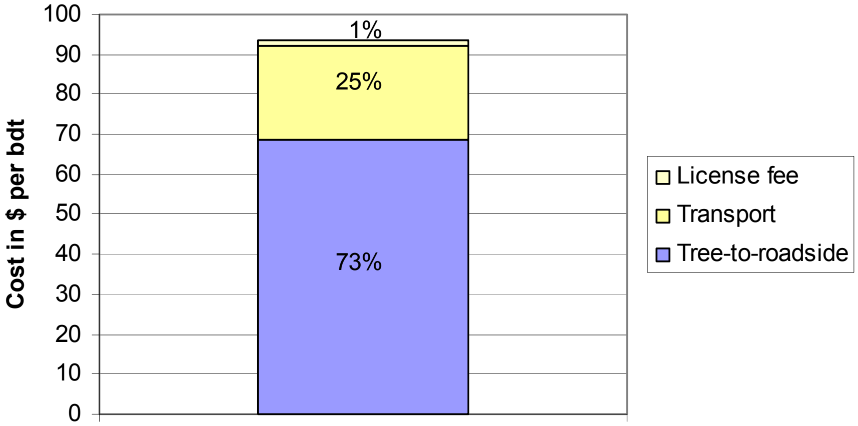
[3] $50 per m³ corresponds to $132 per bdt, compared to only $33 per tonne for coal [BCH 2004]

US$40 to 50 per tonne for bulk products, such as pellets [GSC 2005], not including transfer from trains or additional costs to transport pellets inside Europe.



Based on $68.55/bdt harvesting cost.
License fee: $0.37/m³ stumpage ($0.25/m³ for low-grade wood, see FSBC 2004) and annual license fee + $0.12/m³ assumed bid price for 10-year license, based on CH Anderson bid [BCEIA 2005]

Figure 3.2.1 Composition of Delivered Cost of Wood (Transport Distance: 100 km)

Table 3.2.2 Parameters for Transport

Type	Capacity	Fuel use	Energy use
Logging truck	80 m³/30.4 bdt	0.45 l/km [UU 2003]	16.4 MJ/km
B-Train pellet truck	42 t		
Tanker truck	35,000 l/35 t		
Logs (train)	100 t	0.0034 l/t-km [RAC 2004]	0.124 MJ/t-km
Woodchip gondola (train)	6,000 ft³		
Tank car (train)	88 t		
Ship (solid bulk fuels)	47,000 t or 78,000 m³ [UU 2003]	2,176 MJ/km (HHV) [UU 2003]	See fuel use
Ship (liquid fuels)	70,000 t or 80,200 m³ [UU 2003]	2,651 MJ/km (HHV) [UU 2003]	See fuel use
40-ft container	20 t/2,500 ft³		

Looking at a map showing the major centres in the BC Interior, it becomes obvious that it is unlikely that harvested bugwood would have to be transported further than 100 to 200 km in order to reach a town, where a processing plant can be set up that can be run with grid electricity. The option of setting up small, mobile plants at the harvesting site seems difficult to realise because

- the amount of bugwood harvested per day (more than 1,000 bdt) can easily exceed the capacity of a small plant (10-20 tonnes per hour, i.e. some 100 t per day in one shift);
- in some cases, plant economics might be negatively affected by the need to work in only one or two shifts;
- logging roads leading to the deck are often not of good enough quality to allow vehicles other than logging trucks to access these areas; and
- as it is envisaged to link bugwood uses to existing, large-scale harvesting operations, the scale of operation (at least 100,000 tonnes per year) dictates the use of grid electricity and stationary installations.

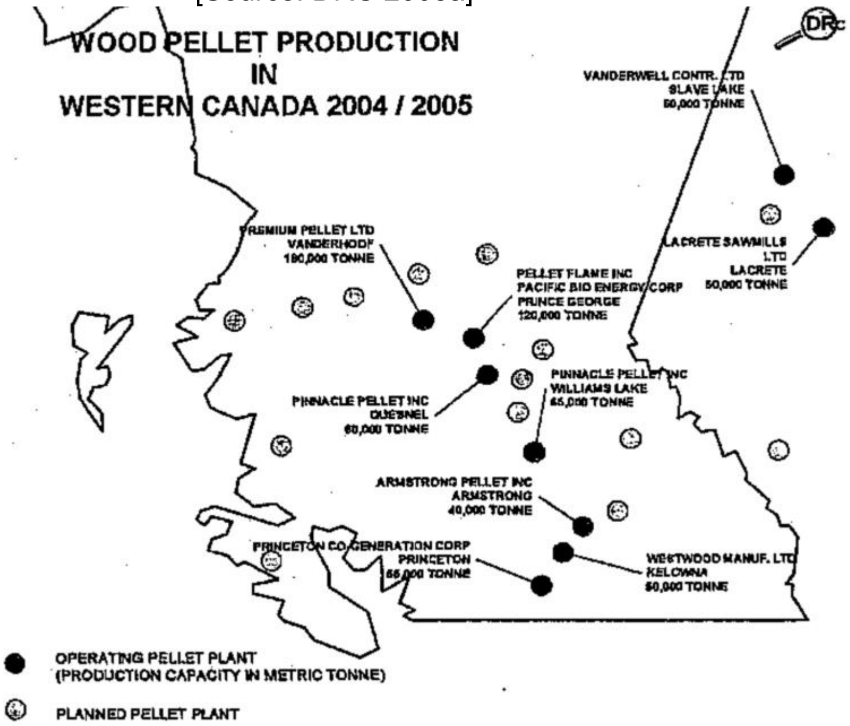
4 PROCESSING BUGWOOD

4.1 Pelletizing Bugwood

4.1.1 Process

Pelletizing serves two purposes: the concentration of energy in wood, providing an advantage in transportation over roundwood and chips, and creating a fuel that burns longer and is easy to handle in combustion applications. Pellet production from wood is already being practised at many sites in BC (see **Figure 4.1.1**), and in 2005, a license was granted to CH Anderson to produce pellets from bugwood for export to Europe (UK).

Figure 4.1.1 Wood Pellet Production in British Columbia (existing and planned capacities)
[Source: DRC 2005a]



There is no Canadian standard defining the quality of pellets, but to be fit for use in the U.S. or Europe, pellets need to have a maximum moisture content of 10% (wet basis), which will require drying in most cases, pending further results from on-going research on the physical properties of bugwood. The bark needs to be removed as it would increase ash content beyond what is acceptable according to international standards. It is envisaged that the bark is burned to create process heat for pre-drying of wood. To make pellets from wood, the wood needs to be ground into pieces smaller than 3 mm, which cannot be achieved with a chipper. A hammer mill is therefore included in the process diagram (**Figure 4.1.2**), which will deliver the right particle size.

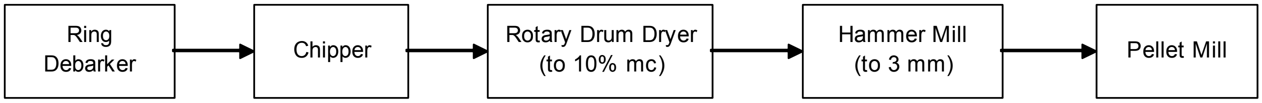


Figure 4.1.2 Pellet Mill Process Diagram

Since chip or pellet trucks have difficulty accessing logging sites, the use of a mobile pelletizing plant (see **Figure 4.1.3**) that moves with the harvesting operation is not envisaged. Instead, logs will be loaded onto logging trucks and transported to a stationary pellet plant with access to the electricity grid.

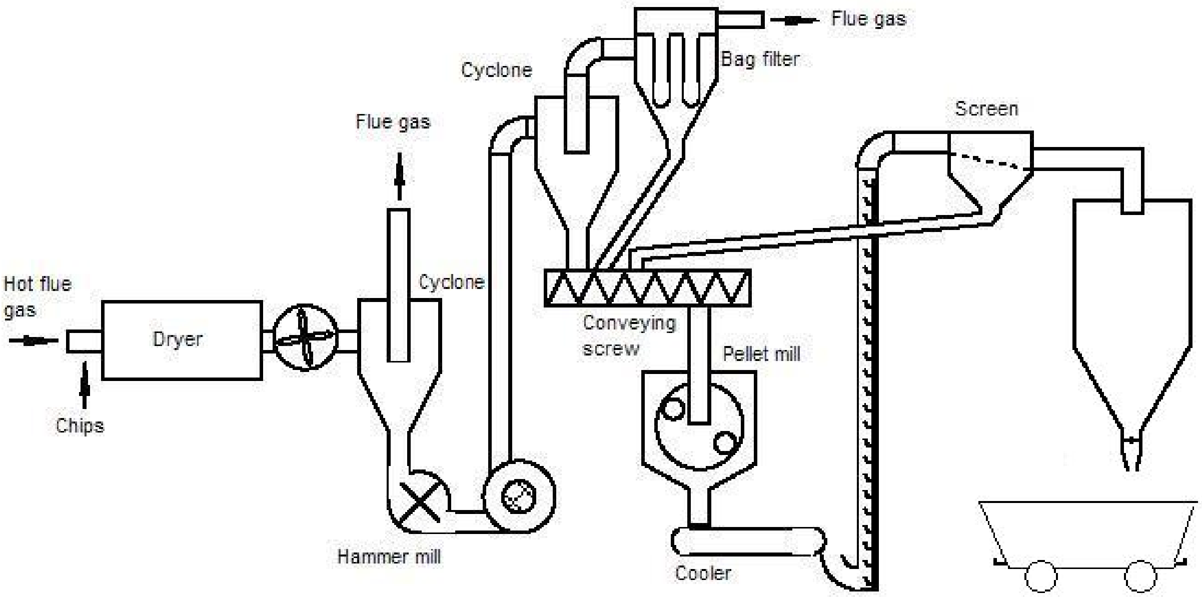


Figure 4.1.3 Pellet Plant (adapted from BfE 2001)

Pellet mills use a roller to press the wood through a die. Under high pressure, the wood temperature reaches 100°C, which makes the lignin in the wood turn liquid, acting like a glue that provides for cohesion of the pellets. In some cases, additives need to be used to improve pellet quality – it is not expected that this is necessary when low-quality bugwood is used as a feedstock. Silos would be used to store pellets (one day's production) before they are filled into a pellet truck or into train cars.

Pellets would be transported in bulk, but could be bagged for retail close to the retail location. Currently, pellets are exported from BC to Europe, where some governments provide subsidies for biomass power plants. Instead, they could also be used in power plants in Canada, or sold to households for use in pellet stoves.

4.1.2 Energy Balance

According to Forintek, more than 90% of softwood harvested is debarked with ring debarkers in Canada, and between 7 and 15% of wood is lost during debarking of dry Black Spruce [FOR 2005]. Assuming that the average bark content of Lodgepole Pine is 10% [BRIGGS 1994, Ch. 7], this is the share used here to make assumptions about the availability of hog fuel from debarking. With an energy content of 23.42 GJ/bdt (HHV) for bark, about 2.34 GJ of energy are available as bark for each dry tonne of wood processed. This is more than enough for what is required for drying: assuming an energy requirement of 2,200 Btu per lb of water, drying from 20% to 10% water content would require 484,000 Btu or 0.51 GJ per bdt of wood.

A large-scale harvesting operation in BC will produce 8,000-10,000 m³ of roundwood per day, with individual contractors accounting for about 1,200 m³, which may come from several harvesting sites. This means that throughputs must be able to cope with a quantity of at least

500 m³ per day from an individual operation, or up to more than 3,000 m³ per day from the combined output of all contractors (see **Table 3.1.1**). The design plant size is therefore 1,000 tonnes per day (250,000 t/yr, assuming 250 work days) – larger than existing pellet plants in BC today (50,000 to 180,000 t/yr). The plant could be operated in three shifts as it is not situated near the logging operation, i.e. the hourly throughput would be about 50 tonnes, or 132 m³.

With several energy-consuming units, a pellet plant is a major power consumer. At an hourly input of up to 50 tonnes, 5 MW of power is required to run the plant. Pelletizing consumes 107 kWh per tonne of pellets produced [SLU 2002] (86.7 kWh per tonne of feedstock). Another source [BfE 2001] quotes a lower consumption of 73.7 kWh per tonne of pellets (59.7 kWh per tonne of feedstock), but both sources do not incorporate chipping and debarking material. Debarking and chipping (including conveyors) energy use is given as 38.8 kWh per tonne of feedstock [LBNL 2000], which would result in a total of 98.5 kWh per tonne of feedstock, which was retained for this analysis.

Rotary drum dryers are a common type of dryer. The dryer needs to be configured to dry the feedstock from 20% to 10% moisture content. The heat for the dryer will be produced using some of the bark produced (i.e., there is very little fuel cost for drying).

For transportation, it is assumed that the wood is transported to the plant by logging truck (capacity: 80 m³ or 30.4 bdt), over an average distance of 150 km. The pellets are transported to the BC customer over a distance of 700 km (one-way), by B-Train pellet trucks (capacity: 44 t or 39.6 bdt). Note that, depending on the customer, a large B-Train may not be able to deliver directly to the point of reception, for example to a small greenhouse in the Lower Mainland. For overseas customers, train transport over 500 km is envisaged, then ship transport out of Vancouver[4] over 16,418 km to Europe (8,865 nautical miles to Rotterdam), with an empty Handymax vessel returning to Vancouver.

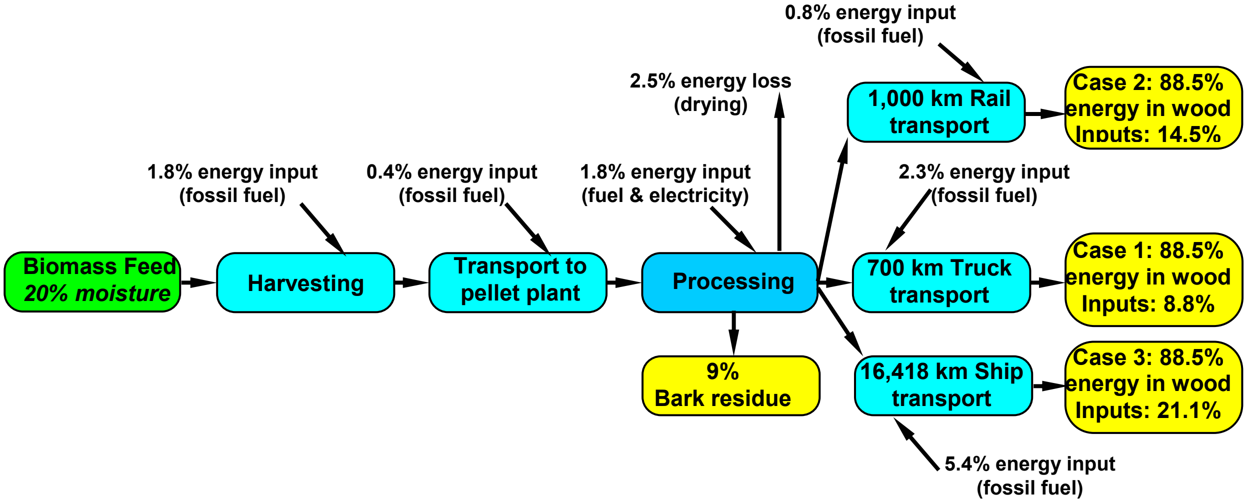


Figure 4.1.4 Energy Balance of Pellet Plant Options

As shown in the energy diagram (**Figure 4.1.4**), only small losses are incurred by each transport step. The main energy uses are drying and processing. 9% of the energy in the wood is lost as bark residues. Only some of the bark is required to dry the wood to 10% moisture content. The remainder of the bark could be used in another application, such as a biomass power station. Note that the diagram does not account for the energy conversion or use of the pellets.

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[4] Pellet shipping out of Prince Rupert is no longer possible as the pellet terminal has been dismantled

4.1.3 Manufacturing and Transport Costs

At a bulk density of 650 to 750 kg/m³ [DRC 2005a], the energy content of pellets is roughly twice as large as that of roundwood loaded on a truck. Compared to chips, the energy is concentrated four to six times (bulk density of 11.2 GJ/m³ for pellets vs. 2.8 GJ/m³ for chips [BfE 2001]). According to Delta Research Corporation, the investment cost for a pellet plant is C$1 million for every 10,000 tonnes of capacity [DRC 2005a], i.e. $25 million for the plant size discussed here (probably conservative due to economies of scale). Eight people per shift are running the plant and shipping facilities, plus one supervisor per shift (three-shift operation) and administrative personnel (salesman, secretary, accountant, director during day shift only).

Capital is procured at an interest rate of 10%, which is the expected ROI of an equity investor. The fuel consumption of the front loader is assumed to be 8 litres of diesel per hour, at a price of $0.90 per litre. The per-kWh cost of electricity is 3.4 cents per kWh. Some ash will be produced by burning bark to dry wood, but the removal cost is considered negligible.

A chipping plant with an annual wood input of 250,000 t is relatively large compared to existing pellet plants in BC, although plants with capacities of up to 180,000 tonnes per year exist. Most of these plants are situated close to sawmills and are using residues from wood products manufacturing. Pellets can be used in different markets:

- for co-firing in coal plants in Alberta;
- for industrial heat applications in BC, such as greenhouses or pulp and paper mills;
- for power generation in Europe; and,
- or for residential and other space heat applications in BC.

According to Pinnacle Pellet in Quesnel, the market price for pellets is $156 per tonne. Pellets are already used for residential heating in BC, and are also exported to various European countries. However, many districts have regulations in place that prohibit the use of wood for heating purposes (Lower Mainland, Kamloops, Golden, Prince George), such that further development of this market in BC seems unlikely. The price for pellets that can be obtained in Europe is closer to $170/t [DRC 2005b].

Table 4.1.1 shows the costs and revenues for three different options. Case 1 sells the pellets to a greenhouse in BC, at a distance of 700 km from the plant, delivered by truck. As freighting pellets by truck is a very expensive option, delivery to clients at a shorter range may reduce costs enough to run a profit. Case 2a exports the pellets to Alberta to be co-fired in coal plants. This is again a simplified assumption as Alberta's pulverized coal plants may not accept pellets as a feedstock, but may require chips instead. BC pellets are ground before they are burned in the UK [DRC 2005b], so for shorter distances, shipping logs to be chipped on-site instead of pellets may be the preferred option. The costs identified do not include the investment to modify the coal plant to accommodate for biofuel co-firing. The costs of co-firing up to 5% biomass are considered negligible, only requiring separate handling and receiving equipment, but no burner modifications. Co-firing up to 15% biomass would require some modifications to feedstock handling and burners. It is assumed that co-firing of biomass will qualify under the emerging federal Renewable Power Production Incentive (RPPI) scheme. This is not guaranteed at this point in time and needs to be verified, especially as a provincial cap may restrict the capacity to be supported by such a scheme to 450 MW_{el}, including all other types of renewable energy production, apart from wind power. The example also includes revenues from carbon credit sales, since 0.9 tonnes of CO_2 are displaced per MWh produced at the coal plant through coal substitution with CO_2 neutral biomass feedstock (0.5 tonnes of biomass generate 1 MWh of electricity). The price of an emission credit is assumed to be equivalent to the current cap of $15 per tonne of CO_2. Whether a coal plant would be accepting biomass pellets at a price of $156 per tonne needs to be confirmed. It may be a very optimistic assumption, seeing that coal plants in Northern Alberta use sub-bituminous coal from open pit mines in the immediate vicinity, and the price of this coal is very low. The carbon credit would be created at the plant level through coal substitution, and would belong to the plant owner. Rather than adding RPPI and carbon credits to the overall revenue from biomass sales, it is therefore more realistic to deduct these amounts from the price paid for the pellets that the electricity company needs to pay, i.e. they are savings incurred through biomass use, which are available to the buyer, not the vendor, of biomass. This reduces the cost of biomass to the buyer from $156 to $113 per tonne, but also means the plant yields a lower profit (Case 2b). Case 3 assumes the pellets are sent to Europe by ship, to be burned in coal or biomass plants. This option does not allow for RPPI or carbon credits to be earned – although an emission reduction will be booked for the power plant using the biomass in Europe. China is also seen as a potential market for BC biofuels.

Table 4.1.1 Annual Cost Overview for a 50 t/h Pellet Plant

	C$ per year	Comments
Capital cost	*25,000,000*	*Total of all equipment*
Salaries	1,405,000	
Maintenance	75,000	3% of annual capital cost
Fuels	43,200	Diesel fuel use
Electricity	837,250	Electricity use
Feedstock harvesting	17,137,500	Harvesting cost only
Feedstock transport	7,507,500	Cost of truck transport to plant

Product transport, Case 1	13,465,238	Truck transport (700 km)
Total cost	40,470,688	Sale in BC
Revenue from product sale	37,283,188	$156 per tonne
Carbon credits	2,907,728	
Total revenue	34,497,728	Sale in BC
Profit Case 1	-5,972,960	
ROI	0	

Product transport, Case 2	8,486,854	Ship by train to Alberta coal plant
Total cost	35,492,303	Incl. 1,000 km train transport to AB coal plant
Revenue from product sale	31,590,000	$156 per tonne
Incentives	4,050,000	RPPI ($10/MWh)
Carbon credits	4,793,551	If applicable, $15 per tonne of CO_2
Total revenue	40,433,551	Incl. 1,000 km train transport to AB coal plant
Profit Case 2a	9,734,799	
Profit Case 2b	4,941,248	Assumes credits and RPPI paid to buyer
ROI (Case 2b)	15%	

Product transport, Case 3	4,243,427	Ship by train to Vancouver
Product transport	13,830,750	Ship Vancouver - Europe
Total cost	45,079,627	Sale in Europe
Revenue from product sale	34,425,000	$170 per tonne
Total revenue	34,425,000	Sale in Europe
Profit Case 3	-10,654,627	
ROI	0	

4.1.4 GHG Emissions

The GHG emissions are directly related to the energy balance. However, electricity emissions in BC are fairly low due to 90% large hydro in the electricity mix. To determine indirect emissions from electricity use, ICF data on marginal electricity generation units for 2007 in BC (average) is used [ICF 2003]. This is a regional value representing emissions due to incremental electricity use in BC and is different from the national emission factor presently under discussion to calculate offsets for the national Offset Trading System.

Three cases are shown in **Figure 4.1.5**. For Case 1 (sale in BC), it is assumed that pellets displace natural gas heating in homes or commercial applications, such as greenhouses. Emission reductions would be larger if pellets displace heating oil. Cases 2 and 3 show the effects of displacing coal as a fuel to make electricity, either in Alberta or in Europe. For transport, emissions assume round trips, with the carrier being empty on its return trip. In all cases, the emission reductions per tonne of bugwood that enters the pellet plant are far greater than those caused by processing and transporting the wood.

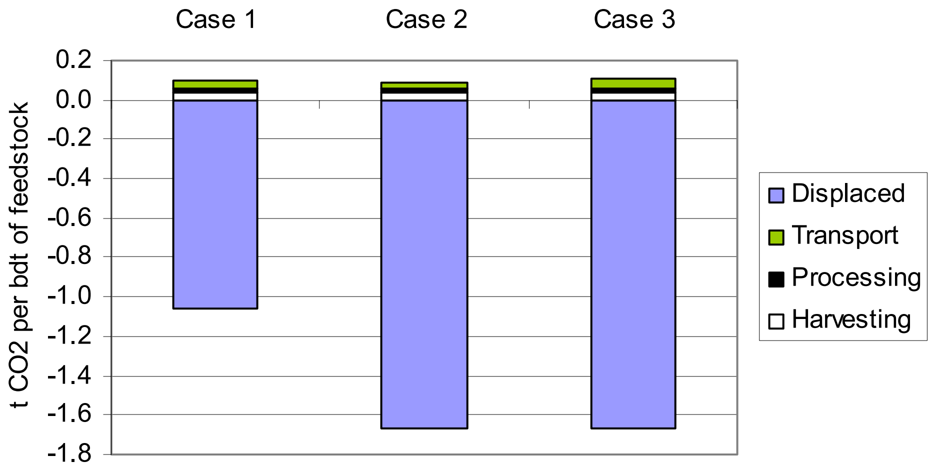


Figure 4.1.5 GHG Emissions for Three Uses of Pellets

4.2 Prehydrolysis of Bugwood to Make Cellulignin

4.2.1 Cellulignin Briquettes

Biomass can be transported in the form of briquettes. To make conventional briquettes, wood is de-barked and ground up into small fines and compressed at high pressure into 50 mm diameter or larger briquettes. No binding agent is used as the heat resulting from the compression can be sufficient in most cases to let the lignin bind the material together. The advantage of this method is that it produces a material which is easy to handle and package, and which can be transported economically. For briquetting, the moisture content of the biomass must be below 10% to 15%, otherwise drying is required. Briquettes have a high specific density of up to 1,200 kg/m^3 and a bulk density of 800 kg/m^3. In comparison, bugwood has a bone dry density of 380 kg/m^3, a density of 460 kg/m^3 at 20% moisture content, and when chipped the interspatial air decreases the bulk density to less than 230 kg/m^3. Biomass briquettes have the following advantages:

- Higher boiler efficiency compared to bulk biomass because of lower moisture content and possibly better conversion rates;
- Reduced loading, unloading, transportation and storage costs;
- Can be economical in some applications depending on feedstock, transportation and manufacturing costs, and are a renewable fuel;
- Less sulfur compared to oil and coal, thereby reducing environmental impact;
- Higher thermal value compared to bulk biomass and much lower ash content compared to bulk biomass and coal;
- Consistent quality,
- Reduced fly ash; and
- Load following for steam boilers is easier compared to coal, due to higher quantity of volatile matter.

Conventional wood briquettes have some shortcomings:

- They cannot withstand direct contact with water;
- A covered storage facility is required;
- They require debarking, sizing and potential drying of the biomass, processes that require energy;
- Precludes the use of branches left over in the forest after logging;
- The maximum attainable temperature is 1000°C due to the low carbon content limiting their applications , for example, in lime kiln;
- Burning capacity per unit volume of furnace is low compared to coal; and,
- Availability in remote regions is not assured year round unless enough storage is made available.

Prehydrolysis of bugwood discussed below produces cellulignin (CL) which can be used to make briquettes. CL briquettes avoid some of the disadvantages of conventional wood briquettes. They burn very cleanly, have less ash and inorganic materials, and can be used to replace natural gas in industrial applications. Shipped as high-density briquettes, cellulignin briquettes can easily be used to generate power and heat at the point of use, where they can replace natural gas as a fuel. In addition, bark and branches can be utilized, which allows for a large variety of biomass feedstocks.

4.2.2 Hydrolysis Background

Bugwood biomass is a lignocellulosic structure consisting of cellulose fibres wrapped in lignin and sheaths of hemicellulose, as shown in **Figure 4.2.1a**. The lignin acts as a stiffening agent and as cement between the wood fibres. The ratio of the three components varies depending on the type of biomass. Typical ratios for softwoods are: cellulose, 42%, hemicellulose, 25%, and lignin, 28%. Cellulose is a polymer of D-glucose, hemicellulose is a polymer of sugars, and lignin is a complex random polyphenolic polymer. Biomass also contains bound water located within the wood structure, which is difficult to remove, and free water in between the fibres. The lignin can be dissolved by various chemical processes when making wood pulps, exposing the cellulose and hemicelluloses in fibrous form. Lignocellulose represents an available substrate for the preparation of sugars which may be fermented, for example, to produce ethanol.

The main goal of hydrolysis is to be able to use all of the tree components by isolating and breaking down wood components into useable fragments to create more valuable bioproducts. Wood can be hydrolyzed to simple sugars by chemical reactions with water using a strong or weak acid solution to produce glucose, which can be further converted to ethanol. Hydrolysis of biomass has been practiced on a commercial scale since World War I. Commercial applications include dilute acid hydrolysis which occurs in two stages to maximize sugar yields from the hemicellulose and cellulose fractions of biomass. The hydrolysis process also results in a dilute liquor containing sugars, organic acids and furfural ($C_5H_4O_2$), a valuable chemical used in the manufacturing of plastics, oil refining and in agriculture. Dilute acid hydrolysis is the oldest technology for converting biomass to ethanol. It has been found that many of these processes producing low yields, are environmentally damaging and hazardous to operators, and efforts to obtain value-added products have often been uneconomical. Prehydrolysis of biomass uses a dilute acid to make cellulignin, somewhat similar to hydrolysis.

4.2.3 Prehydrolysis of Bugwood to Create Cellulignin (CL) Briquettes and Furfural

The long-term strategy for biomass use in Canada is to develop processes that create bioproducts which are cost competitive with current petrochemical methods, and to produce biofuels that are cost-competitive with fossil fuels. This approach is often referred to as the biorefinery approach. Converting biomass to electrical power without using the waste heat with a large-scale steam boiler produces revenues inferior to $90 per BDT in most Canadian regions. Attempts need to be made to use biomass more productively. The recent Canadian R&D Biostrategy [Archambault 2004] promotes developing various bioproducts, biofuels and bioenergy. This can be achieved, for example, by producing cellulignin (CL) cost-competitively so that it can be sold in the pacific basin as square briquettes to displace natural gas as a heat source. Producing CL is an attempt to convert biomass into a material that approaches the combustion characteristics of natural gas to allow for the use of lower-cost gas turbine technology, compared to steam-based system, by directly burning the CL with the pressurized air upstream of the turbine. It is also an attempt to eventually favor the production of high-end usage for biomass, as cellulignin has properties and advantages that can lead to bioproducts that increase revenues from biomass.

Similar to hydrolysis of biomass, prehydrolysis is a method to use a dilute acid to break down biomass into components. Using prehydrolysis, as proposed by the Biomass Energy Materials Program developed in Brazil [Pinatti 2003, Pinatti 2005, Pinatti USPTO], biomass is mixed with a dilute acid to explode the cellulose, lignin and hemicellulose to obtain CL that can be ground to a very fine, micron-scale powder at the point of use, as shown in **Figure 4.2.1b**. The prehydrolysis is performed in a reactor vessel at 160°C and 0.62 MPa, using a 1.7% H_2SO_4 acid solution at a liquid to wood chip ratio of 2 to minimize process costs. The CL produced (**Figure 4.2.1c**) is then washed, dried and converted into square high density briquettes. At the point of use the CL briquettes are ground into a fine powder.

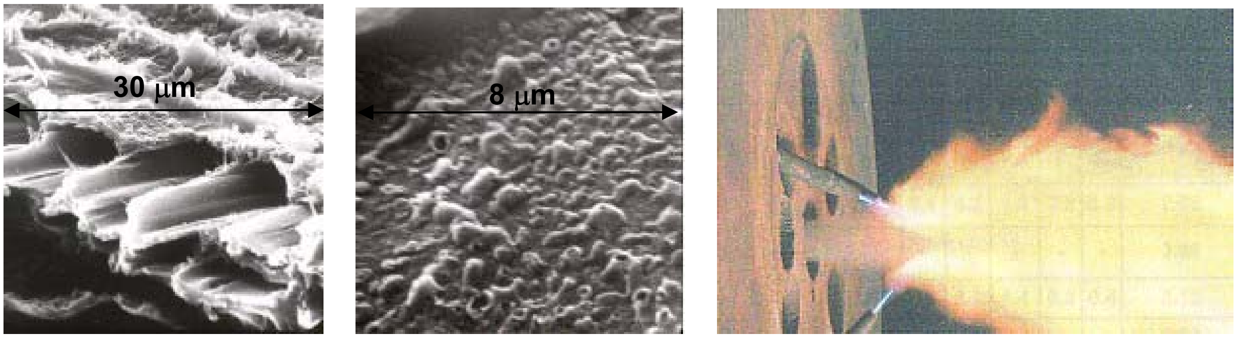


Figure 4.2.1 (a) Lignocellulosic Biomass Showing the Cellulose and Lignin, (b) Cellulignin Obtained After Prehydrolysis, and (c) Burning Cellulignin Directly in a Natural Gas Burner

Prehydrolysis of biomass has several distinct advantages:

- CL can be compacted and formed into square briquettes so that the bulk and the material densities are the same: 1,250 kg/m^3. This results in a specific energy of 23 GJ/m^3 which is similar to bituminous coal, 26 GJ/m^3, a fossil fuel commodity that is shipped and transported over significant distances.
- Both bound and free water are easily exposed during the prehydrolysis process, allowing reduced drying, heating and power costs to make briquettes.
- The prehydrolysis dilute acid and washing process reduces the ash levels to less than 0.2%; potassium and sodium levels decrease to below 100 ppm. This aspect is very important when using biomass, for example, in power production to reduce particulate matter, corrosion and slagging - important elements that impact operating and maintenance costs of equipment. More important, it allows CL to have significantly less contaminants, making it better suited to develop higher-value processes and enabling its use directly in a gas turbine if turbine material problems are adequately addressed. The ash and alkaline contents can be further reduced if washing is performed with distilled water.
- The fine powder produced after grinding can be atomized using a natural gas burner, allowing for substitution of natural gas with CL in many applications, as shown in **Figure 4.2.1c**. This is very important as there are limited equipment modifications required for the end user, thereby limited capital cost involved in fuel switching. In addition, CL avoids the many fuel handling issues characteristic of biomass systems.
- The energy required to grind the CL is low compared to other processes.
- The resulting prehydrolysate liquor contains furfural, a commodity that sells for $1,000 US per tonne.
- The prehydrolysis process is independent of the initial moisture of the biomass feedstock.
- CL can be used to make a syngas without the need of a gasifier, eliminating tar issues. This is important for the production of biofuels.
- Alkaline and ash components are removed at the start of the process by the dilute acid to avoid downstream conversion issues.
- Recycling of the water makes the process environmentally friendly and closed-loop.

The CL approach is well suited to develop the biorefinery concept. Furthermore, the sludge removed from the resulting liquor can be converted to a bio-liquid using low-temperature pyrolysis. CL can be directly used in a gas turbine to obtain power conversion efficiencies exceeding 40% in a combine cycle. Alternatively, CL can be used to power a traditional steam turbine using a simplified fuel feeding system. It can be made from any type of biomass, and the technology is flexible with respect to plant size. CL can be used to make syngas, electricity and liquid fuels: methanol, synthetic crude, diesel, kerosene, naphta, and DME. Properties of CL are shown in **Table 4.2.1**. CL can be exported using intermodal transportation. The disadvantages of this approach are:

- The prehydrolysis adds an extra conversion step of the bugwood, and
- Up to 20% of the biomass is lost during the prehydrolysis step but used to extract furfural and process heat.

Table 4.2.1 Properties of Cellulignin

Properties of CL	
Drying requirements	12 kWhr/Tonnes
Surface porosity	10 times greater than wood
Ignition time	10 ms compared to 300 ms for coal
Bulk density square briquettes	1,250 kg/m^3
Particle size	Less than 0.250 mm
HHV	19 GJ/BDT
Ash	0.2%
K + Na	Less than 100 ppm

4.2.4 Steps for Briquetting Using Prehydrolysis of Bugwood

The various steps for briquetting using prehydrolysis of bugwood are shown in **Figure 4.2.3** and are explained below.

Chipping: Bugwood is first harvested using conventional methods and transported using a small mobile truck or tractor short distances of up to 5 km to a chip compaction tractor. The chipping operations form 5 km cells, shown in **Figure 4.2.2**. No drying or debarking of the biomass is required in the field and branches can also be accommodated by the process.

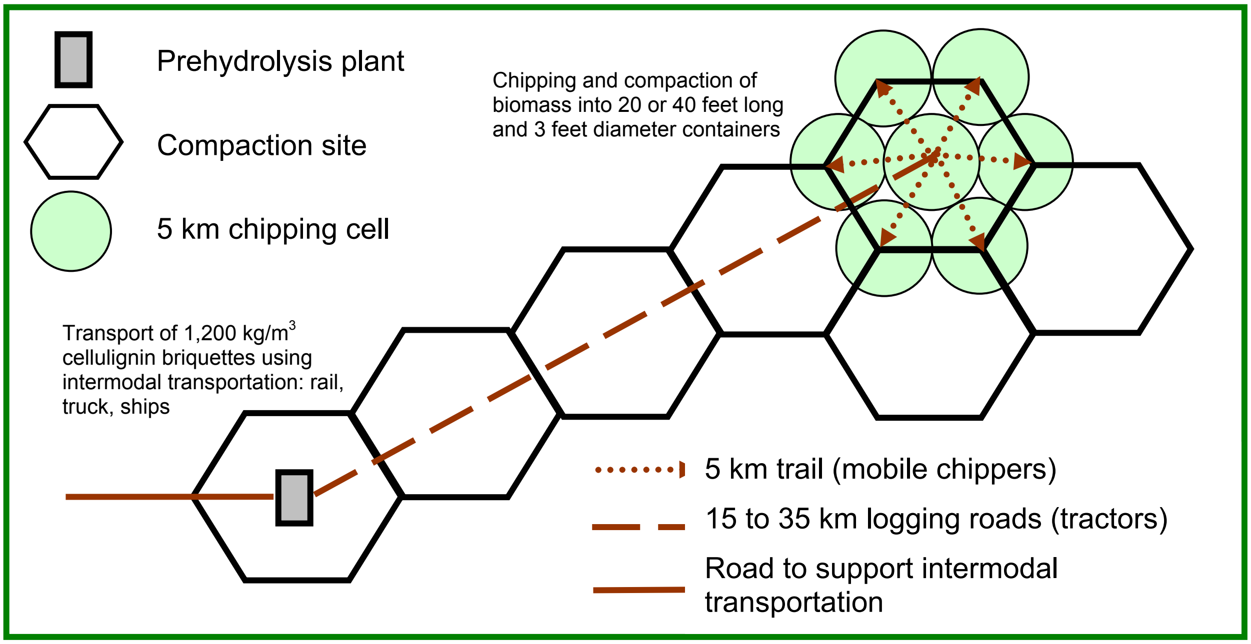


Figure 4.2.2 Location of Chipping Cells, Compaction Site and Pyrolysis Plant

Compaction: A chip compaction tractor having a container 20 feet in length for difficult terrain and 40 feet in length for good terrain is used to transport the chipped biomass to the prehydrolysis site using logging roads inside the forested area. Transportation between the compaction site and the prehydrolysis plant is limited to a minimum of 15 km and a maximum of 35 km for optimal efficiency. **Figure 4.2.4** shows a typical chip transport truck equipped with a compaction system.

Prehydrolysis: Prehydrolysis sites are located in Bugwood Management Units, approximately 15 to 35 km apart. They need to operate in areas which have road access and are located near the electrical grid. Alternatively, a CHP system similar to that described in Section 4.3 can be used to provide the power and heat to the prehydrolysis plant to minimize chip transport costs if it cannot be located near the power grid. This allows locating these plants in more remote areas to access significantly more bugwood infected areas. The process energy requirement is only 6% of the HHV of the original biomass, which is partly achieved by compaction of the wood chips in the reactor and recuperation of the process heat from the prehydrolysate liquor. The reactor can also be placed on a mobile truck and allow to completely utilize all the available wood (trunk, bark and branches), as shown in **Figure 4.2.5**. The heat to the reactor can be supplied using a boiler fired with biomass chips or by an atomization burner fed with CL. The water used in the process is treated and reused requiring only minimal makeup water.

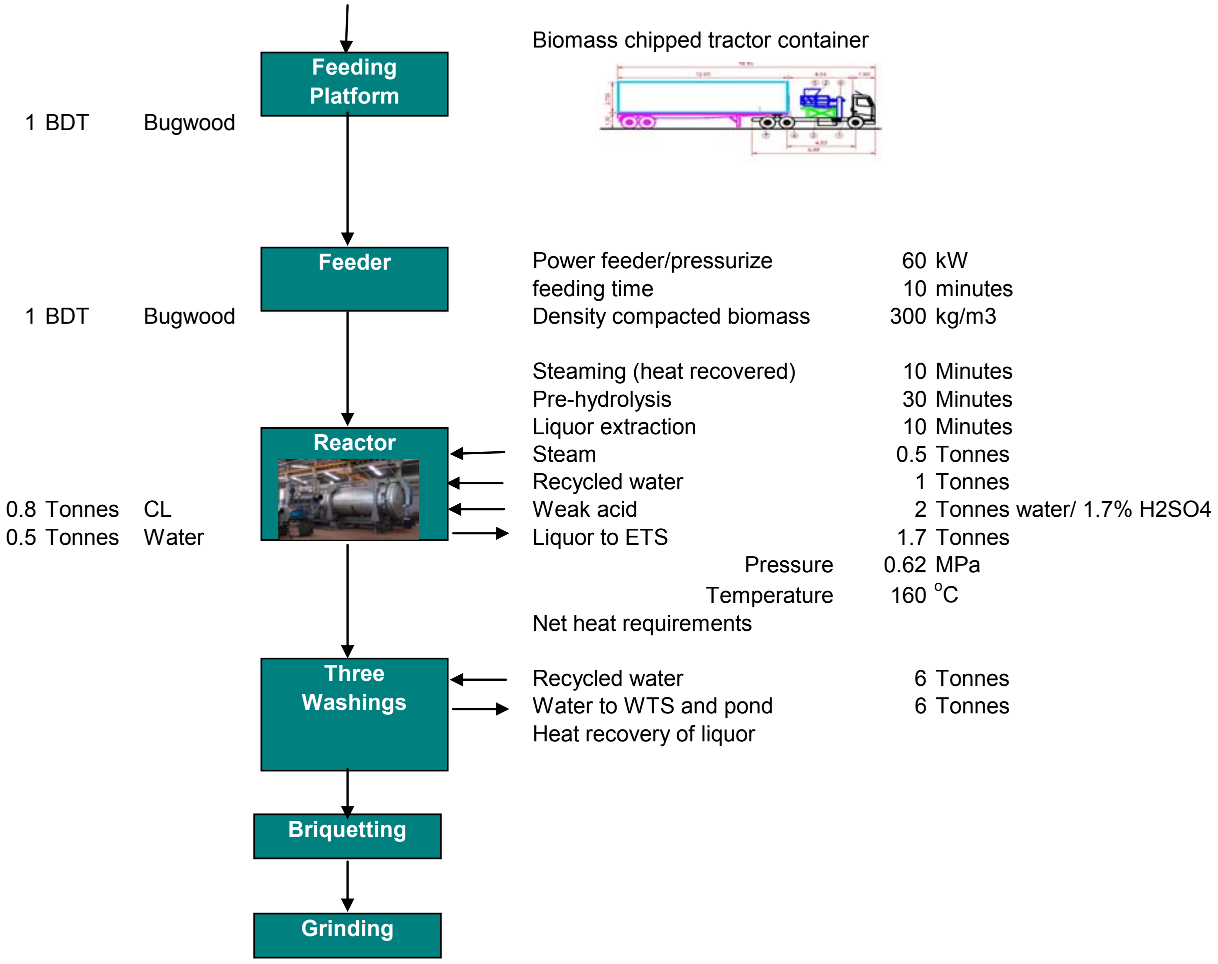


Figure 4.2.3 Prehydrolysis Processing Steps

Semi-mobile prehydrolysis plants can vary in size. One unit will process 90 BDT/day of bugwood using a single 30 m^3 reactor, or can use up to 1,080 BDT/day using two 180 m^3 reactors, as shown in **Table 4.2.2**. The footprint of the 1,080 BDT/day prehydrolysis plant is 150 m by 90 m, thus requiring an area of 13,500 m^2. Prehydrolysis of biomass is performed in a reactor vessel made of 10-mm high-strength low-alloy carbon steel to minimize costs. The reactor is lined with a 2-mm titanium sheet for corrosion resistance. A vacuum between the titanium sheet and the steel vessel ensures reactor integrity is maintained. A feeder compresses the chipped biomass to a 300 kg/m^3 bulk density to reduce the requirements of the weak acid solution by limiting the acid to wood ratio to 2. The prehydrolysis process requires 90 minutes allowing 12.5 cycles per reactor per day producing 90 BDT/day of CL for the 30 m^3 reactor, as shown in **Table 4.2.3**. In addition, furfural, alcohols and xylitol can be produced from the resulting liquor and wash water used to clean the CL.

Table 4.2.2 Prehydrolysis Plant Size

Reactor size (m^3)	Number of reactors per site	Total Reactor Volume (m^3)	Bugwood harvest (BDT/day)
30	1	30	90
30	2	60	180
30	4	120	360
180	6	180	540
180	6	360	1080
Bugwood volume is on a dry basis and density of bugwood is 380 kg/m^3			

This flexibility in capacity when using multiple reactors allows a minimum operation based on seasonal availability of personnel, bugwood, and dispersed biomass harvested during peak operation. Using the data in **Table 4.2.4** for Year 2011, it is necessary to have nine prehydrolysis sites with various sizes in order to process the average daily bugwood available for harvest. Some sites may have two 180 m^3 reactors and other sites may have two to four 30 m^3 reactors. The economics are improved with the use of larger 180 m^3 reactors. Plant capacity shown in **Table 4.2.4** is significantly underestimated to account for the decline in bugwood availability over time and the delay in regrowth. A total of 2,520 BDT/day would be processed and harvested at these nine locations, and because these plants can be relocated, it is assumed that biomass feedstock accessibility would not be an issue over time.

Table 4.2.3 Details of the Prehydrolysis Reactor

Prehydrolysis Plant		
Total cycle time	90	minutes
Batch/day	12.5	per day
Downtime	10	%
Volume per batch of bugwood	30	m^3
Total bugwood volume processed per day	375	m^3
Biomass processed	113	BDT/day
CL efficiency	80	%
CL produced	90	BDT/day

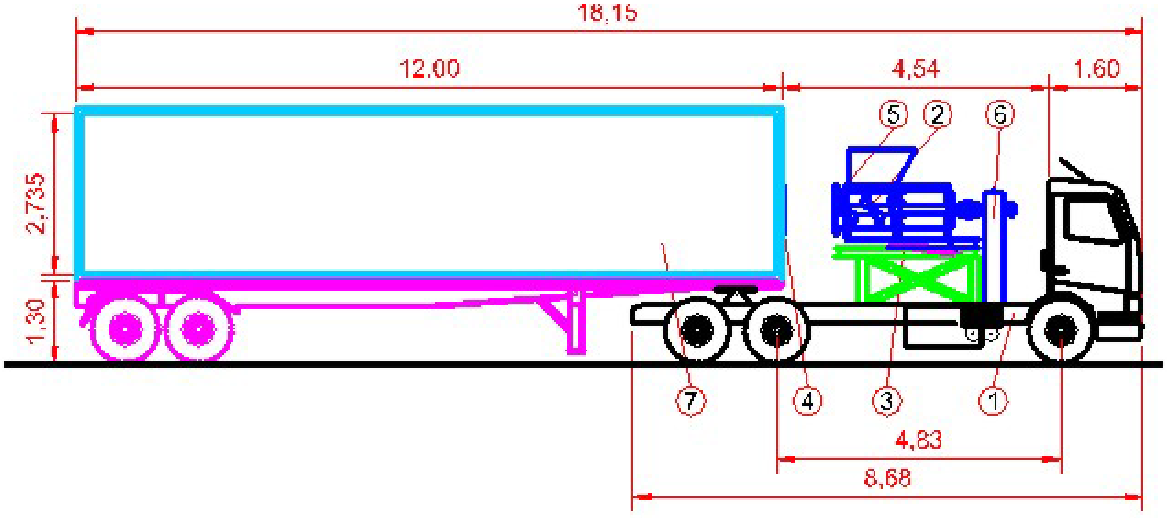
The prehydrolysis process consists of filling the reactor with the preheated dilute acid solution, heating, pressurization, and imparting rotary oscillations. The discharge of the resulting dilute liquor follows a heat recovery process and a sugar-recovering washing operation. The CL has three washing operations. Heat from biomass conversion is then used to dry the CL to 500 ppm of moisture using air temperatures of 125°C. Access to the bound water is no longer problematic and therefore pre-drying requirements for heat and power applications are reduced considerably. The inorganic material reacts with the dilute acid forming soluble sulfates that are extracted from the wash water. Washing can be done with normal recycled water or deionized water obtained from within the process to further reduce the ash and inorganics. Washing with deionized water further reduces the inorganics present in the CL to reduce the impact during direct fired gas turbines. The process limits the liquid to solid ratio to 2 which may allow the treatment using deionized water in applications.

Table 4.2.4 Approximate Distribution and Location of Prehydrolysis Plants

BMU	Average Daily Bugwood Harvest 2011		Prehydrolysis Plants	
	Dry basis (m^3)	Dry basis (BDT/day)	#	Size (BDT/day)[1]
Vanderhoof	3,400	1,292	1	540
Lakes	2,200	836	1	360
Quesnel	3,680	1,398	1	540
Merritt	416	158	1	90
100 Mile House	1,072	407	1	180
Williams Lake	1,540	585	1	360
Cranbrook	275	105		
Boundary	54	21		
Morice	364	138	1	90
Lillooet	121	46		
Ft St James	683	260	1	180
Invermere	265	101		
Kamloops	336	128		
Arrow	244	93		
Okanagan	127	48		
Mackenzie	46	17		
Kootenay Lake	145	55		
Bulkley	50	19		
Prince George	897	341	1	180
Golden	135	51		
Robson Valley	73	28		
Cranberry	0	0		
Dawson Creek	0	0		
Total	**16,123**	**6,127**	**9**	**2,520**

Note 1: Plant size is considerably undercapacity to account for the bugwood aviablity as being transitory from 2005 to 2020. Other feedstocks can be used afterwards.

Figure 4.2.6 shows the Biomass Refinery Materials Program consisting of a sequence of eleven technologies producing ten products. For the BC Bugwood issue, the proposed method relies on using only the upper portion of the Biomass Refinery Plant: prehydrolysis, effluent treatment station, dryer and briquetting. Other technologies or plant expansion could include the Low-Temperature-Conversion for zero discharge of liquids, if desired. Nutrients could be returned to the forest through fertirrigation. The bottom part of the Biomass Refinery shown in the same figure is used at the end point consumption to obtain economies of scale and allow maximizing profits from the operation **Figure 4.2.7** shows the layout for a 1,054 BDT/day biomass refinery plant.



1. Adapted 6x4 truck
2. Compactor
3. Hydraulic cylinder to couple compactor to container
4. Larger diameter container coupling flange
5. Compactor discharge flange
6. Hydraulic transmission to drive compactor
7. Compaction container: 20 or 40 feet long and rectangular

Figure 4.2.4 Truck With Compactor to Transport Chipped Biomass from Cells to Prehydrolysis Plant

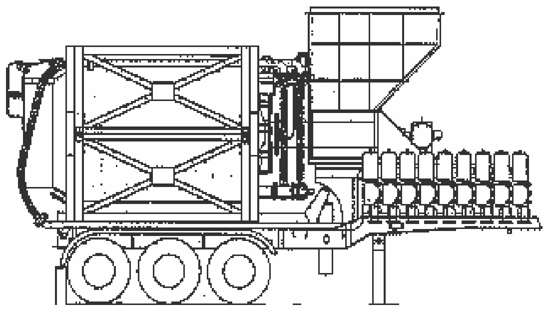


Figure 4.2.5 Mobile Reactor to Use Near the Harvesting Operation

Figure 4.2.8 shows the prehydrolysis reactor, 3 m diameter, 30 m^3, and 90 TDB/day, in a horizontal position with a retracted biomass feeder, and in the CL dumping position after completion of the prehydrolysis process. Dimensions of this reactor meet the highway standards. The 180 m^3 reactor has a diameter of 4.7 m demanding special license for highway transportation. The Low-Temperature-Conversion (**Figure 4.2.8**) treats the sludge resulting from the water effluent treatment plant, producing oil and charcoal. This unit can be avoided if the neutralized effluent is distributed into the forest as fertirrigation, achieving sustainability due to recycling of nutrients and minerals.

	TECHNOLOGIES	PRODUCTS
0	Transport and Reception of Dispersed Biomass	
1	Prehydrolysis (PH)	I – THERMAL CELLULIGNIN
2a	Effluent Treatment Station (ETS) Water Treatment Station (WTS)	
2b	Turbo Dryer	
3	Low Temperature Conversion (LTC)	III –OIL; IV – CHARCOAL.
4	Storage of LTC Oil and Furfural	
5	Furfural (FF)	II – FURFURAL
6	Drying	
7	Simple Cycle Thermoelectric (Steam)(SSTE)	VI – ELECTRIC ENERGY
8	Combined Cycle Thermoelectric (CCTE)(Gas turbineBoiler/Steam Turbine)	VII – ASH/ IX – SILICA VIII – FETILIZER
9	Furnace of Cement, Siderurgy, Calcination, etc.	IX – SILICA
10	Partial Oxidation (PO) – GTL (Metanol, Diesel, H_2 – Fuel Cell)	V – SYNGAS VII – ASH
11	GTL - Gas to Liquid Technology (FT – Fischer Tropsch)	X – Metanol, DME, Synthetic Crude, H2

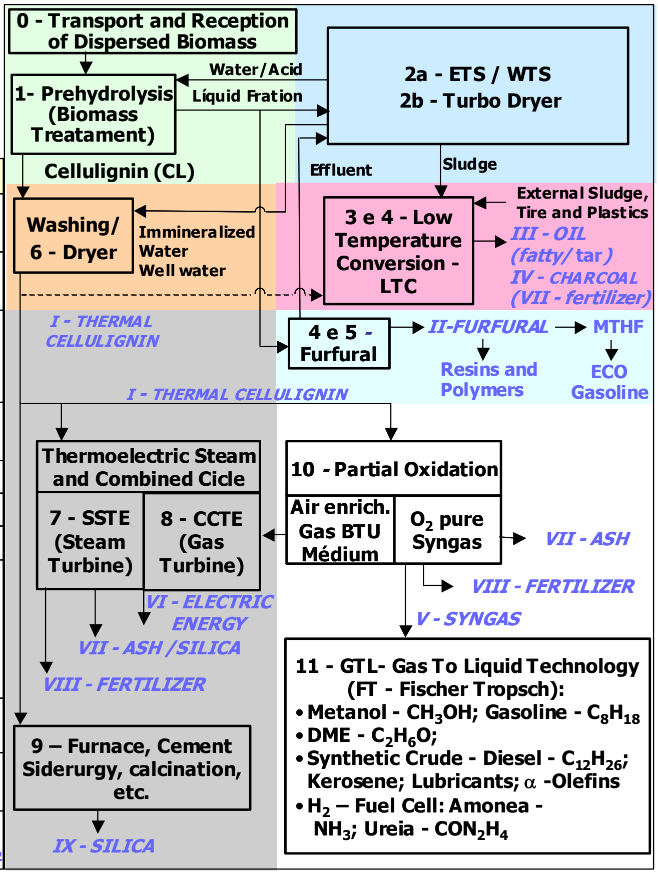


Figure 4.2.6 Biorefinery Concept from Biomass-Energy-Materials Program

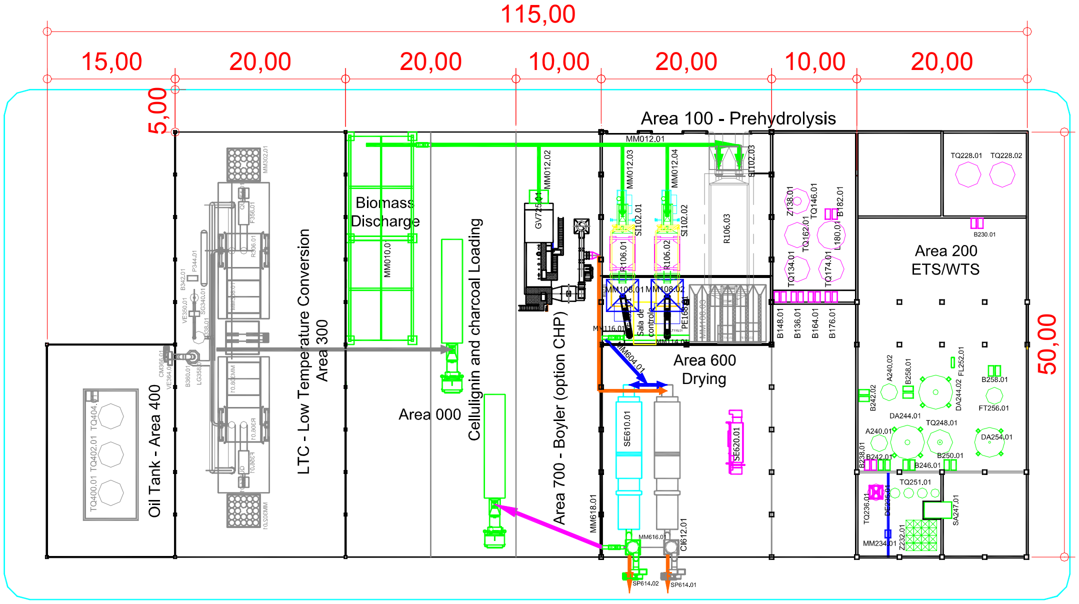


Figure 4.2.7 Layout for Complete Prehydrolysis Site

Configured as a biorefinery application processing 1,054 BDT/day of biomass feedstocks: biomass, cellulignin, charcoal discharge and loading (000), prehydrolysis (100), water treatment station, wash and effluent treatment station (200), low temperature conversion pyrolysis station (300), tanks (400) Furfural (500 not shown) and drying area(600).

Washing: The CL is washed in three steps. After each step, the water is treated and the heat is recycled into the system. The resulting sludge is then processed to ensure that no effluent is released into the environment.

Figure 4.2.8 **Prehydrolysis Reactor (a) Horizontal and (b) Cellulignin Dumping Position**
The same compaction equipment can be used for compaction of the biomass chips in the field. The reactor vessel is lined with Titanium to prevent corrosion and can be licensed to be used on roads.

Figure 4.2.9 **Low-temperature Conversion Pyrolysis Unit**
Located in the prehydrolysis plant to process the sludge from the effluent-and-water-treatment station to recover bio-liquid and charcoal.

Briquetting: CL is then compacted at the prehydrolysis plant to form square briquettes to achieve bulk densities of 1,200 kg/m^3. The efficiency of compaction is such that weight limits do not allow full loading of a 20 feet container.

Transportation: Just-in-time intermodal long distance container transportation—truck, rail, boat and ship—from the prehydrolysis plant located in the forest to users in Canada and foreign countries is then used. Unloading of the container only occurs at the end user site. The briquettes can be used to feed distributed and remote CHP systems operating with atomized biomass burners, to generate syngas without the use of a gasfier to fabricate methanol, DME, crude oil or hydrogen at the end point consumption, fuel large biomass boilers and to be used directly in a gas turbine. CL can be transported to Alberta to co-fire in natural gas plants.

Alternatively it can be used in coal plants as the CL may address the slagging and biomass fuel handling issues raised by the coal industry as a reason not to implement biomass co-firing. A significant portion of the inorganic materials are removed during the prehydrolysis process making CL a strong candidate for co-firing although the cost difference between coal and biomass remains. Transportation of the briquettes is simpler and cheaper than transportation of liquids and gases. The high energy density of the briquettes, 23 GJ/m^3 approaches that of bituminous coal, 26 GJ/m^3.

Grinding: The renewable CL fuel is then ground to 0.250 mm at the point of use. CL has a heating value between 18 and 20 MJ/kg, depending on the biomass feedstock it is derived from, and an ignition time less than 20 ms, making it a possible replacement for natural gas for combustion. The CL produced is a catalytic fuel composed of cellulose and globulized lignin with a specific surface of about 1.5 to 2.5 m^2/g once ground into a fine powder that enhances thermal and biological conversion.

The block diagram of the Biomass Refinery Technology shown in Figure 4.2.6 is based on the production of CL. Conventional technology for pulp, sawmills and OSB separate the harvest and transport operation from factory processing. The idea behind the Biomass Refinery Technology is to integrate both these operations, allowing utilization of dispersed biomass even on difficult terrain. The method first produces clean compacted CL in the forest, which can then be further processed into methanol, DME, Synthetic Crude and H_2 at a central site in large-scale plants. Prehydrolysis can exploit the fact that the market price for cellulose, lumber, paper and furfural is above $300 per tonne - otherwise, the market value of biomass is below $90 per tonne when it competes against fossil fuel as an energy feedstock. For example, wood residues and straw do not command high prices as energy feedstocks once the transport cost has been subtracted from the sales price. Harvest of biomass like bugwood which cannot be used for lumber requires an improvement in concept, technology and operation procedures necessary for bugwood to compete with fossil feedstock. The Biomass Refinery Technology to make CL and furfural is a step towards achieving this goal. The proposed method is also a way to provide a possible solution to the collection, transportation and processing of dispersed biomass.

The energy balance for the fabrication and distribution of briquettes using pre-hydrolysis is shown in **Figure 4.2.10**.

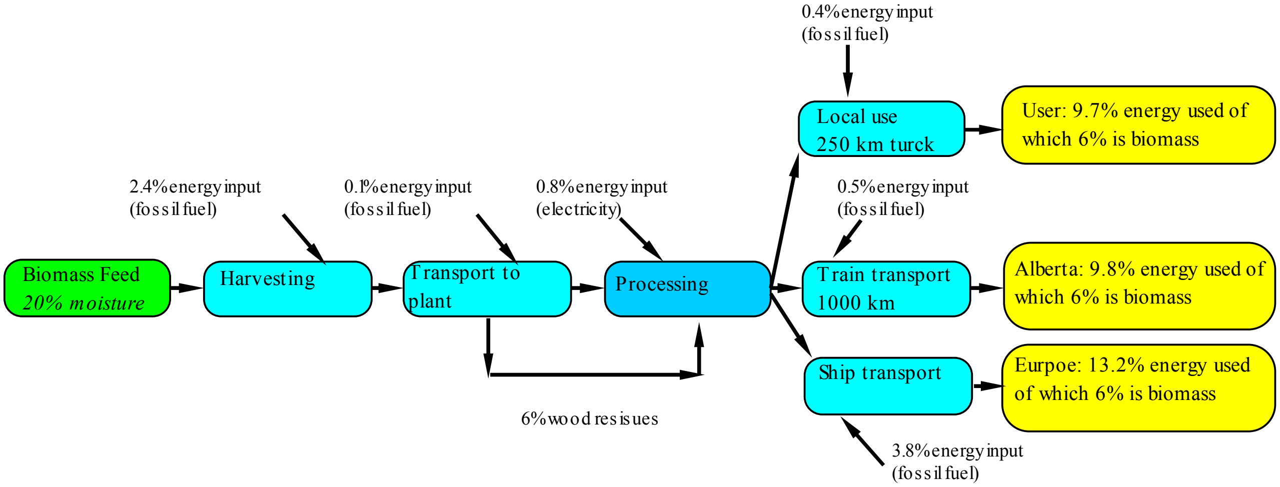


Figure 4.2.10 Energy Balance for the Production and Distribution of Briquettes Using Prehydrolysis

An economic analysis was performed to determine the cost of producing CL and Furfural by harvesting bugwood and implementing prehydrolysis plants according to the layout shown in **Figure 4.2.7**. The economics for the application in Brazil is well known as this technology is entering the commercialization stage. For BC, there are new issues to consider. The bugwood is a transitional resource; road access can be very difficult in certain areas; the cost of labor is substantially higher; because most of the capital items would be purchased in North America, capital cost increases as additional taxation is expected compared to Brazil. The cost of labor has the most profound impact, affecting wood harvesting, followed by plant operations. In Brazil, wood can be cut for less than \$10 per BDT (no chipping and no transportation) depending on the type of biomass being harvested, while in BC, the cost is assumed to be \$68.50 per BDT to bring the biomass to the roadside for large scale harvesting operations. As discussed in this report, some experts place the actual cost at \$106 per BDT. Although different schemes could be proposed to reduce costs by using companies with low overheads and use remote reactors to better integrate the harvesting and the prehydrolysis, it remains that the harvesting cost in BC is a major factor affecting the economics of bugwood.

Based on data comparing our forestry labor rates and the economic analysis for the Biomass Biorefinery plant in Brazil, it was calculated that the labor cost ratio was 5.6 instead of the published national average of 2.83, comparing Canadian wages to that of Brazil. Furthermore, a capital cost ratio of 1.55 was calculated between the two countries by assuming that 30% of the plant cost is labour. An approximate cost of implementing this technology in BC was then calculated. The costs were broken down into:

- Wood harvesting, chipping and hauling to the prehydrolysis plant;
- Prehydrolysis plant capital, operation and consumables. The capital cost of the plant was not used as part of the profit and loss calculation as an internal rate of return was calculated instead over a 10 year time period; and
- Transportation of the CL to a local user is within 250 km by road, freighted by train to Alberta over 1000 km, freighted by train to Vancouver and then shipped to Europe (harbor only). To reduce transfer costs, modal transportation of 20 tonnes containers was assumed. It was also assumed that the Furfural was shipped at the same locations for convince and simplicity.

The revenue for the Furfural was based on current market prices which are approximately \$1,000 USD/tonnes and that 0.044 tonnes of Furfural is produced per tonne of bugwood processed by the prehydrolysis plant. The revenue for the CL is more difficult to predict. To ensure a plausible implementation of this technology, it was assumed that the CL would not be processed to make higher-value bioenergy products like methanol and ethanol, as these technologies are still not within the time frame of the bugwood problem. Instead a more pragmatic approach was taken, where the CL would at first be sold as a fuel replacement for natural gas. Although numerous applications are available, it remains that a long term stable guaranteed market for CL based on natural gas substitution is appropriate, although it may not be the most economic or best long term strategy. The sensitivity of the price was examined by assuming that the price ratio of CL to natural gas based on its HHV on a \$/GJ basis would be 0.6 and 0.8. Although natural gas is very convenient to use when available to the user, it remains there are numerous factors that can decide on the market price for CL substitution. For example, companies wanting to decrease their natural gas cost for heating purposes and areas that do not have access to natural gas will have different price points for switching to CL. Comparison to the cost of pellets, a value of the CL/NG price ratio between 0.6 and 0.8 is a probable market price, as shown in **Table 4.2.5**.

Table 4.2.5 Costs Analysis of Making Briquettes in BC Using Prehydrolysis

Transportation chips		
Mean transport distance to CL plant round trip	20	km
Cost of transport of chips in forest (smaller tractor)	$1.20	$/BDT
Transportation Costs CL briquettes and Furfural		
Mean transport distance plant to user by truck	250	km
Mean transport distance to train	100	km
Mean transport distance to ship	500	km
Modal train Vancouver-Montreal	$3,039	$ per 20 Tonnes
Modal truck Vancouver-Montreal	$4,270	$ per 20 Tonnes
Modal rail transport in BC	$0.025	$/tonnes-km
Modal truck transport in BC	$0.044	$/tonnes-km
Fuel surcharge	0.1	fraction
Transport cost to user by truck only	$12.10	$/Tonnes
Transport cost to user by truck/train to Alberta	$32.34	$/Tonnes
Transport cost to user by truck/train/ship to Europe harbor	$66.00	$/Tonnes
Prehydrolysis plant costs in Brazil		
Power requirement prehydrolysis plant	60	kWhr/BDT
Heat requirement prehydrolysis plant (from biomass only)	6	% of HHV of feedstock
CL consumption for heat boiler	70	kg CL/BDT
Brazil plant cost (10 years 12% ROI)	$4.02	$/BDT
Brazil plant cost (10 years 10% ROI)	$3.70	$/BDT
Brazilian labour cost	$4.63	$/BDT
Brazil consumables except steam	$3.60	$/BDT
Brazil steam (4% of production)	$0.96	$/BDT
Total plant cost Brazil	$16.90	$/BDT of bugwood
Labour cost ratio BC/Brazil average	2.83	
Labour + overhead cost ratio BC/Brazil wood industry	5.56	
Capital cost ratio BC/Brazil	1.55	
Prehydrolysis plant costs in BC		
BC plant cost (assume 25% labour; 10 years 10% ROI)	$10.18	$/BDT of bugwood
BC labour costs (100% labour)	$25.75	$/BDT of bugwood
BC consumables except steam	$3.60	$/BDT of bugwood
BC steam (4% of production of CL)	$2.15	$/BDT of bugwood
Total Plant BC	$41.67	$/BDT of bugwood
Plant Output and Revenue		
CL production	0.8	tonnes/BDT bugwood
CL HHV	19	GJ/BDT of CL
CL Price % of Natural gas (assumed)	0.6	
CL Price	$7.11	$/GJ
US to Cnd	1.12	
Furfural	0.044	tonnes/BDT of bugwood
Furfural price	$1,123.60	$/tonnes of furfural
Sale CL	$108.11	$/BDT bugwood
Sale Furfural	$48.90	$/BDT bugwood
CO2 credits	$16.95	$/BDT bugwood
Total revenue	$173.96	$/BDT bugwood
Total costs		
Harvesting/chipping/transport to plant	$82.86	$/BDT of bugwood
Plant costs	$256.14	$/BDT of bugwood
Total costs before transportation of CL and Furfural	$82.86	$/BDT of bugwood
Total products weight CL and Furfural	0.84	Tonnes/BDT of Bugwood
Transport CL/Furfural to user	$10.21	$/BDT of bugwood
Transport CL/Furfural to Alberta	$27.28	$/BDT of bugwood
Transport CL/Furfural to Europe	$55.67	$/BDT of bugwood
Total cost to user	$93.06	$/BDT of bugwood
Total cost to Alberta	$110.14	$/BDT of bugwood
Total cost Europe	$138.53	$/BDT of bugwood
Net profit to user	$80.90	$/BDT of bugwood
Net profit to Alberta	$63.83	$/BDT of bugwood
Net profit to Europe	$35.43	$/BDT of bugwood

The results for the various costs components, revenues and profits are shown in **Table 4.2.6** for 0.6 and 0.8 CL to natural gas price ratio and assuming a harvest cost of $68.5/BDT. The natural gas price was assumed to be $11.85 $/GJ. The results show that at a price ratio of 0.6, making CL and Furfural may be economical if the CL is sold locally to a user in BC and in Alberta. When sold in Alberta, the ROI is 21.3% as shown in **Table 4.2.7**. When the price ratio is increased to 0.8, transporting the CL by ship to Europe becomes profitable.

Table 4.2.6 Possible Selling Price of CL

CL/NG price ratio	CL Costs per $/Tonne
0.6	$135.1
0.8	$180.2
1	$225.2
Note: Pellets costs vary from $156 to $170 per tonne	

Table 4.2.7 Return on Investment Assuming Freighted to Alberta, CL/NG = 0.6 and $15/tonne of CO2 Carbon Credit

	IRR (over 10 years)
Harvest at $68.5/tonne	21.3%
Harvest at $106/tonne	0.5%
Incentive at $106/tonne for 10% ROI	15.30/BDT

Table 4.2.7 shows that when the harvest cost becomes $106 per BDT, the ROI becomes 0.5% and a subsidy of $15.30 per BDT is required to achieve an ROI of 10% when the CL is shipped to Alberta and a price ratio of CL to NG of 0.6 is assumed.

Currently, it is economically favorable to ship CL produced in Brazil to Italy [Pinatti 2005] if the CL is used by an industry located along the coastline in Italy, as the energy saved from natural gas displacements can result in significant cost savings. For BC, the cost of labor mainly associated with the harvesting of the forest affects the economics. Brazil is looking at growing new energy crops which will significantly increase the costs of obtaining the biomass feedstock. In BC, using available biomass wastes to avoid bugwood harvesting costs would make the proposed approach very economical. It may also be possible to improve the economics by developing mobile units to integrate the harvesting and prehydrolysis components together and allow remote operation without any grid interconnects. In this way, two high-value commodities totaling approximately $170 to $210 per BDT of bugwood with carbon credits included would be removed from the forest with only consumables being brought in.

Table 4.2.8 shows the relative difference in heat densities and the cost of various energy sources. As can be seen, CL has 56.7% the energy density of fuel oil and 88% of bituminous coal. If CL could be used interchangeably with fuel oil, there would be no price difference. It is the market price for CL for industries in the Pacific basin located along the ocean shoreline (California, Shanghai, Japan, and Vancouver) which is presently unknown.

One remaining option is to investigate power production at the prehydrolysis plant. By constraining the plant to be in a grid connected area, the transport of CL can be eliminated by producing power directly with a gas turbine system. For example, the large 540 BDT/day plant proposed in **Table 4.2.2** would produce a net power of 22 MWe after removing the 2.2 MWe parasitic power required to operate the plant. Alternatively, the CL can be shipped to a larger facility but this alterative is more difficult to implement. Although the power option is attractive, it remains that it is another step in the process and the selling of briquettes should in itself be economically feasible to allow the development of this technology to be implemented in BC to help resolve the bugwoodissue. By using the CL to produce power at the prehydrolysis plant, this approach decouples the CL from the market price for this commodity and the requirement for finding a consistent price for this new material. The furfural is still shipped internationally, as the shipping cost is a much lower portion of the overall production cost.

Table 4.2.8 Comparison of Fuel Heating Value, Density and Costs

	Density	HHV		CL Energy	Cost	Notes
	(kg/m^3)	(GJ/m^3)	(MJ/kg)	(%)	(Cdn $/GJ)	
Electricyty					$16.67	6 c/kWhr
Fuel oil (l)	980	43.0	43.9	56.7%	$11.06	$67.42 Cdn $/barrel
Betuminous coal (s)	850	27.7	32.6	88.0%	$2.00	
Natrural gas (g)	0.648	0.035	53.5		$11.85	$11.24 $/MMBTU
CL (CL/NG price ratio 0.60)	1250	24.4	19.5	100.0%	$7.11	
CL (CL/NG price ratio 0.80)					$9.48	
CL (CL/NG price ratio 1.00)					$11.85	

If we assume that turbine issues can be adequately addressed using already commercially available super-coated alloys for the turbine blades when burning CL directly, then we can compare the approach to using biomass to power a steam-based system. The energy efficiency of the gas turbine is higher that the Rankine approach. Furthermore, the gas turbine is well suited for a combined cycle approach for large power plants greater than 20 MWe. Although it is difficult to determine the best cost effective capital costs for a given plant size, the following parameters need to be considered and weighed:

- With the efficiency factored in, the capital cost is 50% less between a gas turbine system compared to a Rankine system; and
- The added cost to process the biomass into CL adds $50/tonnes but removes the transportation cost to a large scale facility and provides a much cleaner and better fuel to burn.

At present, CL can be used to make power in three ways:

- Direct Burning in an external combustor of a gas turbine as implemented by Bioten Corporation, Knoxville, Tennessee USA.
- Direct Conversion to Syngas by reaction of CL powder with O_2 or enriched air in a cylindrical chamber without any catalyser at 420ºC.
- For smaller power the CL–Syngas can be directly used in a GE - Jeanbacher gas engine with 30.5% electrical efficiency. This engine has a very low capital cost for electrical energy generation ($960 per kWe). Such a system is part of the prehydrolysis plant design.

4.2.5 GHG Emissions

The GHG emissions are directly related to the energy balance of the briquetting process using prehydrolysis. For the analysis, all the process heat is provided by either wood chips or CL. Since the proposed implementation of this process is for making CL to displace natural gas, electricity from BC is used to operate the process as no internal power production has been assumed. The emissions for harvesting and manufacturing the CL, transportation, and the net CO_2 displaced from replacing natural gas as a fuel were calculated for the three locations investigated: local use, Alberta, and Europe. The displaced CO_2 is shown in **Figure 4.2.11**. The net GHG displacement is a function of the transport distance and varies around 1.1 tonnes of CO_2 per BDT of CL produced.

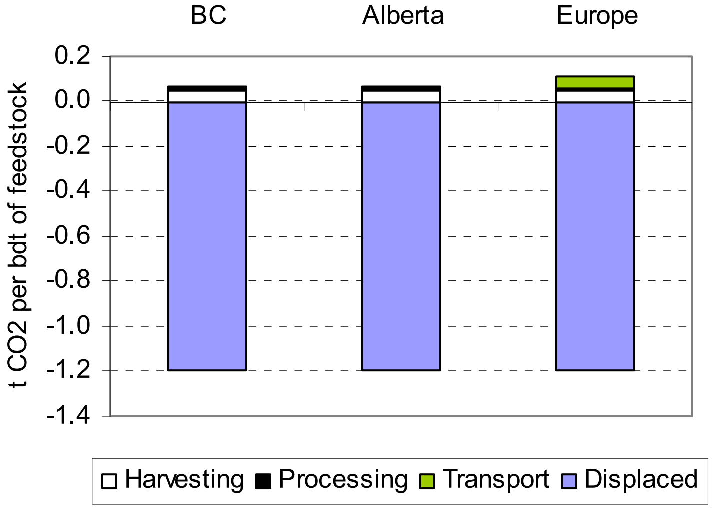


Figure 4.2.11 GHG Emissions for CL Briquettes Using Prehydrolysis

4.3 Small-Scale CHP

4.3.1 Understanding CHP

Combined Heat and Power (CHP) is a generic term that relates to any system producing both power and useful heat concurrently from the same fuel. This is a very efficient way of using fuel when making power. On the one hand, it is easier and more efficient to capture heat energy from fuels than electrical power. On the other hand, we require power to support our modern lifestyles even though power production from fuel sources is a relatively inefficient process. However, the energy not captured while producing power (the rejected energy) can often be used for its heat value. Consequently, taking the fuel that we would normally use for heat and using it first for electricity generation and then using the output of that process to supply our heat will maximize the available energy. CHP is used to obtain both electricity and heat from the same fuel.

The concept of CHP has been known and discussed for decades. Originally it was pursued as co-generation; the use of fuel to meet two purposes in a coordinated system. In particular, co-generation was used industrially where process steam was employed. Steam would be produced at a higher pressure and temperature, passed through a turbine/generator to produce power and then supplied to the industrial process. Where process steam is required, as in pulp and paper mills, such co-generation is highly desirable. Upgrades to add power generation should be encouraged where co-generation has not yet been implemented. A typical industrial process using steam will be capable of supporting relatively large-scale power generation which must be used to displace internal power consumption or supplied to the public power grid.

There is a fundamental “disconnect” between electricity consumption and heat consumption within general society. Traditionally, electricity has been produced in large centralized locations and distributed widely on a utility power grid. However, heat energy is typically generated at the point of use on a small scale, most often using fuels distributed from central facilities. The same fuels that are used for heat generation are often also used at centralized power stations. The most interesting observation is that electricity and heat are generally used on a comparable scale. Industrial users will consume both large amounts of power and large amounts of heat. Individual homes will consume small amounts of power and small amounts of heat. Although not exact, there is a relation between the quantities of power consumed and the quantities of heat consumed. Yet, even though small-scale users have a balance between their heat needs and their power needs, the traditional system treats power on a large-scale and heat on a small scale.

Given the observation that power is consumed on a scale relative to heat consumption, it becomes clear that there are un-addressed opportunities for small-scale CHP systems. The need exists for systems from individual homes (2-3 kW power, 4-5 GJ heat) to small communities (80 – 100 kW power) to townships (1 – 10 MW power). District heat systems that distribute heat (e.g. through hot water pipes) act similar to power delivery in a defined local area. The power generation portion is termed “distributed generation” and is being recognized in some jurisdictions as beneficial for reducing power losses, stiffening the grid and adding independent investment dollars.

4.3.2 Application of CHP for Bugwood

There is a particular advantage to using biomass as a fuel for CHP systems. Biomass is a renewable fuel that reduces dependency on crude oil and natural gas reserves. It can be a low cost energy source where it is a waste stream from another process (sawmills, etc.) or where it is harvested inexpensively. Using biomass-derived energy to displace fossil fuel use will also reduce emissions of greenhouse gases (GHG). Biomass use can bring economic benefits to remote communities that are surrounded by forests yet traditionally import fossil fuel energy for power and heat. Those same communities can reduce wildfire threats by thinning the interface lands, removing underbrush and ladder fuels while capturing the biomass energy.

With respect to bugwood use, the CHP option has both advantages and limitations as compared to other technologies discussed in this report. Use of bugwood as a fuel in CHP systems only makes sense where there is a user for the power and heat produced. Small communities can benefit from these systems and use the dead forests nearby. However, it must be recognized that this option insists on transport of bugwood from the harvest site to the user site. Alternatively, the CHP option may encourage a new small-scale industry to be established due to the availability of low-cost biomass power in remote areas.

CHP may also be used in conjunction with other technologies discussed in this report in a synergistic manner. Where CHP users are far from a source of bugwood, transport costs may become excessive. The potential exists to use technologies described in this report to concentrate the biomass energy in a different fuel form such as pellets or bio-liquid. Transport costs would be lessened. A CHP system may be a potential user for such fuels.

Technologies that concentrate the biomass energy into a different fuel typically require some level of electrical power input for their process. If these technologies are located in remote areas they may require an off-grid power source such as can be provided by the CHP option. This would allow using the local bugwood as a source of off-grid electrical power, rather than importing diesel or other fossil fuel. For example, it can supply all the electrical power and the heat for a prehydrolysis or pellet plant. Many of the technologies that produce a secondary fuel (e.g. pellets) use only a portion of the available biomass with the rest being a reject waste product (bark). CHP systems can use those waste products through a combustion process and thus provide greater utilization of the bugwood resource.

4.3.3 Process

There are several CHP processes that are commercial or will be soon. They are all based on a heat cycle such that the reject heat is made available for secondary uses. Heat cycles generally operate at relatively low conversion efficiencies. Efforts are usually made to maximize the cycle efficiency. These include using higher peak temperatures and pressures, using reheat or regeneration cycles, adding economizers and minimizing the low pressure of the cycle.

Four technologies are typically associated with potential small-scale CHP systems. The systems to be discussed here will include small-scale steam, the organic Rankine cycle (ORC), the Entropic (Turbion) system and the indirect air turbine.

Small-scale steam (see **Figure 4.3.1**)**:** Steam is the most known indirect heat cycle for power production. It forms the basis of nuclear, coal and biomass power systems. It has well-developed equipment, regulations and engineering expertise. Numerous techniques have been developed to maximize cycle efficiency. Large-scale steam systems can operate at overall efficiencies in the low-30%. However, many of these techniques are not suitable for small-scale steam systems as they add complexity and cost that cannot be justified.

Peak pressures and temperatures are generally limited to allow the use of carbon steel materials. This is required to keep costs from becoming excessive. The use of reheat and recuperation cycles is also limited to maintain simplicity and reduce costs. To provide heat in a

CHP system, a positive steam pressure is maintained downstream of the power turbine. This greatly reduces the power extraction as the cycle is sensitive to this factor. Expansion turbines lose efficiency at low flows unless their rotational speed is increased. However, steam is quite voluminous and turbine impeller sizes prevent compensating speed increases. A practical small-scale steam system will have an overall system electrical efficiency of about 10% - 12%.

Steam systems have inherent dangers associated with their boilers. Local regulations determine the training and registration requirements of operators. Highly trained personnel, where needed, add to the operating cost of steam systems. Exiting flue gas is typically about 315°C - 345°C, which limits flue gas cleaning options. CHP heat is offered as low-pressure steam, which limits the transport distance when used for district heat. CHP heat demands reduce the system electrical efficiency significantly. Few steam systems are offered below 3 MWe. They are custom configured and are difficult to justify economically, even in a CHP application.

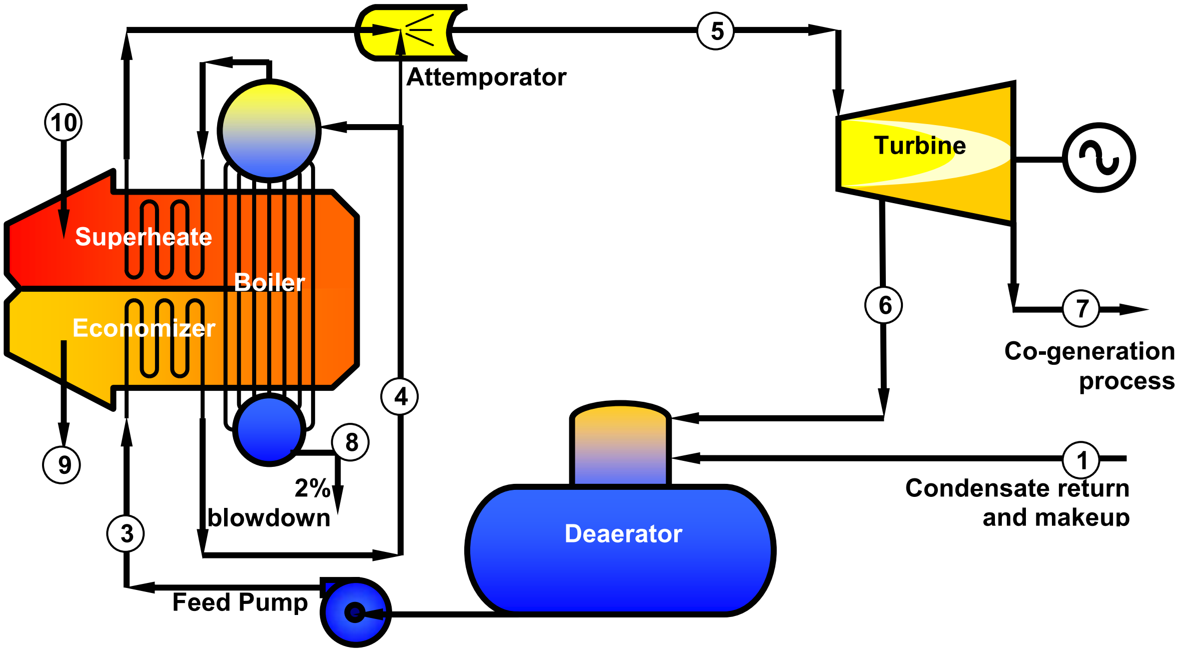


Figure 4.3.1 Small Steam CHP System

Organic Rankine Cycle: The organic Rankine cycle (ORC) differs from the steam system in that it uses an organic fluid (or synthetic oil) in place of steam. The system operates in a closed loop by re-circulating the working fluid between selected pressures. The peak pressure and temperature is again limited by material considerations and will be similar to small-scale steam systems. However, the lower system pressure can be increased and still be matched to the low-heat reservoir temperature. The higher pressure exiting the turbine means a reduced volume flow. A greater mass flow of organic working fluid is required to compensate for its lower enthalpy but this is partially mitigated by the effects of the higher molecular weight of the fluid. The net benefit is that a smaller turbine impeller can be used. The turbine impeller can be as small as 20% of the size of an equivalent power steam system turbine.

To reduce the inherent hazards of steam boilers, ORC systems typically employ a separate heat recovery circuit. ORC systems will use an independent combustor with heat recovery from the hot flue gas. Thermal oil is circulated through a heater in the combustor flue gas to collect heat and transfer it to the ORC power cycle. This approach bypasses the need for a registered steam operator in most jurisdictions. The double circuit adds complexity to the system and thus system cost. Exiting flue gas is typically about 310°C - 315°C which limits flue gas cleaning options. CHP heat is provided as hot water at 80°C (returned at 50°C); having been augmented by heating from the exiting flue gas. A practical ORC system will have an overall electrical efficiency of about 12% - 13%. The most available ORC system is from Turboden, srl, a European company and serves from 500 kWe to 2 MWe.

Entropic Cycle (see **Figure 4.3.2**)**:** The Entropic power cycle is an alternate form of the Rankine cycle that shows distinct advantages for small-scale applications. Like the ORC it uses a non-steam fluid in a closed loop. It limits its peak pressure and temperature to values similar to steam and ORC and its lower pressure is increased compared to steam systems, similar to ORC systems. The volume flow exiting the turbine is lower than ORC systems, allowing an even smaller turbine impeller, higher rotational velocity and slightly better turbine efficiency.

The Entropic cycle uses a non-combustible fluid and can be used safely in direct heat exchanger contact with the combustor hot flue gas. Moreover, within the Entropic cycle the working fluid is pre-vaporised before entering the heater. Thus, the Entropic cycle is inherently safe; having removed the boiling concerns of steam systems and the thermal oil fire concerns of the ORC. The Entropic cycle is a simplified arrangement, which serves to reduce size and cost.

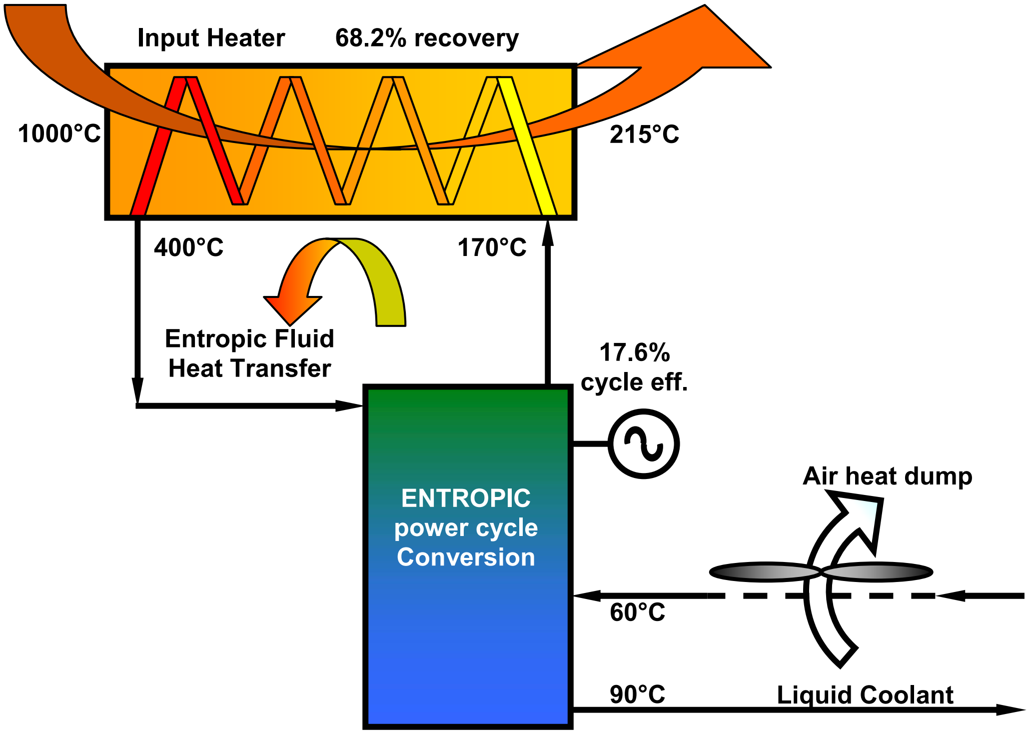


Figure 4.3.2 Entropic Power Cycle System

Greater heat recovery is obtained from the flue gas, which lowers the flue gas temperature further than steam or ORC systems. The typical flue gas temperature exiting the Entropic heater is around 205° - 215°C; well below ignition temperatures and sufficient to be used directly in bag houses or other devices. The higher energy capture assists the overall efficiency of the Entropic cycle. CHP heat is provided by the cycle coolant without augmentation as hot water at 90°C (return 50°C), which allows 100% of the cycle reject heat to be available for useful purposes. The Entropic system will have an overall electrical efficiency of about 12% - 14%. It is a new development from Entropic Energy Inc., a B.C. company, and serves sizes from 250 kWe to 2 MWe.

Air Turbine (Indirect Brayton Cycle): The indirect Brayton cycle uses the “jet engine” concept in which the combustor section has been replaced by an indirect heat exchanger in a hot flue gas exhaust stack. It is sometimes called an “air turbine” system. This concept has been proposed by a number of companies although commercial systems have not been forthcoming. CHP heat is available as clean hot air from the turbine exhaust which is not a useful form for transport in district heat systems. Hot water can be supplied by heat exchange with the turbine exhaust and/or the exiting flue gas.

A rarely discussed and poorly understood limitation of the indirect Brayton cycle is the trade-offs of overall electrical efficiency. The cycle efficiency of the Brayton cycle is increased when operating at higher pressures (and consequently higher temperatures). Unlike the jet engine in which the energy supplied is added to the compressed air heat, the indirect heat input is limited by the temperature of the compressed air. Greater operating pressure means greater compressed air temperature which, in turn, means less heat transfer from the flue gas. The overall electrical efficiency is the product of cycle efficiency and heat recovery efficiency from the flue gas. It can be shown that the balance between these competing processes are best met at 7 – 10 bar while recuperating the turbine exhaust flow energy. An indirect Brayton cycle will have an overall electrical efficiency in the order of 7% – 8% when using carbon steel heat exchangers. These systems are not commonly available at this time.

4.3.4 Energy Flow for CHP Systems

It has been noted in **Table 3.1.1** that current harvesting of bugwood varies in different areas and can be as low as 46 m³ per day. Multiple independent operations within a common area will produce up to 3,700 m³ of bugwood per day. These current operations collect bugwood as a by-product of green wood logging. It is assumed that individual harvesters will collect 1000 m³ of bugwood per day. This quantity equates to upwards of 300 tonnes per day for processing by CHP plants, which equates to about 3 MWe of power production. This power is in the level of consumption needs by townships and much larger than needed by small communities or individuals. Depending on the needs of any given region, several harvesting operations could supply a single township or a single harvesting operation may supply a number of small communities or individuals. CHP operations are by nature continuous (24 hours per day) but subject to demand (not necessarily operating at full capacity).

The four CHP technology options are noted below using the same bugwood harvesting and transport conditions. The energy flows, shown diagrammatically in **Figure 4.3.3** to **Figure 4.3.6**, are adaptations from [ESI 2004]. These figures indicate that the ORC and the Entropic CHP options offer the greatest energy conversion to electricity and the greatest overall CHP energy conversions. Both of these systems produce heat as hot water. This form of heat is particularly suited for district heating applications as it is in the most useful temperature range and it can be pumped significant distances.

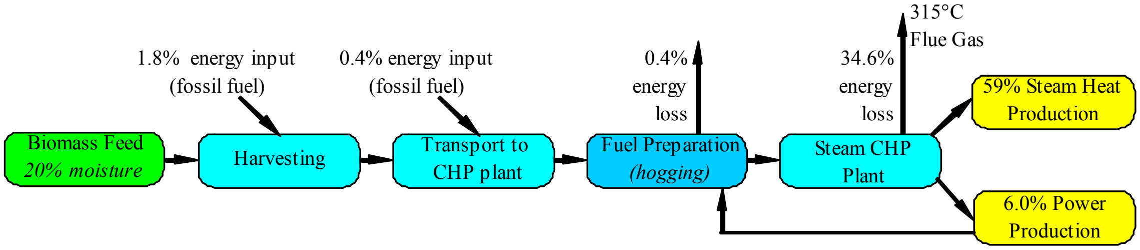


Figure 4.3.3 Steam CHP Energy Balance

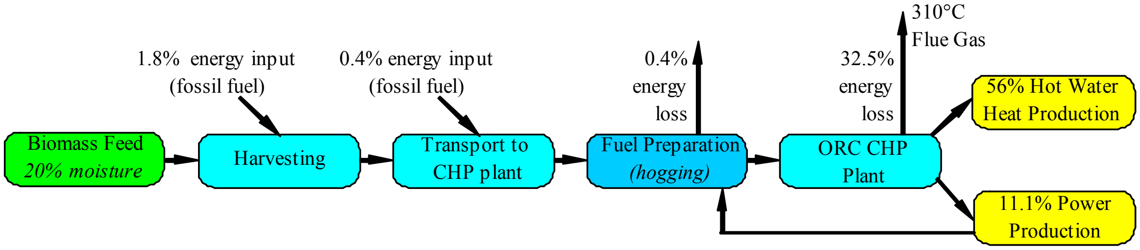


Figure 4.3.4 ORC CHP Energy Balance

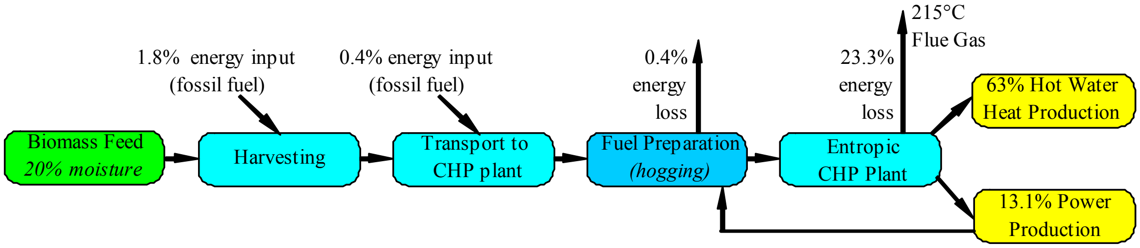


Figure 4.3.5 Entropic CHP Energy Balance

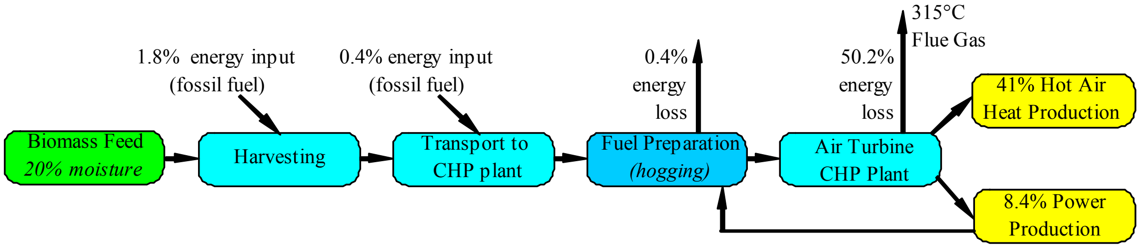


Figure 4.3.6 Air Turbine CHP Energy Balance

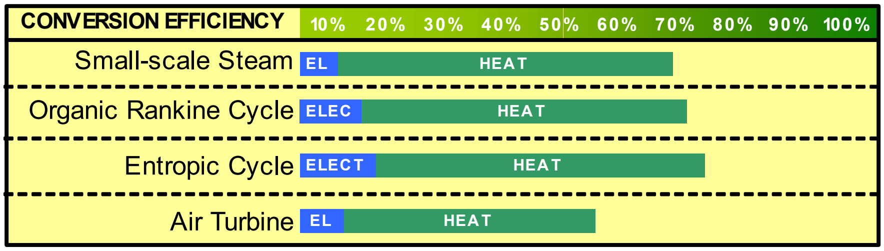


Figure 4.3.7 Conversion Efficiency Comparison

Conversion efficiencies are compared in **Figure 4.3.7**. The steam CHP option shows significantly less power production efficiency, largely due to the operating conditions being biased to supply co-generated heat. A condensing, small-scale steam system would produce almost the same electrical conversion efficiency as ORC or Entropic systems but would sacrifice the production of heat at useful temperature. The steam CHP option produces heat as low-pressure steam. This form of heat is less suited for district heat as it is limited in its transportability. However, certain industrial processes and users located close to the source could benefit preferentially.

The air turbine CHP option produces both poor electrical conversion efficiency and a poor form of heat. Hot air is generally less attractive as a heat source and is difficult to transport. The air turbine has yet to develop a niche application that shows advantages over the other options.

4.3.5 CHP Costs

The traditional expectation of capital costs is based on the experience of large-scale steam systems. Technology for large-scale steam is relatively well-defined and shows significant economies of scale. However, this conventional wisdom is not fully applicable for several reasons. Technology selection can have a greater effect on unit capital cost than scale of operation. Alternate technologies have optimum sizes that may differ markedly from conventional steam systems. Moreover, the economic justification is different for small users than for large enterprises. Similarly, the investment community is greatly expanded for small-scale systems since many more individuals, groups and financial institutions can operate at the lower absolute investment levels required.

Such small-scale (non-steam) systems are generally designed for automated functioning to remove the need for registered operators and allow unattended operation. A single manager can maintain operations without a continuous hands-on need. This reduces direct operating costs and makes remote installations viable.

There is a range of capital costs associated with the various small-scale CHP technologies. Within each technology there are also economies of scale. A summary of the size and costing ranges are shown in **Figure 4.3.8** below. No costing was available for Air Turbine systems.

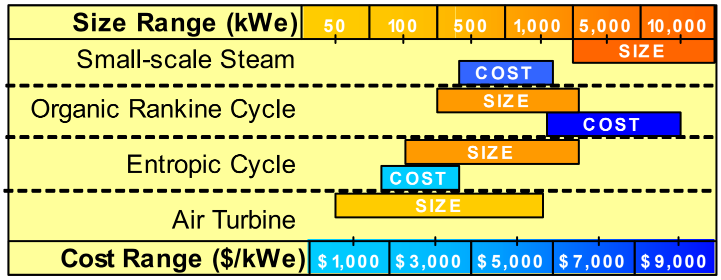


Figure 4.3.8 Cost and Size Ranges

As can be noted, there is a wide range of technologies and costs within the options for small-scale CHP systems. The ranges noted in Figure 4.3.8 may be extended in some circumstances and future systems are expected to extend them. The actual selection of a particular technology will depend on the situation. Where district heat is needed, the ORC or Entropic systems would be favoured. Where low-pressure steam has a specific application, the small-scale steam option would be favoured. Three variations of Entropic CHP systems are shown in the cost tables below (**Table 4.3.1** to **Table 4.4.1**) to indicate the effects of scale as well as off-grid and on-grid applications.

For district heating systems, significant costs can be caused by the construction of the heat distribution system. The costs displayed in the following tables do not include this cost, as it varies depending on the size and location of the plant. The capital cost therefore applies to a situation where an industrial user can use the heat in the immediate vicinity of the plant.

The 250 kWe CHP plant is assumed to be used in a small remote forest community. In this scenario the community is powered by a diesel generator with most buildings using heating oil. The value of power and imported oil can vary significantly in different communities based on location and access. Most power is subsidized in some manner but the true costs are high. This analysis used 18¢/kWh for power and 60¢/litre for heating oil. It is expected that such a community would use material harvested locally. This analysis used an average of 30 km for transport of feedstock. Only 50% of the annual heat produced is used for space heating; the remainder is rejected through air heat exchangers. The diesel generator will be retained for peaking power needs, but strongly reduced in output (or replaced by a smaller unit).

Table 4.3.1 Annual Cost Overview for a 250 kWe Entropic CHP Plant (21 m^3/day @ 95% utilization "off-grid")

	Cdn$ per year	Comments
Capital cost	*$ 800,000*	*Total of all equipment*
Salaries	$ 80,000	Based on Annual Salaries table
Maintenance	$ 80,000	10% of annual capital cost
Feedstock harvesting	$ 199,666	Harvesting cost only (@ $69/bd tonne)
Feedstock transport (30km)	$ 42,020	Truck transport ($4/m^3 + $4.5/100km)
Annualized Cost	$ 401,685	
Electrical Power Sales	$ 374,490	2,081 MW-hr @ $180 /MWe 'off-grid'
Heat Sales (50% utilization)	$ 281,250	468,750 litres @$.6/ litre heating oil
Incentives	$ 20,805	RPPI ($10/MWh)
Carbon Credits	$ 39,958	0.51 t/MWh + 86.1 t/TJ @ $15/tonne
Annualized Revenue	$ 716,503	
Profit	$ 314,818	
ROI	37.75%	IRR over 10 years
Profit ($40/m^3)	$ 205,737	
ROI ($40/m^3)	22.27%	

The 2 MWe CHP "on-grid" plant is assumed to be used to feed power into the provincial power distribution grid. This scenario assumes that the system is located where a portion of its heat can still be used productively. Such an application may serve at an industrial site or larger urban location. For this system, it is assumed that feedstock is transported an average of 100 km to bring it to site. This analysis serves to illustrate the comparison of on-grid and off-grid applications.

The 2 MWe CHP "off-grid" plant is assumed to be used in a larger remote forest community where local industry adds to the power requirement. As with the small CHP scenario, the community is powered by a diesel generator with most buildings using heating oil. The value of power and imported oil was accepted as 18¢/kWhr for power and 60¢/litre for heating oil. It is expected that such a community would also use material harvested locally although going slightly further for its harvest. This analysis used an average of 50 km for transport of feedstock. Only 50% of the annual heat produced is used for space heating; the remainder is rejected through air heat exchangers. A diesel generator will be retained for peaking power needs, but strongly reduced in output (or replaced by a smaller unit).

Table 4.3.2 Annual Cost Overview for a 2 MWe Entropic CHP Plant (165 m^3/day @ 95% utilization "on-grid")

	Cdn$ per year	Comments
Capital cost	*$ 4,250,000*	*Total of all equipment*
Salaries	$ 120,000	Based on Annual Salaries table
Maintenance	$ 212,500	5% of annual capital cost
Feedstock harvesting	$ 1,545,031	Harvesting cost only (@ $68.55/bd tonne)
Feedstock transport (100km)	$ 530,254	Truck transport ($4/m^3 + $4.5/100km)
Annualized Cost	$ 2,407,785	
Electrical Power Sales	$ 998,640	16,644 MW-hr @ $60 /MWe 'on-grid'
Heat Sales (50% utilization)	$ 2,250,000	3,750,000 litres @$.6/ litre heating oil
Incentives	$ 166,440	RPPI ($10/MWh)
Carbon Credits	$ 245,958	0.24 t/MWh + 86.1 t/TJ @ $15/tonne
Annualized Revenue	$ 3,661,038	
Profit	$ 1,253,253	
ROI	26.73%	IRR over 10 years
Profit ($40/m³)	$ 409,177	
ROI ($40/m³)	-0.68%	

Table 4.3.3 Annual Cost Overview for a 2 MWe Entropic CHP Plant (165 m^3/day @ 95% utilization "off-grid")

	Cdn$ per year	Comments
Capital cost	*$ 4,250,000*	*Total of all equipment*
Salaries	$ 120,000	Based on Annual Salaries table
Maintenance	$ 212,500	5% of annual capital cost
Feedstock harvesting	$ 1,545,031	Harvesting cost only (@ $68.55/bd tonne)
Feedstock transport (50km)	$ 383,752	Truck transport ($4/m^3 + $4.5/100km)
Annualized Cost	$ 2,261,283	
Electrical Power Sales	$ 2,995,920	16,644 MW-hr @ $180 /MWe 'off-grid'
Heat Sales (50% utilization)	$ 2,250,000	3,750,000 litres @$.6/ litre heating oil
Incentives	$ 166,440	RPPI ($10/MWh)
Carbon Credits	$ 313,366	0.51 t/MWh + 86.1 t/TJ @ $15/tonne
Annualized Revenue	$ 5,725,726	
Profit	$ 3,464,443	
ROI	81.30%	IRR over 10 years
Profit ($40/m³)	$ 2,620,367	
ROI ($40/m³)	61.13%	

These examples indicate the effects of size on the CHP economics. On a direct comparison it appears that the 2 MWe CHP system would be favoured over the 250 kWe CHP system. However, as was noted above, the economic justification is often different for small users. For instance, the 250 kWe system would be best suited for smaller communities. For such a community that is "off-grid" with power supplied by diesel generation, the cost of power is high (if unsubsidized). At $180 / MWe for diesel electricity, the simple ROI for the 250 kWe system is about 38% of capital investment whereas the larger plant provides over 80% return.

Small-scale CHP is a direct conversion of bugwood to its final use. It does not produce an interim fuel form to be further converted by another user. This implies that CHP systems require local users. Although it is possible to locate distributed generation plants that feed into the provincial power grid, they must be associated with a heat user to maintain satisfactory economics or incentives would be needed to offset the high cost of harvesting. The heat use of CHP systems has a marked effect on favourable economics. As was noted previously, there is typically a relative balance between heat consumption and power consumption. This balance makes local users a synergistic opportunity for small-scale CHP with limited excess power available to feed the general power grid.

4.3.6 Greenhouse Gas (GHG) Emission Implications

The effects of small-scale CHP on GHG emissions can be quite dramatic. Where power generated is used to displace grid power in B.C. the GHG implications are minimal. B.C. has predominantly hydro-electric power which does not have a significant GHG footprint. However, where CHP systems are used to displace diesel generated power, the GHG reduction equates to approximately 800 tonnes of GHG per GWe-hr. The heat component of small-scale CHP systems is used to displace fossil fuels. Natural gas, propane and heating oil are the typical fuels used for space heating. Natural gas in larger, well-served areas produces approximately 49.7 tonnes of GHG per TeraJoule of heat (tonne/TJ). Propane will emit approximately 30.9 tonnes/TJ and heating oil will emit 86.1 tonnes/TJ.

Two small-scale CHP scenarios were evaluated in this report for GHG emission implications (see **Figure 4.3.9**). They represent the two extreme situations but strictly with respect to emissions; not for economic or other aspects. The first scenario represents implementing a 2 MWe CHP system connected to provincial grid power and displacing natural gas used for heat. The second scenario represents implementing a 2 MWe CHP system displacing diesel generated power and heating oil. Both of these systems are assumed to operate at 95% output with 50% of the available heat being used productively.

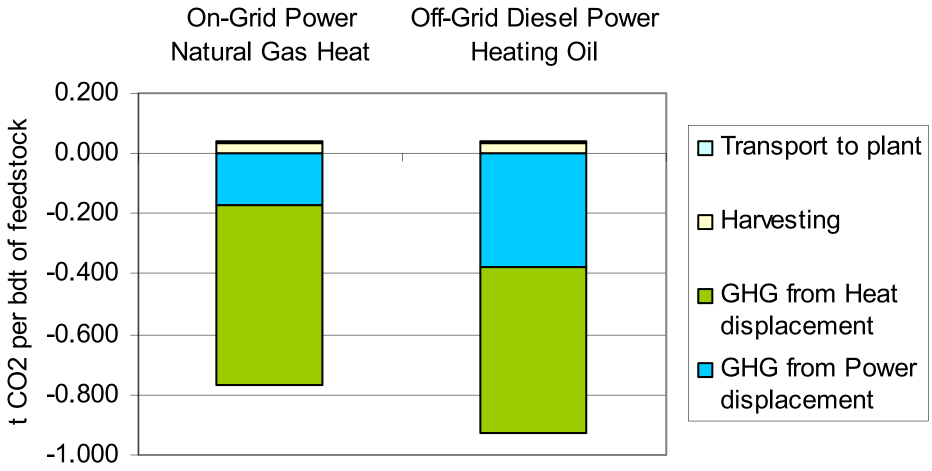


Figure 4.3.9 GHG Emission Reductions for Two CHP Applications

4.4 Bio-liquid Production Using Bugwood

4.4.1 Understanding Bio-liquid

Bio-liquid is a term used to describe the liquid products created when applying pyrolysis to organics. It has been traditionally called bio-oil but this term can be somewhat misleading as the bio-liquid is not similar to crude oil or its refined products. This study will use the term bio-liquid to maintain that distinction.

Bio-liquid is a fuel that has concentrated the energy of the original bugwood into a "higher value" product. This reduces the volume and, presumably, the cost of shipping bugwood energy. The bio-liquid product requires a market that will purchase and use this fuel.

Heating organic feedstock in the absence of oxygen will cause a chemical "breakdown" and release of numerous compounds. Many of these compounds can be condensed to form a "soup" of complex molecules – called bio-liquid. Some companies are using bio-liquid as feedstock to extract useful chemicals. Other companies are promoting bio-liquid as an energy fuel. In this report we will consider bio-liquid strictly as an energy carrier.

The fundamental pyrolysis process is to heat organic feedstock in the absence of air, collect the resulting gaseous emissions, cool and condense the gases into bio-liquid. It has been found that both the temperature and the speed of pyrolysis reaction affect the yield and "quality" of the resulting bio-liquid. Rapid reaction in fluidized bed retorts is the approach taken by Dynamotive Energy Systems Corporation of Vancouver, BC and Ensyn Technologies Inc. of Ottawa. Controlled temperature using mechanical augers is the approach taken by Advanced Biorefinery Inc. of Ottawa, Ontario (ABRI). A slow pyrolysis process is promoted by JF BioEnergy Inc. of Boston Bar, BC.

In all conversion processes, the original water content of the fuel becomes part of the resulting bio-liquid but since the feedstock has been concentrated, water forms a greater portion of the bio-liquid on a percentage basis. Biomass feedstock must be dried to <10% moisture content to result in 22%-25% water content in bio-liquid. Water is a necessary component in the bio-liquid as it acts to prevent the various molecules from separating into multiple phases.

There are two secondary products from the pyrolysis reaction of forest biomass: non-condensable gas and char. The non-condensable gas contains volatiles and is usually burned in the conversion process. Char is a powdery mixture of carbon mixed with the ash content of the original biomass. It is highly reactive and will spontaneously combust given the right conditions. Char has been promoted – unsuccessfully to date - for several applications. ABRI and Ensyn use the char for process heat during bio-liquid conversion. Other companies supply added heat from external sources and offer the char to the market.

Every pyrolysis process requires energy input to support the equipment. Motors are required to drive biomass feeders, pumps, fans, etc. Often this parasitic load is not clearly identified by the promoters. In addition, some processes require consumable makeup beyond the biomass feedstock; i.e. nitrogen and sand for fluidized bed systems. For most systems this means they must be located close to populated areas where power and supplies are accessible. The Advanced Biorefinery (ABRI) approach differs in that it uses less parasitic power in its process, it expects to be located in more remote areas and it will produce its required power locally if it is not available. ABRI promotes remote processing of biomass with a self-sufficient system that creates bio-liquid to be shipped to users.

4.4.2 Application of Bio-liquid to Bugwood

Bio-liquid is not a product in demand and markets must be developed. The primary reason for using bugwood for bio-liquid production would be to concentrate energy to reduce transport costs. This is a niche application being promoted by Advanced Biorefinery Inc. Bugwood would be converted into bio-liquid in relatively small-scale, distributed facilities with the product shipped to central user facilities or markets. Bio-liquid is a renewable fuel that can reduce dependency on crude oil and natural gas reserves.

The bio-liquid process uses all biomass components of the tree; including white wood and bark, recent or old dead wood. Bugwood has not been well studied so the quality of its bio-liquid has not been determined. However, as a feedstock, there is no reason to believe that there will be any difference in bio-liquid quality although yields may be slightly affected. One advantage of this process is that there is no major waste from the bugwood processed as is the case with pellet manufacture, which requires debarking. Conversion to bio-liquid will use whitewood, bark, bug-damaged wood and even the smaller wood and branches that cannot be used in other processes or products.

ABRI supplies bio-liquid conversion plants that consume 50 tonnes/day of dry biomass to produce approximately 30 tonnes/day of bio-liquid. Greater production is accomplished by multiple parallel conversion systems. This plant is designed to be self-sufficient. Non-condensable gas and char produced is used to dry the feedstock and heat the process. It is also available for power production if a suitable generator (e.g. a Stirling engine) is found. Motors and controllers consume less than 100 kWe of power per 50 tonne module which must be supplied from a grid connection or by local (diesel) generation.

Box 2 Ontario Ministry of Natural Resources: Bio-liquid

ABRI has signed a Memorandum of Understanding with Ontario Ministry of Natural Resources to supply and operate a 50 dry tonne per day distillation plant in Ontario. The transportable plant is to be built in modules and shipped to the selected sites for converting logging residues (slash) to distillate. Currently the slash is being left to decompose naturally or is burnt on site. The slash, when combined with diseased wood, low value species, and fire damage could provide enough electrical energy for over two million Ontario homes - all fuelled from clean, renewable energy.

Source: www.advbiorefineryinc.ca/News/news2.htm

Bio-liquid produced would be collected and transported to market. The major drawback is that there currently is no ready market for bio-liquid. The most direct options would be to use this renewable fuel in existing applications to reduce fossil fuel usage. This could be the case where existing power boilers could enhance output. There may also be some heating or process applications that could be fed by bio-liquid. Few of these potential users are aware and negotiations would be needed to establish these markets. There are also new applications that could be developed specific to bio-liquid use which may be encouraged by availability of bio-liquid, cost effectiveness and government policy encouragement. This study will assume that a market will develop to consume bio-liquid produced from bugwood.[5]

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[5] In 2005, Dynamotive has agreed principal terms with a company to sell its bio-liquid and char from the Lorne, ON plant. Electricity, steam and wood residues are sold to Erie Flooring.
See http://www.dynamotive.com/news/newsreleases/051206.html

4.4.3 Process

As noted above, there are several bio-liquid processes available for application to bugwood, each promoted by a separate company. Fluidized bed technologies are based on a rapid pyrolysis reaction intended to limit the time for chemical dissociation of large polymer molecules and create a more complex bio-liquid "soup". Power input to these systems is substantial to maintain the fluid state of the sand carrier. Moreover these systems need makeup materials, such as nitrogen and sand on an on-going basis. The processes are relatively sophisticated and require well-trained operators. This makes these systems less suited to remote areas where support services, material and energy are not readily available.

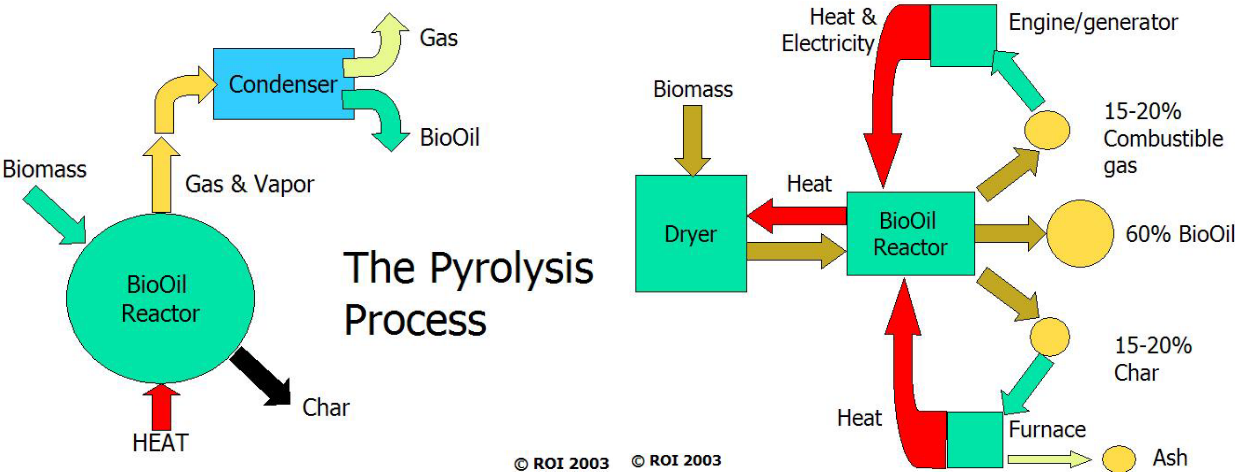

Figure 4.4.1 The ABRI Pyrolysis Process (formerly ROI) [ROI 2003]

Temperature-controlled pyrolysis can produce bio-liquid of similar quality in equipment that is much simpler. Power required for operation is still significant although much less than fluidized bed systems. Equipment maintenance is required but makeup consumables are not. The ABRI system (see **Figure 4.4.1**) in particular has been developed for remote, small-scale implementation and could be applied to bugwood consumption in B.C. Operators do not need high qualifications although they must be specifically trained to operate the equipment.

4.4.4 Energy Flow for Bio-liquid Systems

It needs to be noted that this analysis is made on an energy basis. However, no "quality" is assigned to the forms of energy referenced. The term "quality" is used here to note a combination of energy form and level of processing to reach its consumer form. For instance, fossil fuel noted in the energy balance diagram is typically diesel, which is a highly refined form of the original crude oil. The consumption of diesel represents a final use although one with a significant associated efficiency loss. Similarly, electricity represents energy in a final form before use, which has inefficiency losses associated with its supply. In general, energy quality suggests energy is in a form pre-prepared for its final application.

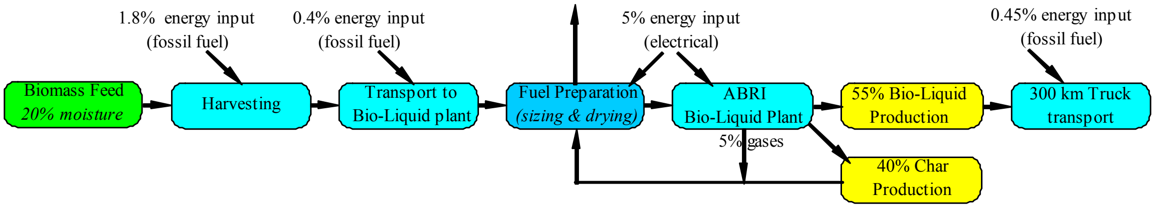

Figure 4.4.2 Bio-liquid Energy Balance

In the Bio-liquid energy balance (**Figure 4.4.2**), the chemical energy content of the original fuel is used as a baseline. This unfairly equates high-quality energy with biomass heat potential. It should, but doesn't, account for efficiency losses associated with the supply of the input energy. The fossil fuels and electrical energy used in the bio-liquid production process are compared on a direct conversion basis.

Similarly, the product, bio-liquid, should be considered of less quality than the fossil fuels it could replace. Bio-liquid has a lower heating value, greater water content, more handling concerns and fewer direct application opportunities. Typical bio-liquid has an energy content of 17.5 GJ/tonne (LHV).

4.4.5 Bio-liquid System Costs

Costs have been based on the ABRI bio-liquid system. ABRI has developed a strategy of bio-liquid production for locations that lack a local or direct use of biomass energy. In such applications the ABRI approach is to concentrate the biomass energy into a bio-liquid product more suited for storage and transport. This implementation strategy is consistent with the scope of this study.

The ABRI system is developed as a module sized to handle 50 tonnes/day of feedstock. This is a standard unit that is pre-constructed and commissioned in the manufacturing facility, then shipped to site. Multiple units are used to serve greater throughput. The ABRI system is semi-mobile, which allows flexibility when applied to bugwood harvesting (see **Figure 4.4.3**). It can also be operated off-grid, although in such applications it requires local power generation and currently uses diesel generation. In the future, it is hoped that an affordable bioenergy electrical supply system will be found to make the ABRI system almost completely energy self-sufficient.

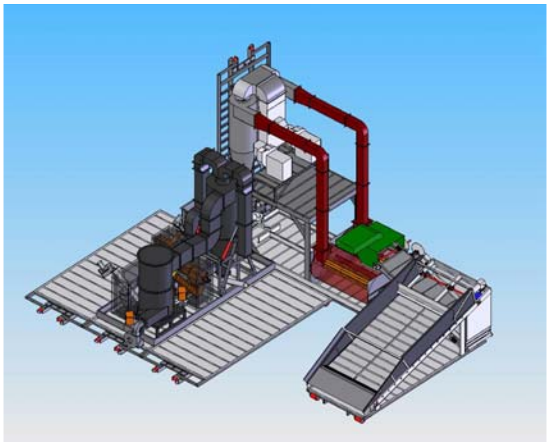

Figure 4.4.3 ABRI 50 t/day Pyrolysis Plant Module [ABRI 2006]

The generally accepted minimum size of bio-liquid plant is 100 tonnes/day of feedstock. This size is considered necessary to justify the equipment and operating costs while producing sufficient product for market. ABRI supplies two parallel units to form a 100 tpd installation. Larger plant sizes may be appropriate for bugwood utilization to address the very large quantities of biomass material. However, it may be most useful to distribute bio-liquid plants in various remote areas, rather than a central production facility. The fundamental advantage of the bio-liquid conversion approach is the ability to concentrate the bugwood energy into a liquid fuel while still in the remote area and ship it to market more efficiently than shipping the original biomass. Bugwood converts approximately 60% by weight to bio-liquid. **Table 4.4.1** indicates the potential cost structure of a bio-liquid facility in a way comparable to other potential systems in this study. Revenue was based on using the bio-liquid product to displace oil used to augment power boilers. Oil prices are currently fluctuating and increasing so a value of $9 /GJ was used as an expected average.

Table 4.4.1 Annual Cost Overview for a 100 tonne/day Bio-liquid Plant

	Cdn$ per year	*Comments*
Capital cost	*$ 3,500,000*	*Total of all equipment*
Salaries	$ 120,000	Based on Annual Salaries table
Maintenance	$ 175,000	5% of capital cost
Operating Power Costs	$ 59,532	1,751 MW-hr @ $34/MW-hr
Feedstock harvesting	$ 2,500,574	Harvesting cost (@ $68.55/bd tonne)
Feedstock transport (100km)	$ 858,195	Truck transport ($4/m^3 + $4.5/100km)
Product transport	$ 635,813	300 km @ $.0635/t-km +$10/t loading
Total Cost	$ 4,349,115	
Revenue from Product Sales	$ 3,447,180	383,020 GJ @ $9. /GJ
Carbon Credits	$ 494,670	86.1 t/TJ @ $15/tonne
Total Revenue	$ 3,941,851	
Profit	$ (407,264)	
ROI	negative	
Profit ($40/m³)	$ (1,773,369)	
ROI ($40/m³)	negative	

The above analysis indicates that this technology is not profitable under the pre-conditions cited. It should be noted that the high cost of harvesting is almost solely responsible for this result. For those situations, where bugwood can be made available from a harvest that is attributed to a different cost centre (such as sawmill feedstock), this technology could be economically viable. In the Ontario demonstration project described above, (see box 2) the feedstock is brought to the roadside by others and not costed against the ABRI system.

4.4.6 Greenhouse Gas (GHG) Emission Implications

Two GHG scenarios were evaluated and plotted in **Figure 4.4.4** with respect to a 100 tonne/day bio-liquid plant. The first is situated where grid electrical power is readily available. The second considers off-grid power generation from diesel, sufficient to operate the bio-liquid conversion system. In both cases it was assumed that the bio-liquid product would be used to displace heating oil (bunker C) within BC.

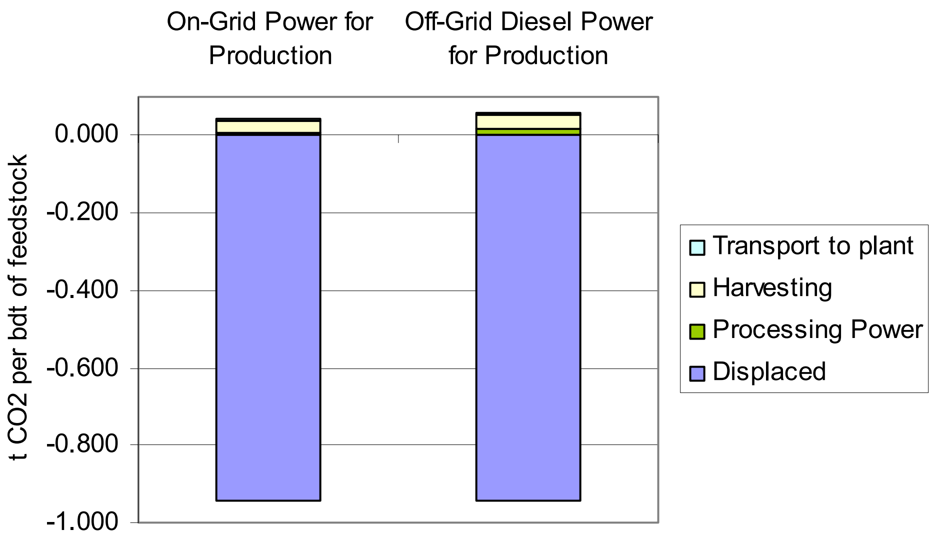

Figure 4.4.4 GHG Emission Reductions for Bio-liquid Production

4.5 Lignocellulosic Ethanol

4.5.1 The Lignol Process

There is currently no commercial technology to extract ethanol from softwood, although attempts are being made to gasify wood to produce ethanol or methanol (see chapter on methanol). MEMS USA is planning to build a gasification plant in Ontario by 2010, using low-cost forest residues.[6] However, Lignol Innovations, a Vancouver, BC company, is working on the commercialization of the Organosolv process that allows using softwood as a feedstock for ethanol production while avoiding the energy-intensive gasification step. The company has recently attracted new investors and installed new management. They have advised that some of the older public information available on their process may not reflect the current state of the technology but they are not prepared to publicly release new information. Much of the data described below is therefore based on older information. **Figure 4.5.1** shows the Lignol process, which uses enzymatic hydrolysis and results in a large number of products, including lignin, ethanol. xylose, and furfural. The first demonstration plant is planned to be completed by 2007, and successful testing could result in commercialization of the process in the coming decade, when the bugwood resource is at its peak.

Incoming bugwood would have to be de-barked and chipped. The existing (laboratory-scale) pilot plant processes 6 kg quantities of lignocellulosic fibre treated with a 50:50 blend of ethanol and water at approximately 200°C and 27 bar (400 psi) pressure. The generated black liquor is then sequentially processed to recover a series of chemical byproducts. The remaining cellulose fibre is sufficiently delignified to be more readily converted to ethanol. While the extraction process is a batch process in the pilot plant, solvent and byproducts recovery is operated continuously. Lignin is recovered by “flashing” the high pressure black liquor to atmospheric pressure, followed by rapid dilution with water. Subsequently, lignin precipitates readily and is dried to a fine powder. The remaining solution contains numerous valuable materials such as ethanol, furfural, extractives and dissolved sugars. This liquid stream is fed to a distillation tower for ethanol recovery while the resulting ethanol-free stream, or stillage, is processed in various systems to isolate and purify several high value products described below.

The process produces several by-products, some of which may have significant market value:
Organosolv lignin major current market applications include antioxidants (greases, lubricating oils), resin replacements for waferboard or OSB production, animal feed supplements, additives (brake linings, rubber products, concrete) and advanced light weight materials.

Acetic acid is sold commercially in several grades, depending on its purity. It is the basis for manufacturing acetic anhydride used in the production of cellulose acetate fibres and membranes. It is also used in the production of vinyl acetate, a basic raw material used to manufacture latex paint and paper coatings.

Xylose is a five-carbon sugar widely present in fruit and root vegetables. It is readily converted into a specialty polyol (xylitol) that has about 60% of the sweetness of sucrose and is suitable for diabetics to consume without the need for insulin. However, no xylose can be extracted from softwood feedstocks.

Furfural can be used to produce polytetramethylene ether glycol for the production of Lycra® and spandex. It is also used to produce lubricants, coatings, adhesives, plastics and foundry resins for cores and moulds to cast metal components.

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[6] See http://www.northernontariobusiness.com/regionalReports/ThunderBay/01-05-Hearst.asp

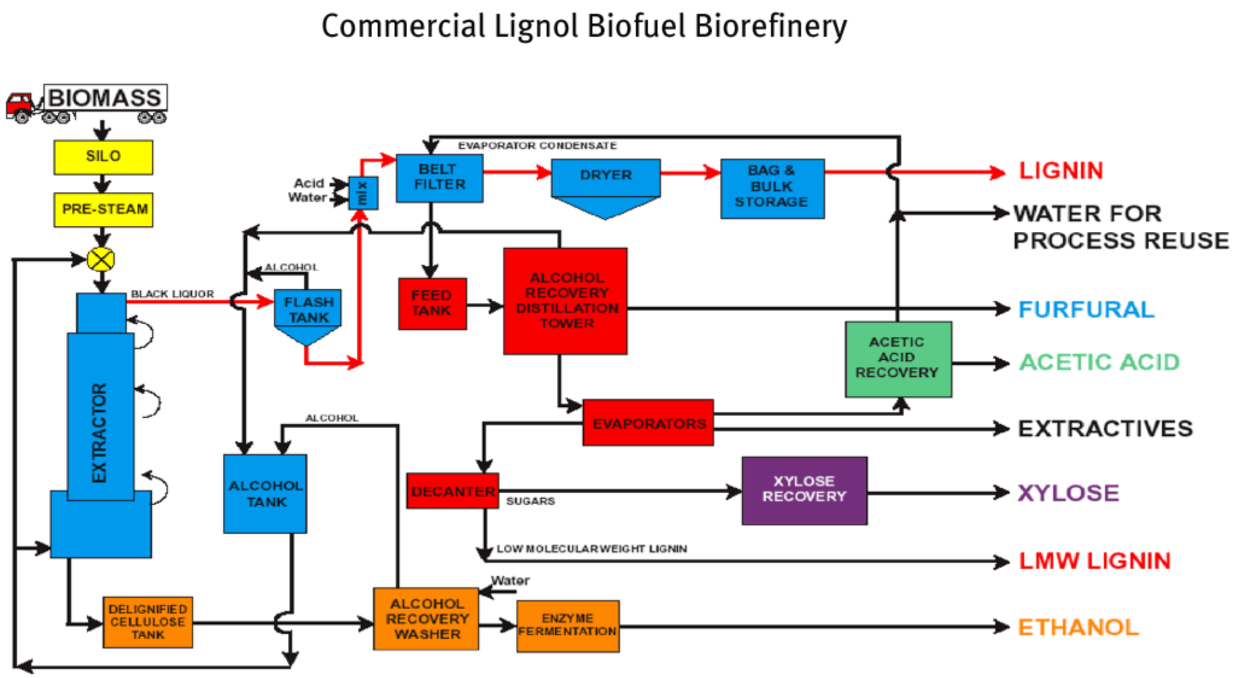

Figure 4.5.1 Lignol Process Diagram [LI 2005a]

Wood extractives include various chemical compounds and are raw materials for a substantial chemicals industry including printing inks, flavours and fragrances. BC companies lead the way in studying one component — phytosterols — recovered from the extractives fraction of softwoods such as spruce or pine. Phytosterols are increasingly in demand for the manufacture of cholesterol-lowering margarines and spreads.

4.5.2 Energy Balance

The energy balance presented here is preliminary with respect to process energy needs as the exact process data were not available for this analysis. In the absence of actual process data, it is therefore assumed that the plant uses an amount of energy similar to starch-based ethanol production processes, rather than those based on lignocellulosic feedstocks, such as the energy-intensive Iogen process. Steam use for that process is 13.5 MJ/litre, and electricity use is modelled as 0.074 kWh/litre of ethanol [AAFC 1999]. However, half of the energy demand for steam can be covered by the combustion of the bark residue. The plant is also allowed some diesel fuel to run various engines (0.03 litres per litre of ethanol). Transport parameters are 150 km transport of logs to the plant, and 700 km rail transport of ethanol. No transportation of co-products was included here.

As shown in **Figure 4.5.2**, a bit more than 40% of the energy contained in the biomass feedstock can be used as transportation fuel. A credit of 5.6% is given for the acetic acid co-product, which would otherwise have to be manufactured at that energy expense. The remaining feedstock energy is contained in the other co-products, such as the lignin. While lignin is not used as an energy feedstock, but sold for other purposes, its use displaces other chemicals for which processing energy can be credited. If lignin is used in OSB production, it replaces phenol-formaldehyde resin as the binder in this application. Phenol-formaldehyde production requires an energy input of 16,486 BTU/lb, or 38.5 MJ/kg [Kline 2002], which is thus displaced. Lignin accounts for the bulk of energy (and emissions) displacements from co-products. The remaining products' energy impacts were not quantified here, but mean that the overall energy displaced by these products is larger than the 14.4% of the feedstock energy input, which are attributed to lignin alone.

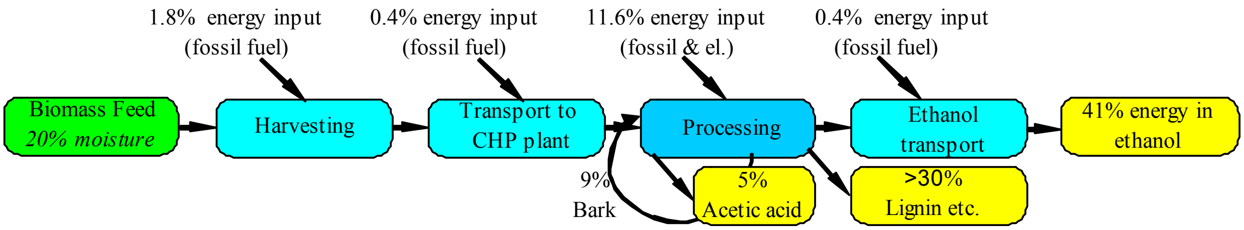

Figure 4.5.2 Preliminary Energy Balance of the Lignol Process

4.5.3 Manufacturing and Transport Costs

Plant revenues will come from both the ethanol and co-product sales. The most important product is actually not ethanol, but lignin. This fact implies that there needs to be a stable market for the lignin produced, at the projected price level. Commercial values for Organosolv lignins range from US$0.30 to US$1.40 per pound (a value of US$0.50 per pound was assumed for this analysis). On a mass basis, the expected (confirmed) ethanol yield from cellulose is 19 - 20% of feedstock input, and the projected yield from C-6 hemicellulose is 3.5 - 5.5%. The overall ethanol yield would therefore be between 22.5% and 25.5% [LI 2006].

Lignol's plant design envisages a 35,000 tonnes per year (wood feedstock) plant size. Due to the current stage of its business development, Lignol Innovations is not ready to publish all of the process data required for this study, and the mass balance was therefore established based on several sources indicating the amounts of co-product streams from Lignol and other hydrolysis processes (see **Table 4.5.1**). The capital cost for a commercialised Lignol plant is given as $36 million, and the operating costs as $10.4 million per year [LI 2004].

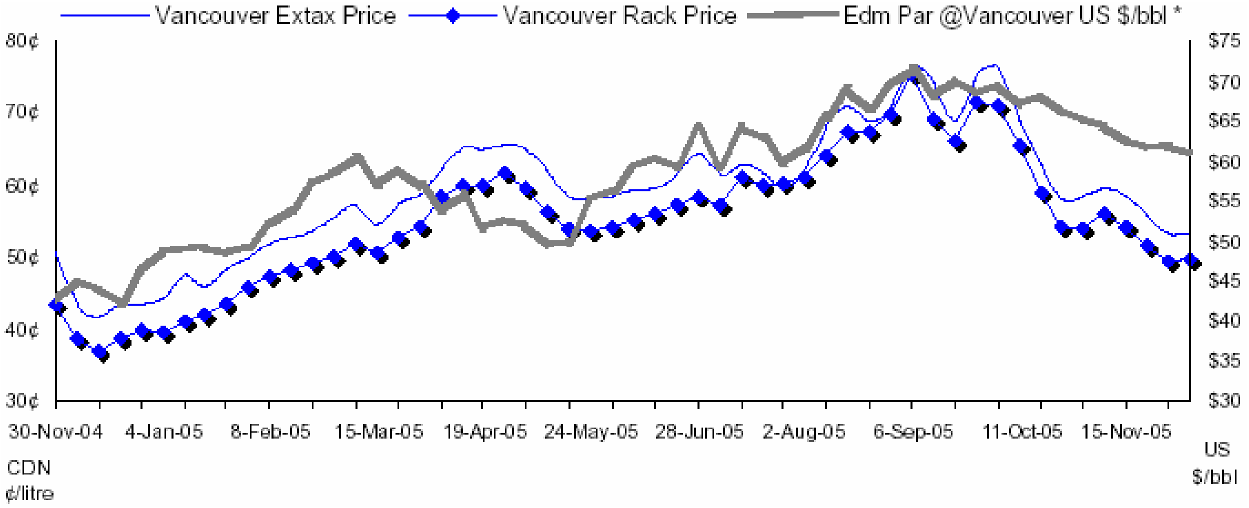

Figure 4.5.3 Vancouver Gasoline Rack Price [CPPI 2005]

The ethanol would have to be transported to an oil refinery to be mixed with gasoline. Refineries exist in Burnaby, BC (Chevron)[7] and Alberta. For this study, it is assumed that ethanol is

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[7] The Chevron refinery is the only refinery on the west coast of Canada, and has a capacity of 2.5 million tonnes per year (52,000 barrels per day). Adding 10% of ethanol to the fuel would mean the refinery could take up to 250,000 tonnes (313,000,000 litres) of ethanol.

transported to a refinery in the Vancouver area by train. The refinery will mix ethanol with gasoline (some provinces have made it mandatory to achieve a certain percentage of ethanol in gasoline), and pay close to the rack price for gasoline to the ethanol producer. The Vancouver rack price for gasoline was around 50 cents per litre in 2005 (see **Figure 4.5.3**). Ethanol has a lower energy content than gasoline, but enhances performance through its higher octane value, such that there is no energy penalty if ethanol is mixed with gasoline in quantities up to 10%. However, a 10% lower price is assumed as the revenue to remain conservative, i.e. $0.45 per litre.

Co-products are sold into existing markets in Canada or the U.S. at the prices indicated in **Table 4.5.1**. The percentages in the table indicate the mass-based product streams as a share of feedstock input. As the bark represents about 10% of the stem, the yields per bdt of harvested wood are somewhat lower. The revenue is based on a preliminary mass balance, which should be replaced by actual Lignol process data with bugwood as the feedstock when a more detailed feasibility assessment is undertaken. The mass balance was established based on the Lignin yield provided by Lignol, which was then used to estimate the other product streams based on a presentation by Lignol Innovations given in 2004 [LI 2004]. The furfural yield was assumed to be the same as the yield used in the previous chapter on briquettes and prehydrolysis. The revenue from ethanol is composed of several elements: first, the market value is assumed to be close to the rack price of gasoline, i.e. $0.45 per litre. The Canadian federal government provides an ethanol consumption incentive of $0.10 per litre. Gasoline is taxed with between 14.5 and 20.5 ¢/litre in BC [MSBR 2005]. A provincial excise tax exemption for ethanol therefore reduces the price of ethanol by this amount when it is used as a transportation fuel mixed with gasoline in quantities between 5 and 25%. Assuming an average tax reduction of $0.17 per litre for the provincial gas tax, this adds another $0.27 to the market value of ethanol, to a total of $0.72 per litre ($0.90 per kg).

No transport costs were taken into account for co-products in the calculations below, but their effect is deemed to be moderate, or they may be borne by the buyer. The precise amounts of ethanol and co-products that would be produced from bugwood are not even known to Lignol Innovation themselves, i.e. the numbers presented here are still very preliminary and based on default values obtained from mixed softwood residues from sawmills. Once a demonstration plant has been completed, testing with bugwood as a feedstock should be carried out to confirm these yields.

Table 4.5.1 Expected Revenues from Sale of Products and Co-Products

Co-product	Amount per 35,000 bdt of bugwood	Price per kg	Revenue
Ethanol	7,875 t (25%) [LI 2006]	$0.90	$7,087,500
Lignin	5,643 t (16%) [LI 2006]	$1.32	$7,448,760
Furfural	1,540 t (4.4%) (see Chapter 4.2)	$1.12	$1,552,320
Acetic acid	1,500 t (~4%) [LI 2004]	$1.20	$1,620,000
Extractives	12% of total revenues [LI 2004]	unknown	$2,125,030
TOTAL			**$19,833,610**

As shown in **Table 4.5.2**, the plant does provide an ROI of 13.8%, even with the high price of bugwood as a feedstock. However, whether the plant performs that well depends largely on co-products yields and their market values. The quality (and hence, price) of lignin from bugwood is not known with certainty, and product quality may vary depending on the age of the dead trees that are harvested. The world lignin market is about 1.2 Mt per year, 25% of which in North America [TCG 2004]. This seems a large enough market to accommodate the quantities expected from several ethanol plants, but Lignol would have to compete with other companies for this market. More certainty about the parameters used for the calculations is required before the private sector would be ready to use this technology with bugwood as the feedstock.

Table 4.5.2 Annual Cost Overview for a 35,000 bdt Lignol Plant

	C$ per year	Comments
Capital cost	36,000,000	Total of all equipment
Salaries	10,400,000	20 people
Maintenance		Based on Lignol 2004 estimate
Enzymes		1.5 cent/l
Electricity		0.074 kWh/l, 3.4 cents/kWh
Natural gas		13.5 MJ/l (steam),partly covered with bark
Diesel		0.008 gal/l
Feedstock harvesting	2,399,250	Harvesting cost only
Feedstock transport	1,051,050	Cost of truck transport to plant
Product transport	252,550	700 km by train (ethanol only)
Total cost	14,102,850	
Revenue from ethanol sale	7,087,500	$0.72 per litre (ethanol)
Revenue from lignin sale	7,448,760	$1.32/kg
Revenue from furfural sale	1,552,320	$1.12/kg
Revenue from acetic acid s	1,620,000	$1.20/kg
Extractives	2,125,030	12% of total revenues
Carbon credits	667,477	If applicable, $15 per tonne of CO_2
Total revenue	20,501,087	Sale in BC
Profit	6,398,237	
ROI	12.10%	IRR over 10 years
Profit ($40/m³)	*5,087,487*	
ROI ($40/m³)	*6.84%*	IRR over 10 years

4.5.4 GHG Emissions

Emissions were calculated for Lignol process (see **Figure 4.5.4**) based on the estimated energy inputs above. For ethanol, it is assumed that it replaces gasoline on a 1:1 basis (1 litre for 1 litre) because of its higher octane value (i.e., no correction for the lower energy content of ethanol was made). This rule applies for small quantities of ethanol mixed with gasoline (10% or less), whereas an adjustment would have to be made for high ethanol content in automotive fuels (e.g., E80). Credits are given for avoided emissions from acetic acid production and for lignin displacing phenol in resins, assuming production energy requirements would be covered by natural gas in an industrial process (simplified assumption). No credits are given for any of the other co-products. The net displacement is 1.27 tonnes of CO_2 per tonne of feedstock.

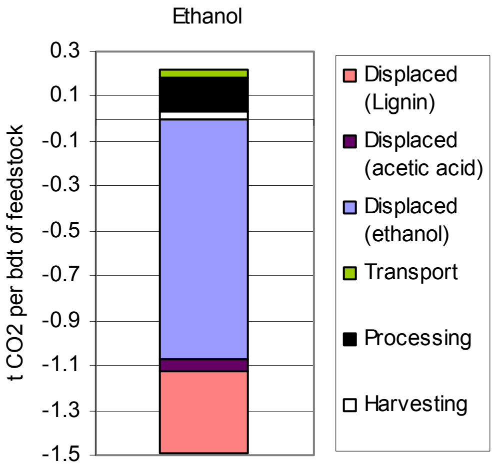


Figure 4.5.4 **GHG Emissions and Emission Reductions from Ethanol, Based on the Lignol Process**

4.6 Bugwood to Methanol

4.6.1 Methanol Production through Gasification of Bugwood

The conversion of biomass to methanol requires numerous processes some of which are only necessary depending on the choices upstream (see **Figure 4.6.1**). The two main steps which can not be avoided and which constitute the key parts of the process are the gasification and methanol synthesis. The first step, gasification is the transformation of the feedstock to syngas. The correct choice of gasification will minimize the subsequent cleaning steps that will be necessary for the utilization of the syngas for methanol production. The second step methanol synthesis involves the transformation of the syngas to methanol. All the processes are complex and use many pieces of specialized equipment which makes the operation expensive and places emphasis on the importance for optimization of the process as a whole. The choice of gasifier is dependant on many parameters with the major one being size of operation. Different sized operations suite different transportation and gasification method which ultimately give the net efficiency.

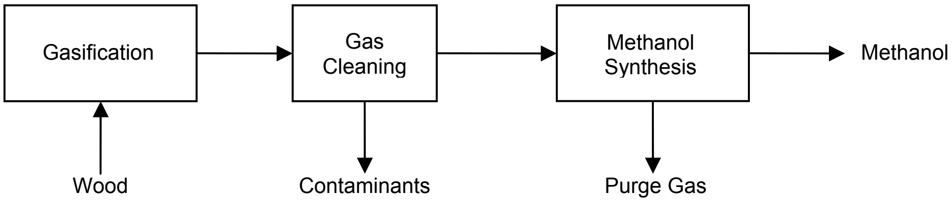


Figure 4.6.1 Bugwood to Methanol Flow Diagram

4.6.2 Feedstock Pre-processing

Although methanol production is technically challenging, feedstock requirements for production of methanol from thinnings are minimal. Most analysis assumes the process from bugwood to methanol requires the feedstock to be debarked, but this assumption may be considered conservative. The debarking of feedstock in other processes like pelletization, bio-oil and syngas have end uses that are incompatible with contaminants that may be produced from including the bark. For methanol, the chemical composition of the bark does not impact the final product the same way as it does for other processes; unlike most studies this analysis assumes that debarking is not required. The first three pre-processing steps best suited to roadside processing are shown in **Figure 4.6.2** below. The energy used for these steps is usually in the form of diesel at location or electricity if done at the plant. For our study, we will make use of the end product (methanol) for these processes.

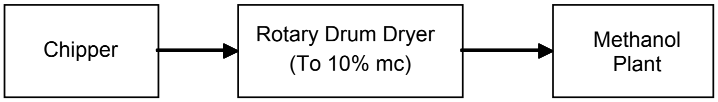


Figure 4.6.2 Pre-processing Flow Diagram

Entrained flow gasifiers require more pre-processing than fixed bed and fluidized bed gasifiers. This is because entrained flow gasifiers require the feedstock be pulverised into fine powder. Entrained feedstock must be 100 to 600 µm compared to the 3000 µm needed for fast pyrolysis. This is accomplished by either grinding or using torrefaction and then grinding. Torrefaction is a thermochemical pre-treatment carried out at a temperature of 200°C to 300°C in the absence of oxygen (see **Figure 4.6.3**). The short period of exposure to heat in an oxygen-free environment breaks down the hemicellulose that holds the macro fibrils together, which allows for easier grinding and decreases the amount of energy required to process the feedstock. The heat energy requirement for torrefaction could be supplied by the waste bark and would represent approximately 25% of the bark, or less than 0.5 GJ. With this process, it may be possible to integrate torrefaction and grinding into a mobile unit, which could make decentralised entrained gasification possible in either a large mobile unit or a transportable processing plant.

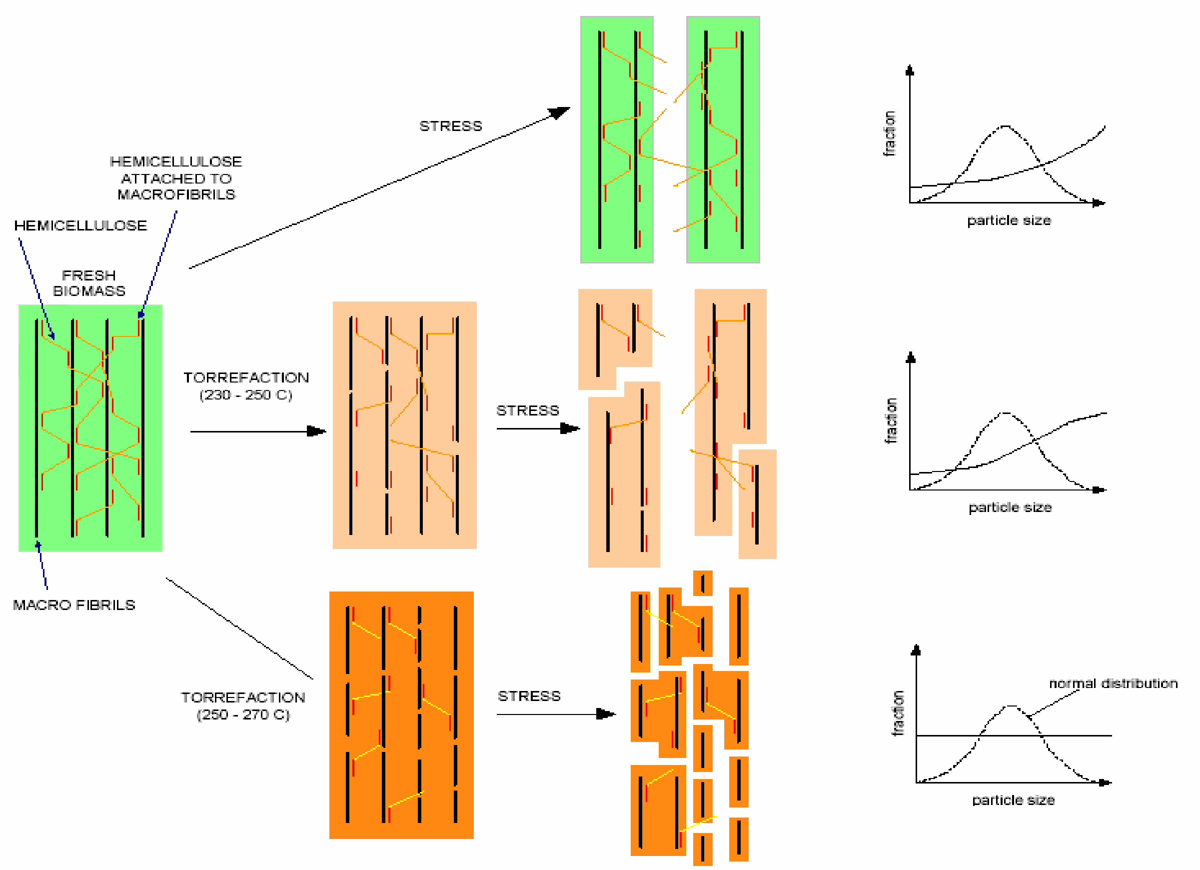


Figure 4.6.3 Simplified Representation of the Torrefaction Process

4.6.3 The Gasification Process

Gasification for Conversion to Methanol: The purpose of the gasifier is to decompose the biomass into a gaseous form. The ultimate goal is to create a gasifier that can convert a solid biomass material to a syngas with high energy content: H_2, CO and CH_4. Significant research has already been invested and is continually being put into gasifier research. The best way to classify the many existing gasifier configurations is to separate them into three main types, i.e. fluidized bed, entrained flow and fixed bed gasifiers. These categories can be further split into direct or indirect / co-current or cross-current. For large-scale operations, only the first two are considered feasible since fixed bed gasifiers are impractical for high biomass throughputs. For mobile production, all three are possible choices since throughput will be small. The size and complexity of the gasification equipment dictates the ease and feasibility of being able to take what is commonly stationary equipment and producing either mobile or transportable equipment. The complexity of the gasification equipment varies greatly, from the simplest being a fixed bed direct gasifier to a more complicated entrained or indirect fluidized bed gasifier.

Figure 4.6.4 A Gasifier by Vidir Machine Inc. This Stationary Gasifier Unit Could Easily be Converted Into a Mobile Unit.

Gasifiers: *Fixed Bed Gasifiers* - The counter-current fixed bed ("up draft") gasifier (Figure 4.6.4) consists of a fixed bed of fuel through which the "gasification agent" (steam, oxygen and/or air) flows in counter-current configuration. The ash is either removed dry or as a slag. The slagging gasifiers require a higher ratio of steam and oxygen to carbon in order to reach temperatures higher than the ash fusion temperature. The throughput for this type of gasifier is relatively low. Thermal efficiency is high as the gas exit temperatures are relatively low. However, this means that tar and methane production is significant at typical operation temperatures, so product gas must be extensively cleaned before use, or be recycled to the reactor. The use of a tar cracking bed to break down the components to usable species is preferred over removal but the technology does not suit mobile applications since cost and complexity is increased. An example of a counter-current fixed-bed configuration is the MESH Technologies Inc. unit in **Figure 4.6.5**, showing a gasifier configuration with low technological complexity. This style of gasifier is well suited to small-scale or mobile applications due to simple configuration and scalability. The trade-off in terms of efficiency loss is made up by the low equipment and operational cost.

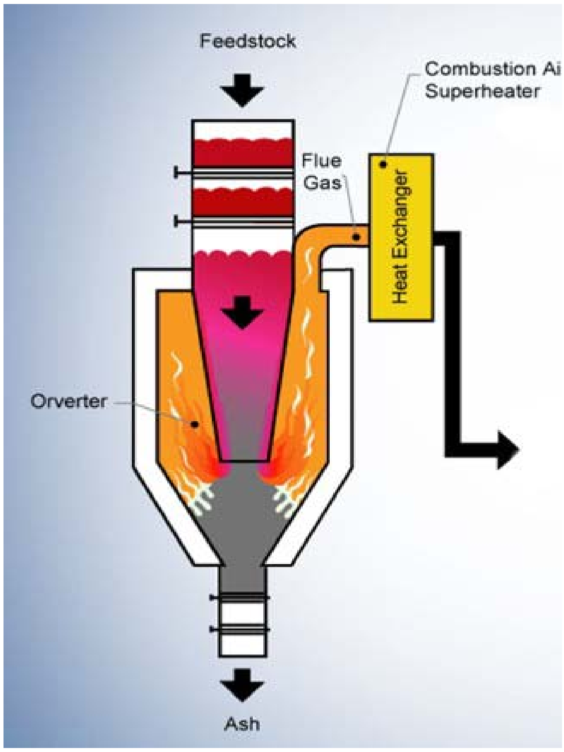


Figure 4.6.5 Counter-Current Fixed-Bed Gasifier from MESH Technologies Inc.

The co-current fixed bed ("down draft") gasifier is similar to the counter-current type, but the gasification agent gas flows in co-current configuration with the fuel (downwards, hence the name "down draft gasifier"). Heat needs to be added to the upper part of the bed, either by combusting small amounts of the fuel or from external heat sources. The produced gas leaves the gasifier at a high temperature, and most of this heat is often transferred to the gasification agent added at the top of the bed, resulting in the same efficiency as the counter-current type. Since all tars must pass through a hot bed of char in this configuration, tar levels are much lower than the counter-current type.

Fluidized Bed Gasifiers - Fluidized bed gasifiers come in two forms, direct and indirect. In the direct fluid bed gasifier, the fuel is fluidised in air, oxygen or steam. The ash is removed dry or as heavy agglomerates that de-fluidize. Fuel throughput is higher than for the fixed bed, but not as high as for the entrained flow gasifier. The conversion efficiency is rather low, so recycle or subsequent combustion of solids is necessary to increase conversion. Fluidised bed gasifiers are most useful for fuels that form highly corrosive ash that would damage the walls of gasifiers. Biomass generally contains high levels of such ashes.

In indirect fluidized gasifiers, gasification is accomplished using steam as an oxidant. However, steam reforming of biomass is endothermic and often heat transfer limited. Endothermic gasification generates more methane than direct gasification per volume of gas, so the energy density may be higher. However, additional methane conversion may be required for methanol applications. The thermal input required for steam reforming of biomass means that a high heat transfer rate is required. Known methods of indirect heat transfer include heat exchangers embedded in the gasification zone (MTCI/Thermochem Recovery Intl.), circulating preheated sand (Battelle/FERCO, Inc.), and cycling of phase change materials (Iowa State University). Steam gasification is thermodynamically more efficient than direct gasification, but practical heat transfer limitations and thermodynamic availability requirements for high-temperature heat exchange often makes reality a bit different. Even so, the main benefit of indirect gasification is that it can eliminate the need for an oxygen plant in a syngas application.

Entrained Flow Gasifiers - In an entrained flow gasifier, a dry pulverized solid, an atomized liquid fuel or a fuel slurry is gasified with oxygen (much less frequently with air) in a co-current flow. The gasification reactions take place in a dense cloud of very fine particles. The high temperatures and pressures also mean that a higher throughput can be achieved; however thermal efficiency is somewhat lower as the gas must be cooled before it can be cleaned with existing technology. The high temperatures also mean that tar and methane are not present in the product gas; however the oxygen requirement is higher than for the other types of gasifiers. All entrained flow gasifiers remove the major part of the ash as a slag as the operating temperature is well above the ash fusion temperature. A smaller fraction of the ash is produced either as a very fine dry fly ash or as a black-coloured fly ash slurry. Some fuels, in particular certain types of biomass, can form slag that is corrosive for ceramic inner walls that serve to protect the gasifier outer wall. However, some entrained bed type of gasifiers do not possess a ceramic inner wall but have an inner water or steam-cooled wall covered with partially solidified slag. These types of gasifiers are resistant to corrosive slags. Some fuels have ashes with very high ash fusion temperatures. In this case, limestone is usually mixed into the fuel prior to gasification. Addition of a little limestone will usually suffice for the lowering the fusion temperatures. The fuel particles must be much smaller than for other types of gasifiers. This means the fuel must be pulverised, which requires somewhat more energy than for the other types of gasifiers. By far the most energy consumption related to entrained bed gasification is not the milling of the fuel but the production of oxygen used for the gasification. **Figure 4.6.6** shows the various gasifier configurations.

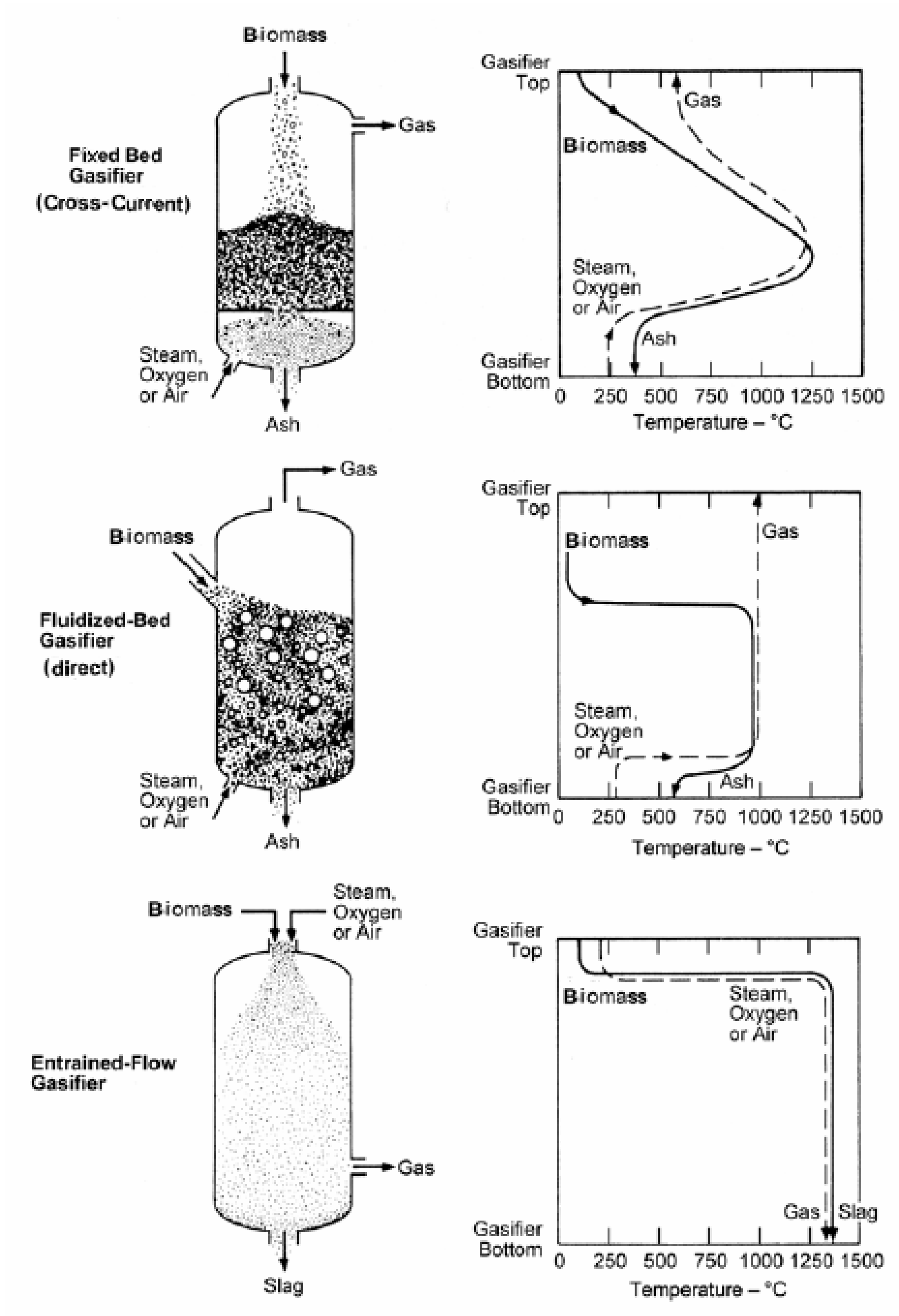


Figure 4.6.6 Gasifier Schematics and Corresponding Temperature Profiles

Five key reactions take place in a gasifier (see **Table 4.6.1**); the five equations and their enthalpies of reaction are listed below. The strong exothermic reaction (e) drives the endothermic reaction (c) & (d) to create the syngas.

Table 4.6.1 Gasification Reactions

Reaction	H (kJ/mole)	
	298K	1000K
a. $CO + H_2O \leftrightarrow CO_2 + H_2$	-41.2	-34.8
b. $C + 2H_2 \leftrightarrow CH_4$	-74.9	-89.6
c. $C + H_2O \leftrightarrow CO + H_2$	131.4	136.0
d. $C + CO_2 \leftrightarrow 2CO$	172.6	170.7
e. $C + O2 \leftrightarrow CO_2$	-393.8	-394.9

It can be seen below from **Table 4.6.2** that the different gasification processes produce syngas that differs in proportions and species. Even with the gas makeup it is not possible to choose a gasifier based solely on efficiency or end gas concentrations since pre-processing and transportation make up a significant portion of the energy required for synthesis.

Table 4.6.2 Typical Syngas Composition from Different Types of Gasifiers Entrained flow, Direct and Indirect Fluidized Bed, Air or O_2

Mole Fraction	Direct Fluidized* (Air)	Direct Fluidized** (O_2)	Indirect Fluidized*** (O_2)	Entrained Flow**** (O_2)
H_20	0.0%	31.8%	19.9%	18.4%
N_2	53.9%	0.0%	0.0%	0.0%
H_2	11.7%	20.8%	16.7%	30.7%
CO	12.3%	15.0%	37.1%	39.0%
CO_2	13.3%	23.9%	8.9%	11.8%
CH_4	4.3%	8.2%	12.6%	0.1%
C_2+	3.1%	0.3%	4.8%	0.0%
HHV (GJ/kg)	10.45	8.22	15.72	9.80

4.6.4 Cleaning Processes

Syngas contains a number of contaminants, which for the most part depends on the type of gasification process selected. The methanol process requires that particulate levels be around 3 to 5 ppm and alkali metal concentrations around 20 ppb. This means the syngas will have to undergo a cleaning process before it can be used to make methanol. Tars (hydrocarbons with a molecular weight greater than 78 kg/kmole) should also be removed to prevent fowling of equipment. Although every system uses different configurations of cleaners, they all use part or all of the four cleaning systems that are represented in **Figure 4.6.7**.

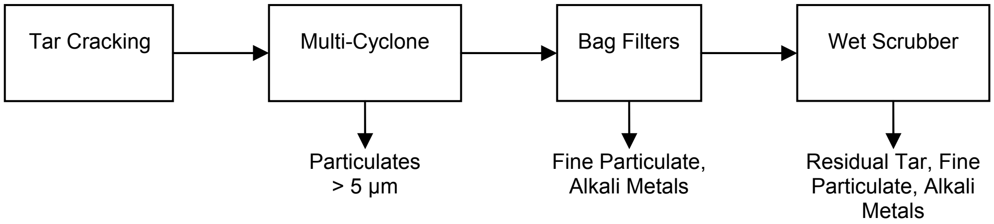


Figure 4.6.7 Typical Syngas Cleaning Schematic

Tar Cracking, Multi-Cyclones and Bag Filters: Tar cracking occurs in a separate reactor at an elevated temperature of around 900°C. The reactor contains a catalytic bed material that promotes the cracking of heavy, condensable hydrocarbons into lighter species. Multi-cyclones are centrifugal separating cyclones that operate in series to remove particulate matter. They are capable of removing over 90% of the particulate matter greater than 5 µm in diameter and are only limited by the temperature of the material that the cyclones are made from. Bag filters are used to remove finer particles but require a drop in temperature. This temperature drop is due to material considerations and requires that the bag filters operate at temperatures below 350°C. At a temperature of around 600°C, alkali vapours condense to fine particulates less than 5 µm in diameter. This coincides with the bag filter temperature drop and because of the temperature reduction, it allows for the capture of much of these condensed aerosols.

Wet Scrubbing: Wet scrubbing refers to the process in which water is used to capture particulates in the syngas. This requires lowering the gas temperature and spraying jets of water into the syngas stream. The procedure, although effective, has two serious detrimental effects on the processing of biomass. One is a thermodynamic penalty due to the cooling of the gas, which must be re-heated to continue processing for methanol. The other drawback is that wastewater treatment is required. This creates a number of added expenses and makes mobile applications more unlikely due to the need to dig new evaporation pools at each new site adding to the difficulty of obtaining permits for the mobile unit. Research is currently focusing on developing dry, hot gas cleaning systems. There is currently no commercial system but high temperature particulate removal has been demonstrated and will continue to be a topic of research.

4.6.5 Methanol Synthesis

The creation of methanol from syngas requires a number of reactions prior to the actual synthesis; the process flow is illustrated in **Figure 4.6.8**. The synthesis of methanol requires four species, hydrogen, carbon monoxide, carbon dioxide and water. The first step in synthesis is the reforming of light hydrocarbons, which some gasifiers produce (particularly indirect gasifiers) and which contains a significant amount of energy, enough to warrant recuperation. To extract the energy from the light hydrocarbons, the gas undergoes a recovery process by steam reforming over a nickel catalyst to form CO and H_2. These reactions are described in **Table 4.6.3**.

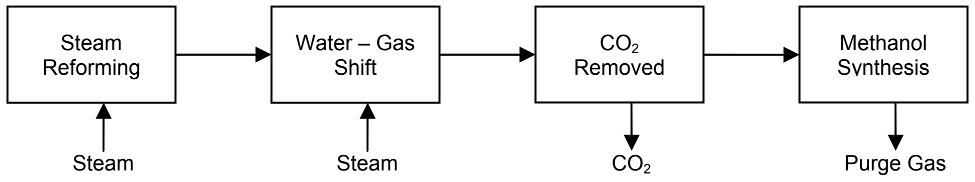


Figure 4.6.8 Syngas Material and Process Flow

Before reforming, syngas is generally compressed, which helps decrease the size of the equipment needed downstream. Compression is usually between 1 to 3.5 MPa and represents a significant fraction of the total power requirement.

Table 4.6.3 Steam Reforming Reactions

Steam Reforming Reactions
a. $CH_4 + H_2O \leftrightarrow CO + 3H_2$
b. $C_2H_4 + 2H_2O \leftrightarrow 2CO + 4H_2$
c. $C_2H_6 + 2H_2O \leftrightarrow 2CO + 5H_2$
d. $C_nH_m + nH_2O \leftrightarrow nCO + [n+ (^m/_2)]H_2$

After the steam reforming process, the H_2:CO ratio must be adjusted in a water-gas shift reaction in order to obtain the optimum ratio of 2:1. The two-to-one ratio corresponds to the molecular structure of methanol. This molecular species adjustment is accomplished by passing the gas over a catalyst at an elevated temperature to produce a water-gas shift ($CO + H_2O \leftrightarrow H_2 + CO_2$). There are two options for this process, one at 360°C over an iron-oxide-chromium oxide catalyst and then at 190°C over a zinc oxide-copper oxide catalyst or in a single reactor at 210°C. After the water-gas shift reaction, the species ratios must be adjusted in order for the methanol synthesis to proceed. The (H_2 - CO_2) to (CO + CO_2) ratio must be at least 2.03. This is accomplished by removing some CO_2. The most common and readily available system that is used for CO_2 removal is the Selexol process. The Selexol process is a chemical reaction using a solvent that reacts with the CO_2 to remove it. The process is a mature technology that is highly reliable and suitable for both mobile and stationary applications. The final process is the actual methanol synthesis. In this process, the methanol is produced by two gas-phase reactions over a copper catalyst as listed in **Table 4.6.4** below. The reactions take place isothermally and adiabatically at a temperature between 230°C - 260°C.

Table 4.6.4 Methanol Synthesis Reactions

Methanol Reactions
a. $CO + 2H_2 \leftrightarrow CH_3OH$
b. $CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O$

The methanol synthesis produces a purge gas along with the methanol; this purge gas consists of primarily CO_2 and H_2O but contains some residual CO and H_2. The low energy content causes combustion instability and makes it difficult to recover the energy. Large facilities use a more advanced approach of combustion in a combined cycle but this would most likely not be feasible in a mobile application.

4.6.6 Hydrogen versus Carbon Dioxide Removal during Methanol Synthesis

Methanol synthesis requires a balance of molecular species but gasification creates the problem of a large excess of carbon dioxide in the syngas. Current technology removes the carbon dioxide, leading to low overall carbon conversion rates, ultimately making the process economically inattractive. Instead, a novel approach to this problem is to add electrolytic hydrogen to the species in a sufficient quantity to balance the ratios. This has numerous benefits over CO_2 removal: electrolysis produces both hydrogen and oxygen, which can be used in the gasification and synthesis process. By balancing the species with hydrogen, both the water gas shift and CO_2 removal steps can be eliminated, decreasing equipment cost. The electrolyser costs are minimal since the apparatus is quite simple; hydrogen costs are primarily determined by the cost of electricity. Since this project is planned for the interior of British Columbia where electricity is both relatively inexpensive and has low GHG impacts, it makes the electrolytic hydrogen option well suited. The use of electrolytic hydrogen does have a few drawbacks, such as its massive electric power consumption. Adding hydrogen does not improve the energy balance, but reduces overall energy yields. Large amounts of electricity are required to synthesize methanol. For provinces other than BC with higher grid electricity emissions the electrolytic hydrogen option would create more GHGs than it saves and could cost significantly more due to higher electricity prices.

4.6.7 Bugwood to Methanol Energy Balance

The energy analysis of the conversion of bugwood to methanol is primarily focused on the gasification and syngas composition. The various different gasification routes produce gases which require different processes to utilize. Our report focuses on four gasification routes and two alternative plant locations. The locational scenarios focus on chipping and drying in the field and then either processing with mobile units, or transporting back to a plant and processing there. In this analysis, the end product (methanol) augments the transportation fuel supply. However, the added capital cost of the mobile units out weighs the small energy savings gained with mobile units.

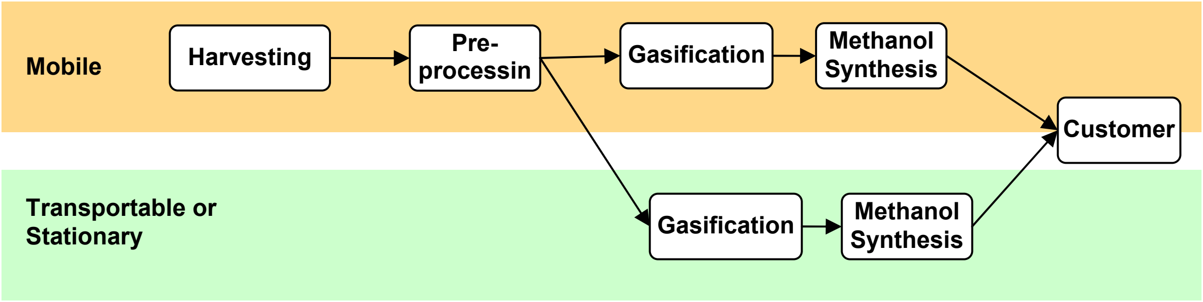


Figure 4.6.9 Torrefaction Material and Process Flow

In the stationary scenario, it is assumed that the wood is chipped near the harvesting site and then transported to the plant by chip truck (40 bdt) over an average distance of 100 km. The methanol is freighted by tanker train to a BC customer over a distance of 700 km (one-way). As shown in the energy diagram below, only small losses are incurred by each transport step. The main energy uses are drying and processing, except in the case of hydrogen addition where electrolysis dominates the energy use. Methanol can be used both for drying and as a 60/40 mix in transport. In the mobile application, methanol or methanol/diesel mix can replace all required energy usage. As the amount of methanol increases when hydrogen is added, the transport energy for product transport is likewise higher than for the conventional process.

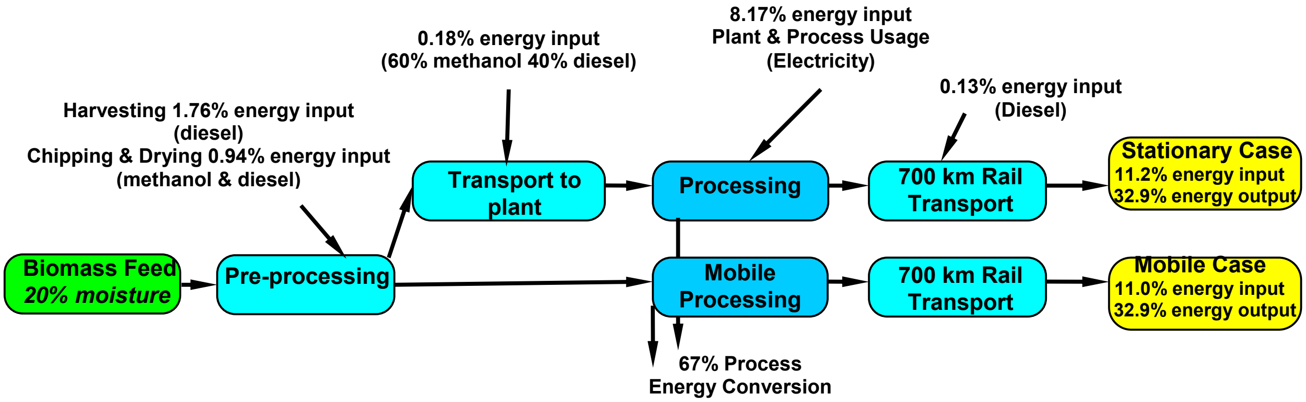


Figure 4.6.10 Energy Balance of Mobile and Stationary Methanol Plant for the Direct Fluidized Gasification Option

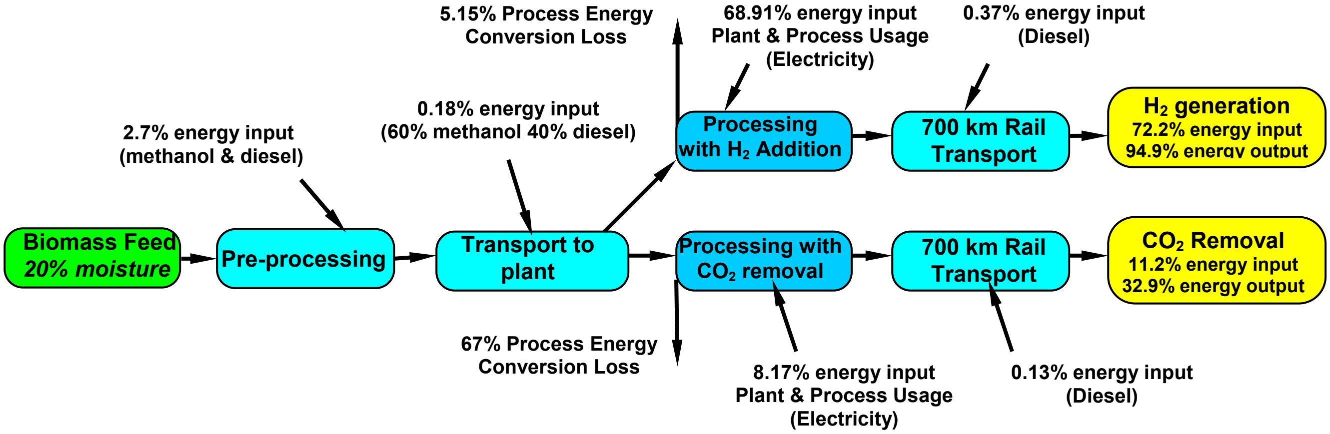


Figure 4.6.11 Energy Balance of Stationary Methanol Plant Options With and Without H_2 Generation.

4.6.8 Methanol Economics

The base case is a direct fluidized large stationary application. Since all processes are commercially available, it is assumed the economics for the base case would be accurate to within a reasonable margin. Uncertainties concerning cost estimates arise from the gasification portion of the process. Some of the numbers will differ due to the differences in each of the gasifiers. The base case estimate represents the largest possible methanol processing plant. As feedstock costs represent 60% of production cost, a reduction of this cost and/or increase of the market price of methanol by a small amount translates into a major improvement of the economic feasibility of the process. Fluctuations in methanol pricing make gauging a good estimate for its market value difficult. Currently, consumers in Alberta are purchasing methanol for anywhere from 42¢ to $1.60 a litre (delivered); Methanex (wholesale) pricing has increased steadily over past years and is currently (January 2006) at about US$1 per gallon. For this study a price of 30¢/l (CDN) is assumed, although this may be conservative when a 2010 application is considered.

Various gasification processes produce significantly different syngas constitutions which in turn affects the economics of the process. Indirect fluidized gasification showed the best economics. The economics of the electrolysed hydrogen addition show significant improvements by decreasing CO_2 removal cost while increasing the amount of methanol produced. Mobile units derived from the base case scenario will incur a large equipment cost increase. The only benefit to mobilization is a decrease in transportation cost. By partly utilizing methanol as a fuel for feedstock transport, transportation costs decrease from 11.4% of production cost to 10.5% (indirect gasification case). Eliminating feedstock transportation cost will only decrease production cost by 0.7% - not enough to make mobile units feasible. The added mechanical and logistical complexity of mobile units would most likely lead to higher maintenance costs and more down time than stationary units. The mobile unit would most likely have to consist of more than one trailer for the entire process from feedstock to methanol. This may be a benefit because it would allow for the sharing of the trailers between several processing sites, which could help maximize production: while processing goes on at one site, the gasification trailer could be operated at a second location while the cleaning and methanol synthesis could continue till it is completed.

Table 4.6.5 Cost Analysis of Three 1000/BDT Stationary Gasification Scenarios. The third strategy involves hydrogen generation to balance the molecular species.

Direct Fluidized Gasification with Air		
	C$ per year	**Comments**
Total capital cost	79,437,116	Total of all equipment
Salaries	1,040,000	20 people - average salary of $52,000/yr
Maintenance	2,383,113	3% of capital cost annually
Processing Cost	2,830,575	Chipping & Drying ect.
Electricity	3,911,060	Processing & plant electricity
Feedstock Harvesting	17,137,500	Harvesting cost at $68.55/BDT
Feedstock Transport	202,500	Chip truck - 40 BDT capacity
Product transport	2,359,488	Methanol train tanker transport
Total cost	29,864,237	
Revenue from Methanol	27,882,715	$0.30 per litre (methanol)
Carbon credits	2,035,075	If applicable, $15 per tonne of CO2
Total revenue	29,917,790	Sale in BC
Profit	53,553	
ROI	negative	IRR over 10 years
Profit ($\$40/m^3$)	*-9,308,947*	
ROI ($\$40/m^3$)	*negative*	

Indirect Fluidized Gasification with O2		
	C$ per year	**Comments**
Total capital cost	$80,282,594	Total of all equipment
Salaries	$1,040,000	20 people - average salary of $52,000/yr
Maintenance	$2,408,478	3% of capital cost annually
Processing Cost	$2,830,575	Chipping & Drying ect.
Electricity	$1,677,124	Processing & plant electricity
Feedstock Harvesting	$17,137,500	Harversting cost at $68.55/BDT
Feedstock Transport	$202,500	Chip truck - 40 BDT capacity
Product transport	$2,756,624	Methanol train tanker transport
Total cost	$28,052,800	
Revenue from Methanol	$32,658,274	$0.30 per litre (methanol)
Carbon credits	$2,712,893	If applicable, $15 per tonne of CO2
Total revenue	$35,371,167	Sale in BC
Profit	$7,318,367	
ROI	negative	IRR over 10 years
Profit ($40/$m^3$)	*-2,044,133*	
ROI ($40/$m^3$)	*negative*	

Indirect Fluidized Gasification with O_2 & H_2 Electrolysis		
	C$ per year	**Comments**
Total capital cost	$74,522,916	Total of all equipment
Salaries	$1,040,000	20 people - average salary of $52,000/yr
Maintenance	$2,235,687	3% of capital cost annually
Processing Cost	$2,830,575	Chipping & Drying ect.
Electricity	$7,744,910	Processing & Plant Electricity
Feedstock Harvesting	$17,137,500	Harversting cost at $68.55/BDT
Feedstock Transport	$202,500	Chip truck - 40 BDT capacity
Product transport	$6,747,092	Methanol train tanker transport
Total cost	$37,938,264	
Revenue from Methanol	$80,643,696	$0.30 per litre (methanol)
Carbon credits	$6,643,041	If applicable, $15 per tonne of CO2
Total revenue	$87,286,738	Sale in BC
Profit	$49,348,473	
ROI	117.08%	IRR over 10 years
Profit ($40/$m^3$)	*39,985,973*	
ROI ($40/$m^3$)	*65.80%*	

The ROI of methanol production is highly sensitive to the methanol price. Although currently only the Indirect Fluidized Gasification with hydrogen enrichment has a positive ROI, increasing methanol pricing may make alternative process options viable when the technology is expected to be available in the coming decade.

4.6.9 GHG Emissions

Since the main use for methanol will be automotive the GHG emissions are directly related to the methanol produced by bugwood offsetting gasoline emissions from vehicles. The emissions for harvesting and manufacturing the methanol, transportation, and the net CO_2 displaced were calculated for four different gasifiers utilizing either CO_2 removal or hydrogen electrolysis to balance the molecular species in the syngas. The displaced CO_2 is shown in **Figure 4.6.11**. The various scenarios rely on a 60/40 methanol to diesel mixture in trucks and equipment as well as methanol for drying, which produces no GHGs. Energy usage in the hydrogen generation scenario is very large but the process effectively creates a situation in which hydro-generated energy can be used to remove large amounts of GHGs by displacing automotive fuels. Added to this is the fact that the GHGs are being removed from an industry (transportation) that is trying to decrease its dependence on non-renewable fuels to green renewable ones.

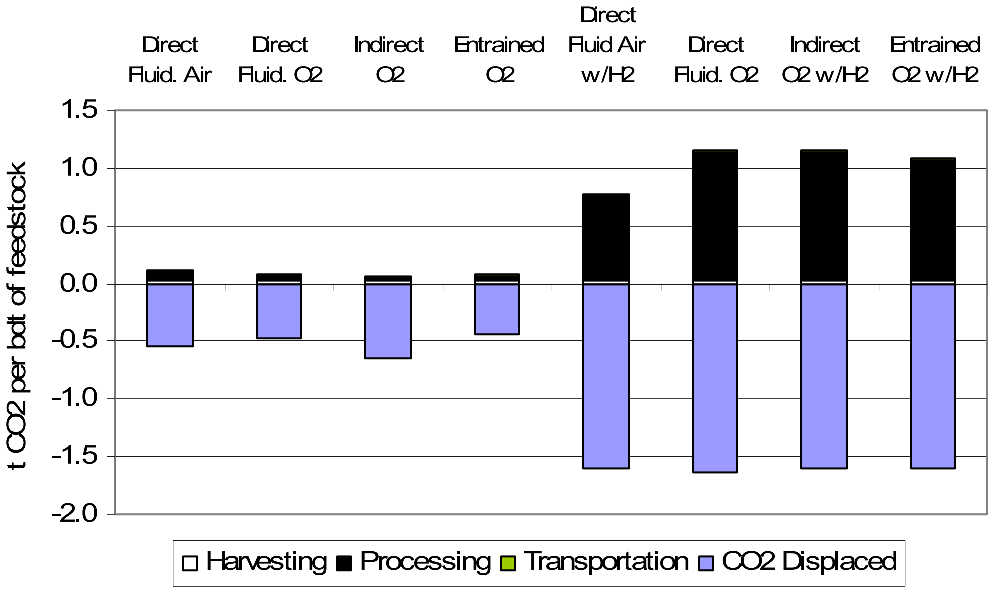


Figure 4.6.12 **GHG Emissions for Various Gasifier Strategies With and Without Hydrogen Generation**

4.7 Gasification and Purification to Pipeline Standards

4.7.1 Gasification Overview

Gasification is an attractive energy-from-biomass option as it is a demonstrated technology, relatively energy efficient and capable of converting solid biomass into a variety of useful gaseous energy streams. In normal wood combustion, the combustible gases released from the heated wood burn with a visible flame. Under reduced air conditions, as found in gasifiers, the combustible synthesis gas (also known as syn-, wood, or producer gas) consists mainly of hydrogen (H_2), carbon monoxide (CO), and hydrocarbons, from CH_4 (methane) to heavier and carry condensates that need to be cleaned or cracked to achieve pipeline standards. Carbon dioxide (CO_2), nitrogen (N_2) and water vapour are usually also present but add no direct heating value to the gas. As discussed above under methanol production, the gasifier type or process and the temperatures determine the amount and type of hydrocarbons produced and the overall gas composition. Lower temperatures produce proportionally more hydrocarbons than higher gasification temperatures, which tend to drive the reaction to CO and H_2. The type of gasifier and the temperature will usually be chosen to match the required end use of the gas. Some of the process options available for wood gas are shown below in **Figure 4.7.1**.

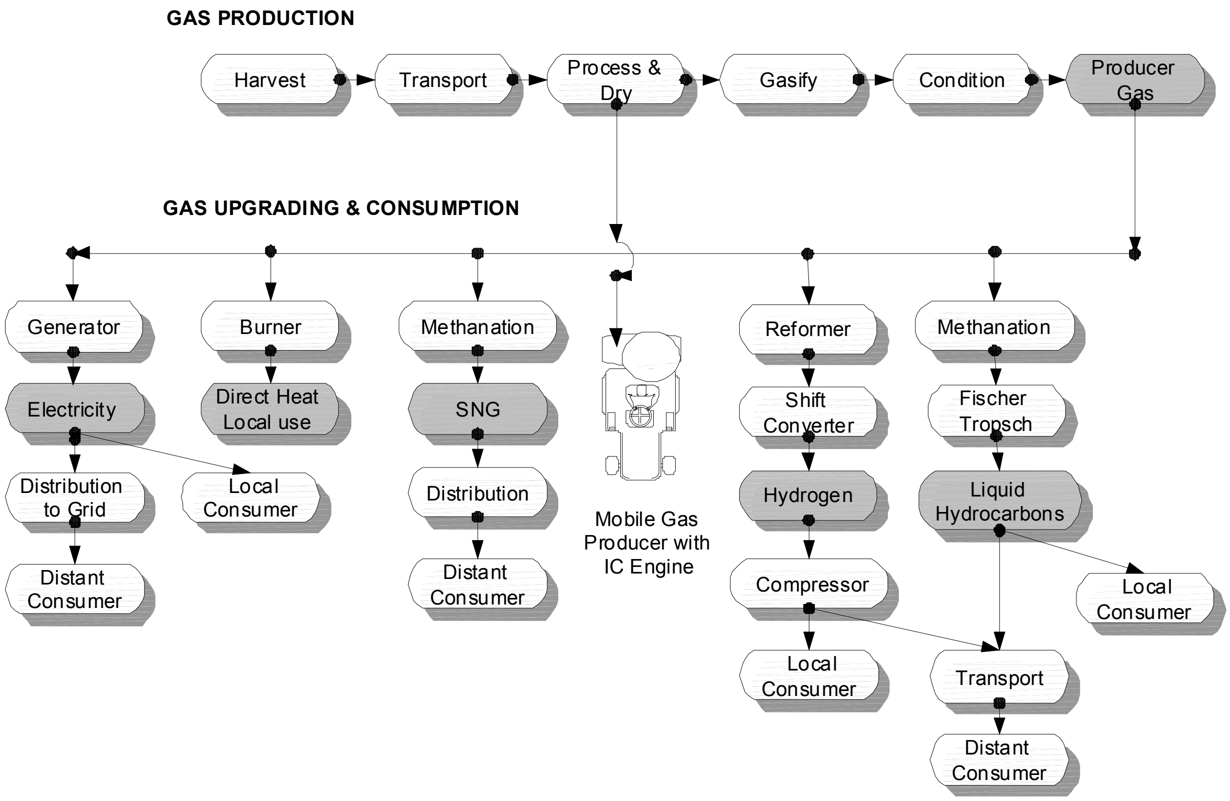


Figure 4.7.1 Possible Options for the Use of Wood-gas

As shown above, there are several small and micro-scale utilization options for local wood gasification. For example, wood gas could be used to power vehicles such as harvesting or delivery vehicles or a mobile whole log or non-stem wood log chipper. Usually such mobile units used to power internal combustion engines are locally made with equipment readily available from a variety of sources. Several manufacturers currently do make and market micro-scale biogas electrical generator sets (25 to 300kw) that could be used for small communities or industries. These small-scale local uses, although technically feasible (and proven), are often based on the operator providing low-cost (or internal, no-cost) labour to fuel and maintain the systems. In addition, the small scale, while providing a potentially wider market, usually makes the return on investment poor relative to larger systems. Such micro-scale options are therefore not included in this current study.

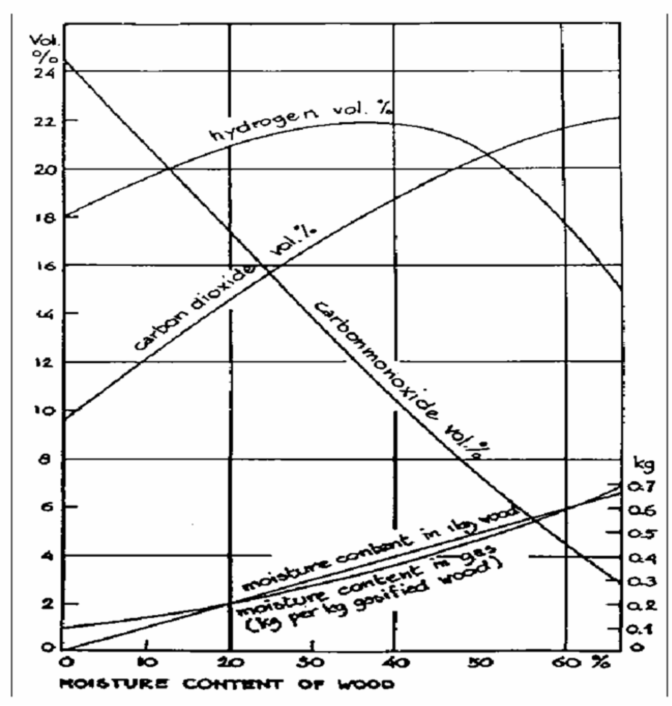


Figure 4.7.2 Gas Composition as a Function of Wood Feedstock Moisture [FAO 1986]

Figure 4.7.2 shows the effect of moisture content on wood gas composition and demonstrates that above 35 % moisture in the wood the hydrogen content in the gas drops rapidly and the CO content has already dropped by 50% (from 24% to 12% CO). The water content of the gas increases with the moisture content of the wood. To reduce the amount of water vapour and achieve a high heat content of the syngas, it is important that the wood feedstock has a low water content of at most, 35%. With an assumed water content of 20%, bugwood is therefore well suited for the gasification process.

The heat content of syngas varies greatly with the type and moisture content of the fuel feed, as well as the conversion process used. Most gasification processes use air to introduce oxygen into the process, which results in a gas mixture of a gross calorific value 4-7 MJ/Nm^3 (dry). Special processes using pure oxygen would result in a gas mixture of a gross calorific value of 10-18 MJ/Nm^3 (dry). For comparison, natural gas typically has a calorific value of 35 MJ/Nm^3. Higher moisture content in the biomass feedstock causes a lower calorific value of the resulting syngas because more energy is needed to evaporate the moisture and this energy comes from more carbon being completely oxidized to carbon dioxide.

4.7.2 Wood Gasification and Conversion to Synthetic Natural Gas

This thread focuses on the option of gasifying bugwood and feeding a purified synthetic natural gas (SNG) into existing natural gas pipelines where it would displace natural gas in industrial heating and wood drying or in residential heating and cooking applications. The production of SNG allows for the use of existing natural gas pipelines, and infrastructure that reaches into many of the major towns, allowing for a decentralised approach and avoiding any product transport costs. Several (mainly European) working groups pursue the aim of making gasification processes commercial. However, their research indicates that wood gasification to SNG is not yet a commercial process, and there are no systems available today that can convert wood gas into pipeline-grade methane in commercial quantities. Market-readiness of gasification processes able to produce pipeline-grade methane from biomass is expected by about 2011 [ECN 2003]. There are a number of obstacles to be overcome before such processes become commercial:

- The primary difficulty is to create a product that will approach the purity and heating value of fossil natural gas, and therefore, meet the pipeline specifications. These relate to the need to eliminate the nitrogen present if air is used as the gasifying oxidant. It is possible to use pure oxygen instead of air, but the cost of oxygen then adds significantly to the processing cost. Indirectly heated gasifiers use steam as the gasifying agent, thus, avoiding the introduction of nitrogen into the process stream.

- The nature of the initial syngas produced requires the subsequent conversion of carbon oxides (CO and CO_2) and hydrogen to methane (CH_4). While this is technically possible, the methanation reactor is costly and the system is not likely to be economical unless the plant runs longer than the 10-15 years the bugwood resource is expected to last.
- The gas must also be cleaned and dried to remove tars and moisture. In addition, the presence of carbon monoxide, which provides much of the heating value of wood gas, must be eliminated or converted to methane as CO is an odourless and toxic gas that would add a toxicity risk in addition to an explosive risk if combined with natural gas. Likewise, hydrogen concentrations must be kept low to prevent pipeline corrosion and other problems.
- In the methanation step, carbon can be formed, which will plug the nickel catalysts and disturb the process. The catalyst is also sensitive to some other impurities, such as hydrogen chloride or sulphur compounds.

4.7.3 Gasification Process to Produce SNG

As described above, wood gasification produces a syngas composed of CO, CO_2, methane, hydrogen and water, as well as impurities (tar, sulphur etc.). In a first step, SNG produces impurities which are filtered out. As pipeline-grade gas requires a high methane content, the next step is to covert CO and CO_2 to methane in the methanation step:

$$CO + 3\,H_2 \leftrightarrow CH_4 + H_2O$$
$$CO_2 + 4\,H_2 \leftrightarrow CH_4 + 2\,H_2O$$

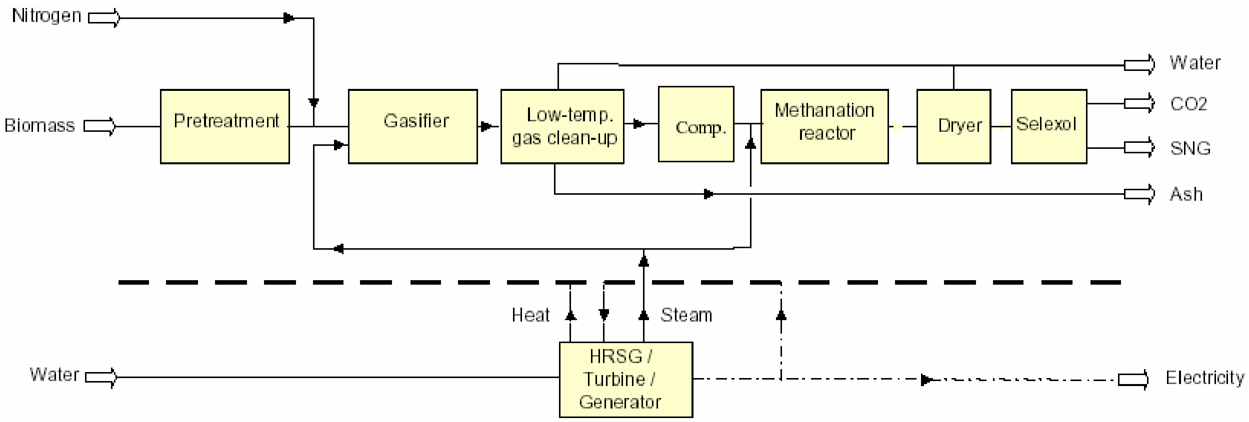


Figure 4.7.3 Flow Diagram for the Battelle Indirect Wood Gasification and Methanation Process [ECN 2003]

The process identified as the most cost-effective among several options by the Energy Research Centre of the Netherlands (ECN) is the Battelle indirect gasification process (see **Figure 4.7.3**). This process works at atmospheric pressure and uses the char it produces to heat the biomass in the gasifier. The wood itself was modeled by ECN as willow, with a 15% moisture content. As this is close to the 20% assumed for bugwood, no adjustment is made to account for this difference. The syngas produced in the gasifier is cooled so it can be treated in the gas clean-up unit. A heat exchange recovers some of the heat to be used for generating and superheating 40-bar steam. Steam produced with process heat is used to drive a condensing steam turbine to generate electricity. The gas cleanup comprises a dust filter, a quench (also serving as acidic wash to remove NH_3), a neutral wash to remove sulphur, halogens and ammonia content, and guard beds to fully control sulphur and halogen concentrations. The gas is then compressed to 15 bar before entering the methanation unit, which is based on the Lurgi coal-to-SNG process. Reaction heat is used to produce 40-bar steam and to preheat boiler feed water. The product gas is then cooled to 10°C, using heat exchangers and cooling water. An electric cooler brings the gas within specifications to comply with the -10°C dew-temperature requirement. Finally, a Selexol unit removes CO_2 from the gas (89.2% efficiency). Some of the separated CO_2 is used as a transport gas to insert biomass into the gasifier. The synthetic natural gas can then be fed into the pipeline grid at 15 bar and 20°C.

Table 4.7.1 shows that gas cleanup is a major component of the process. Specifications for BC pipelines only exist for a few of the parameters listed; European limits were therefore used for the ones missing. Several gas cleaning steps need to be integrated to achieve the stringent specifications for gas pipelines. There are no specifications for nitrogen or hydrogen in natural gas pipelines in BC, but it is expected that only a few percent of hydrogen can be tolerated due to corrosion problems and possible complications with burners in home heating units. The criterion for CO_2 (2%) cannot be achieved with the proposed technology. While this could be a "deal stopper" it may be possible to allow for some SNG with these specifications to enter the BC pipeline network, as long as the gas is mixed and can reach the 2% threshold in combination with fossil natural gas.

Table 4.7.1 Anticipated Synthetic Natural Gas Quality and Pipeline Specifications Compared to Methanation Step Requirements and the Untreated Syngas [ECN 2003; TC 2005]

Component		Concentration in product gas from gasifier	Requirement methanation step	Requirement SNG	Anticipated Quality
H_2S	ppm	100	0.1	23 mg/m³	
COS	ppm	10	0.1		CH_4: 87.6%
HCl	ppb	25000	< 25	<1000	
HF	ppb		< 25		
NH_3	ppm	2830	100	<1	N_2: 1.44%
HCN	ppm	280		<10	
Hg	mg/Nm³	0.02	0.5	<0.01	
Cd	mg/Nm³	0.94	0.05		
Na+K	mg/Nm³	1630	1		HHV: 42.64 MJ/kg
Dust	mg/Nm³	10,000	10	<0.5	
BTX[16]	ppm			<500	
Tars	mg/Nm³	10,000-15,000	5	0.1	
Heavy metals	mg/Nm³	< 300	< 1	<0.01	
CO2	[Vol.-%]			2.0	8.9
CO	[mol.%]			<0.8	0.06
H_2	[mol.%]			a few %	1.95
O_2	[Vol.-%]			<0.4	-
H_2O				Dew point <-10°C	OK
Wobbe index	[MJ/Nm³]			36.94	43.74

4.7.4 Energy Balance

Based on ECN 2003, the overall process efficiency of the wood-to-SNG conversion is 67%. 33% of the feedstock energy is used for processing, including internal electricity production (**Figure 4.7.4**). The process uses 109.5 kWh of external electricity. No extra energy is required to feed the synthetic natural gas (SNG) into the pipeline as it is produced at a pressure of 15 bar.

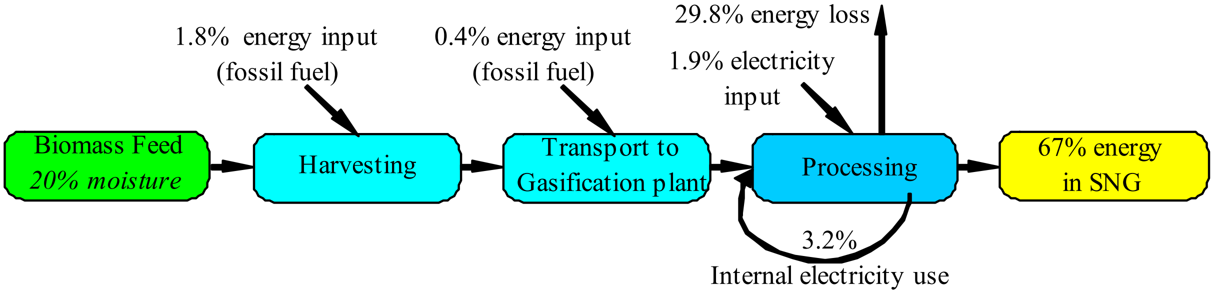


Figure 4.7.4 Energy Balance of Wood Conversion to SNG

4.7.5 Manufacturing and Transport Costs

No transportation costs are incurred by this system, apart from feedstock transportation because the gas produced is transported via the existing natural gas pipeline network. Major gas pipelines cross the BC Interior from Vancouver to Prince George, and also across to the Prince Rupert seaport (see **Figure 4.7.5**). The planned Alaska Pipeline (not shown) will run through the northern corner of BC, close to Fort St. John and then on to the coast and north into Yukon. For the BC Interior, Duke Energy and Pacific Northern Gas pipelines are the most relevant. Both pipelines are shown in more detail in **Figure 4.7.6**.

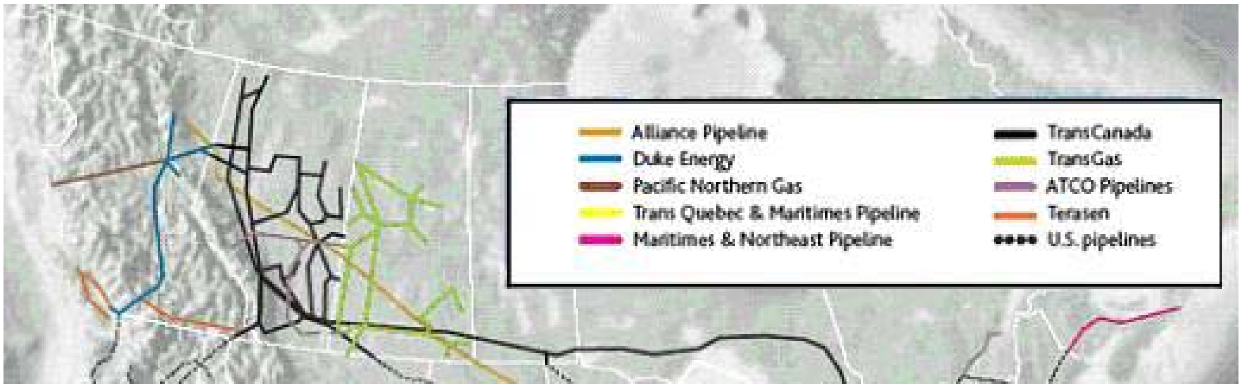
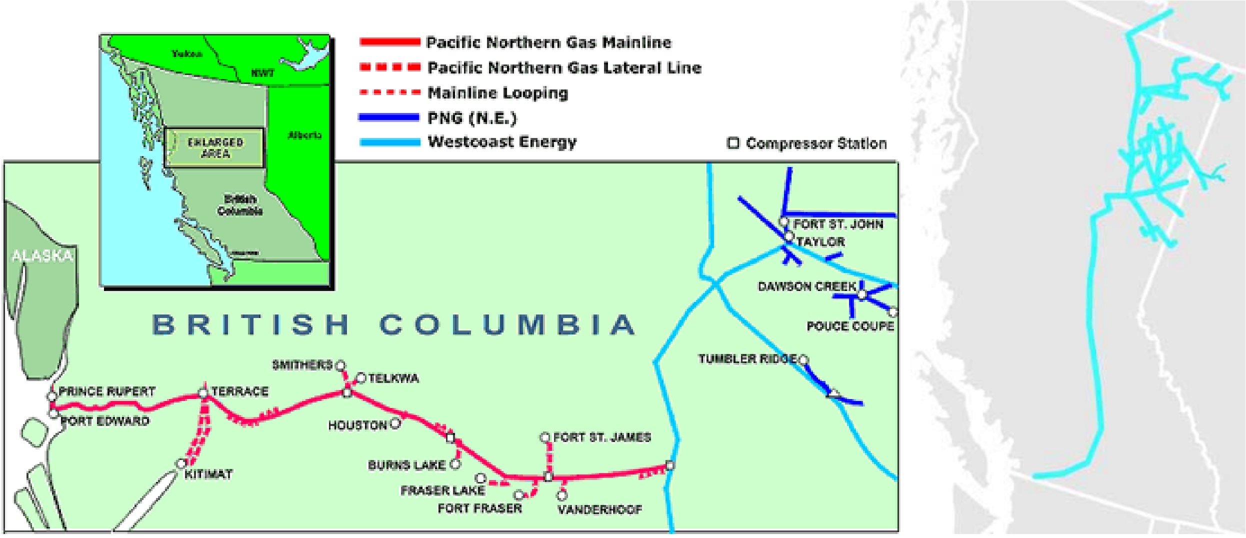


Figure 4.7.5 Major Natural Gas Pipelines in Western Canada [CCEI 2004]

Natural gas prices are linked to the price of crude oil, which continues to remain above $50 per barrel. Forward pricing for natural gas for the years 2006/2007 moves around C$10 to 12 [TG 2006]. Due to increased use of liquefied natural gas, future pricing is expected to relax slightly. The lower amount of $10/GJ was therefore used to model revenues from natural gas sales after 2010, when the technology discussed here may become available.

Production costs included in **Table 4.7.2** are based on the calculations made in ECN 2003, but were modified to reflect feedstock and other costs in BC. Conversion from € to C$ was made at a rate of $1.40 per Euro. The capital investment for a gasification and methanation plant is given as €449 per kW installed in the 2003 study. As this seemed too low, we enquired from the authors and obtained a newer estimate, which is €850 per MW_{th} for a 100 MW_{th} plant [ECN 2006]. We adjusted this to €900/MW_{th} for a plant of 50 MW_{th} capacity. To match the size of the bugwood harvesting operations and use a feedstock consumption similar to plants discussed above, the unit size for this study is modeled as a 50 MW plant (about 100,000 bdt/year). The annual plant capacity factor is assumed to be 90%. Operating and maintenance costs are taken as 5% of capital costs from the original study. Process power output is 2.4 MW (181 kWh/bdt), but power consumption is 3.85 MW (290 kWh/bdt). Electricity costs were adjusted to BC prices. Ash production is not clearly identified in the original study, but is assumed to be equal to bugwood ash content (1.74%).



Source: Pacific Northern Gas Source: Duke Energy

Figure 4.7.6 Pacific Northern Gas (left) and Duke Energy (right) Pipelines

Table 4.7.2 Production Cost of Synthetic Natural Gas from Bugwood

	C$ per year	Comments
Capital cost	*63,000,000*	*Total of all equipment*
Ash disposal	172,921	17.4 kg/bdt; €68/t
Operating and Maintenance	3,150,000	5% of capital cost
Electricity	388,681	Net consumption: 109.5 kWh/bdt
Feedstock harvesting	7,155,990	Harvesting cost only
Feedstock transport	3,134,856	Cost of truck transport to plant
Total cost	14,002,449	
Revenue from gas sale	14,191,200	$10 per GJ
Carbon credits	1,141,389	If applicable, $15 per tonne of CO2
Total revenue	15,332,589	
Profit	1,330,141	
ROI	negative	IRR over 10 years

The result shows that the plant cannot break-even at the modelled feedstock cost and value for synthetic natural gas (ROI is negative). However, using low-cost feedstocks (e.g., sawmill waste) might enable the process to become profitable while using a small portion of bugwood. Likewise, a natural gas price of $16.30 per GJ would make the process reach an ROI of 10% (to compare, peak pricing in December 2005 was $15.20/GJ in BC, while the month's average was $12.60 [TG 2006]). Also, less ambitious methanation and purification of the gas may still produce a gas that is useful for use in gas engines. This would also increase the amount of carbon credits, displacing gasoline or diesel. However, it also requires that users modify their vehicles to accommodate wood gas as a fuel.

4.7.6 GHG Emissions

The process uses some external electricity, and on the other hand produces synthetic natural gas, which displaces regular natural gas produced in BC. Net emission reductions are 0.73 tonnes of CO_2 per bdt of feedstock (see **Figure 4.7.7**). As SNG displaces natural gas, which has low GHG emissions in comparison to other fuels, such as oil or coal, emission reductions per tonne of feedstock are fairly low despite the good conversion efficiency (67%)

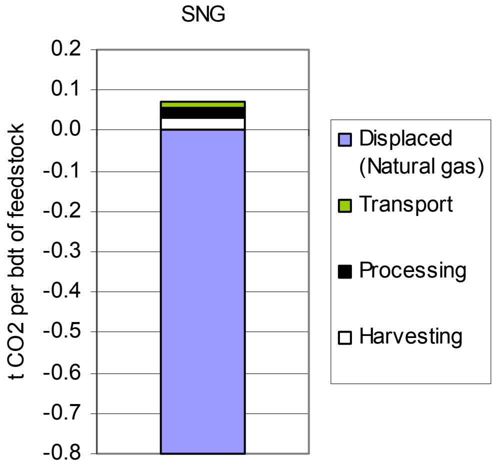


Figure 4.7.7 GHG Emissions and Emission Reductions from SNG Production

5 ENERGY AND COST COMPARISONS

5.1 Energy Comparisons

Figure 5.1.1 compares the energy balances of the technologies examined in this report. It shows both the energy contained in the products of each process, and the energy (both external and internal feedstock use) consumed by the process over its cycle from harvest to delivery of the product. A simple process such as de-barking will take away about 10% of the energy contained in the original feedstock. The bark is sometimes used in the process, e.g. to generate heat, or can be removed and used as a feedstock in another facility, such as a biomass CHP plant. The graph designates bark residues separately from other co-products, such as lignin and acetic acid (ethanol production) or electricity (CHP, with heat being the main product). Note that the CHP option already includes the energy conversion step (conversion to heat and electricity), which is not included in any of the other options. CHP is therefore a very energy-efficient option, whereas other options are likely to result in lower energy use factors once the conversion step is included (conversion efficiencies in engines and for power conversion is between 20 and 35%, whereas heat conversion can be 75 to 95%). However, the heat of a CHP plant is only partly used if it is used for district heating (during the heating season), reducing the overall energy payback. There is year-round heat utilization, only if the heat is used in industrial processes.

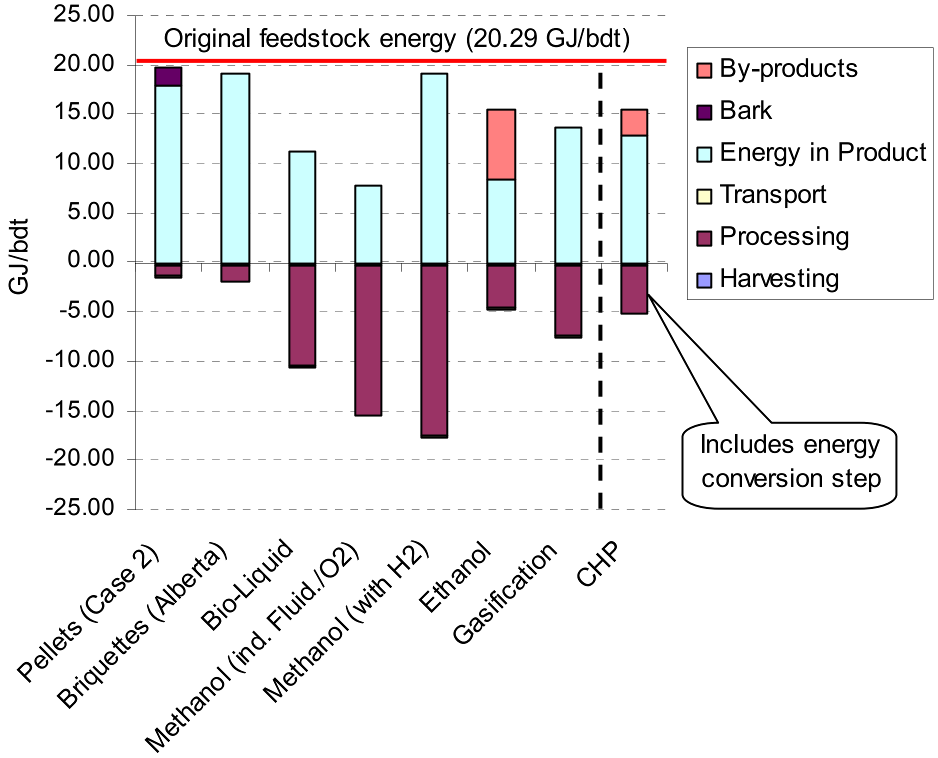


Figure 5.1.1 Comparison of the Original Feedstock Energy Contained in Products and Energy Consumed for Harvesting, Processing and Transportation

A low energy content in the product should not be interpreted as a “red flag” for a given process: for example, the Lignol process only concentrates 41% of the feedstock energy in ethanol. However, several other valuable co-products are created, which contain most of the remaining feedstock energy, but have a higher market value than could be obtained when using them for energy recovery. While the top part of the graph shows the useful energy obtained from the process, the bottom part indicates process energy inputs. As expected, pelletizing and briquetting only takes small energy inputs, whereas ethanol, synthetic natural gas (SNG) and CHP require around one-quarter of the amount of energy in the feedstock for processing. Bio-liquid production is a very energy-intensive process, using as much as 50% of the amount of energy contained in the feedstock. Methanol production through gasification is even less efficient, as 67% of the feedstock energy is lost during processing. However, adding electrolytic hydrogen to the process strongly increases the overall methanol yield from bugwood. Note that this does not make sense in all scenarios: for example, when electricity is generated with coal at 35% conversion efficiency, the overall energy loss would discourage the addition of hydrogen to the gasification process. In any case, only about 20% more energy is gained from this process than is consumed.

The graph in **Figure 5.1.1** has the disadvantage that the CHP option actually includes the energy conversion step. Whereas, all other threads simply produce a biofuel (and co-products) which is then converted to electricity, heat or motional energy at another location. To account for this last step, energy conversion was assumed to be 35% efficient for electricity generation in a coal plant (pellets) and 45% in a (small) combined cycle natural gas plant (cellulignin pellets); bio-liquid conversion was also assumed to be 35% efficient in electricity production, ethanol use in vehicles is modelled with a 20% conversion efficiency in the internal combustion car engine (methanol use in diesel engines as 23%), and SNG is taken as 85% efficient if used for residential space heating. The use of bark (pellets only) is also modelled as 35% efficient, assuming a case where bark is mixed into the pellets for use in coal or biomass power plants. Heat conversion (pellets/briquettes) is assumed to be 76% efficient in residential biomass furnaces (higher efficiencies are possible). The CHP numbers are unchanged.

To compare all threads in terms of energy use (see **Figure 5.1.2**), the total energy output (energy produced in the conversion process, plus co-product energy displacement) it divided by the total energy input (original feedstock energy plus all fossil and electric energy inputs for processing and transport) to calculate overall processing efficiency. For transparency, the types of energy obtained are given different colours to distinguish the quality of energy (electricity, automotive fuel, heat).

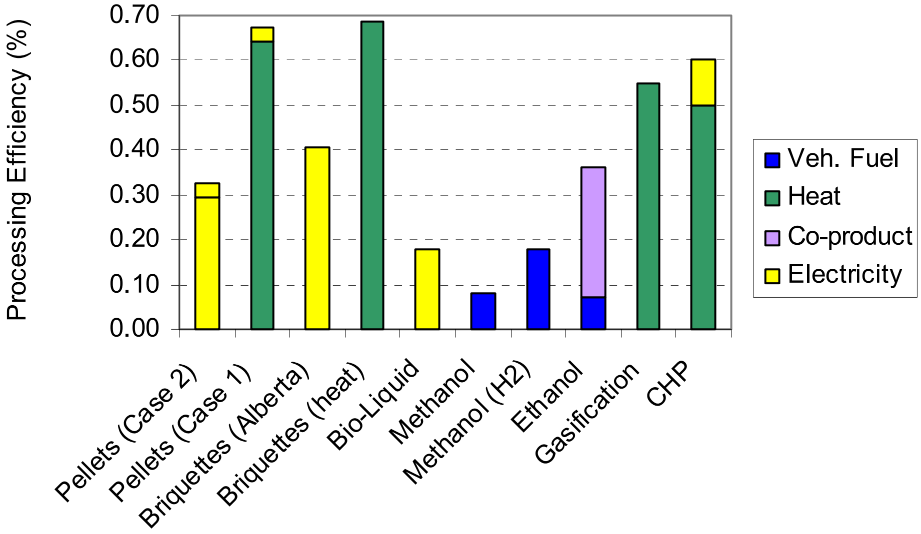


Figure 5.1.2 Processing Efficiency Comparison (All Energy Outputs Over All Energy Inputs, HHV Basis)

Clearly, the heat related threads fare best in terms of process energy efficiency, since heat conversion is usually a very energy efficient process. If electricity is the required type of energy, pellets or briquettes seem to be the best option (this is a hypothetical comparison, as Alberta pulverized coal plants are not likely to accept pellets or briquettes, although cellulignin powder may be suitable). Cellulignin yields more electricity if it can be used in a combined cycle gas turbine. However, CHP offers the benefit of combined heat and power generation, optimising overall energy benefits from the feedstock. The methanol and bio-liquid processes have the smallest processing efficiencies. In the case of bio-liquid, the efficiency could also be increased if the liquid was used for heat production instead of electricity, as was modelled here, but would again not achieve the same results as the other technologies. Ethanol and methanol conversion are the only pathways that create an automotive fuel. While the energy conversion in an internal combustion engine is not very efficient, it is a high-value application and displaces a lot of fossil fuels, decreasing dependence on international oil imports. Note that much of the energy benefits of this thread come from the lignin, which displaces resins in wood products manufacturing. The efficiency of methanol production increases when adding electrolytic hydrogen to the process, albeit this requires the increased use of electricity, which is a high-value form of energy and can incur high life-cycle energy efficiency penalties depending on how that electricity is generated. Overall, processing efficiency as displayed here should not be taken as the sole criterion to select technologies, but if the aim is to produce a certain type of energy (electricity, heat, etc.), this comparison shows that some processes can deliver a higher efficiency than others.

5.2 Cost Comparisons

Table 5.2.1 compares the cost of delivering one GJ of energy to a point of use at a distance of 500 km from the plant. The CHP option was left out as it is supposed to be located close to the users and product transport for heat and electricity will thus be over very short distances, meaning the cost of delivery is very low if the existing infrastructure can be used (the construction of a district heat system would increase delivery costs). Transport of bugwood logs to the plant is assumed to bridge a distance of 150 km by truck in all cases. The first case reflects the use of chipped wood, including bark, whereas the other cases are based on the technologies examined in this study. Loading cost for the product is included in processing for some cases. The ethanol is received at the refinery, which is assumed to cover any unloading costs for receiving the ethanol. For ethanol, only 35.7% of harvesting and processing costs were included because this is the share of revenues from ethanol; the remainder of the cost is allocated to the other co-products. For pipeline quality gas, the distance is irrelevant and only the cost up to the feed-in point is accounted for.

It is obvious from **Table 5.2.1** and **Table 5.2.2** that concentrating the energy does not necessarily lead to life-cycle cost savings. This result is mainly due to the fact that, while transport costs can be reduced as energy is more concentrated in liquids etc., upstream costs are increased because of losses due to de-barking, processing losses and costs. For example, the cost of transporting entire wood logs for chipping and co-firing is nearly the same as when pelletising or briquetting the wood before it is shipped, although chipping may be a simplified approach (i.e., more processing may be required). Extrapolating to longer distances for truck transport would, however, show a distinct advantage for briquettes due to lower shipping costs. On the other hand, train transport over a distance of 1000 km does show now clear advantage for the concentration of energy in liquids, log transport being fairly cheap in comparison.

Pre-treatment and processing of the wood therefore becomes more of an issue of developing markets and improving handling of wood energy products, rather than one of cost. The above calculation does not include de-barking before pelletizing, as this may not be necessary if the wood is burned in a coal plant (i.e. pelletizing costs are slightly reduced compared to “premium pellets” and harvesting costs are the same as that for wood logs). Still, because of the fairly high transport cost for pellets, transporting unprocessed logs appears to be the cheaper option. (Note that this cost could be reduced if the hauling company can take a load on the return trip.)

Table 5.2.1 Cost Comparison of 1 GJ Delivered by Truck at a Distance of 500 km (+150 km Feedstock Transport to Plant)

Product	Harvesting & Transport	GJ HHV	Processing Cost***	GJ HHV	Kg bdt	Loading	Transport	Unloading	Total
Wood	$4.86	1	$0.65	1	49.3	n/a	$3.20	incl.	$8.71
Pellets**	$4.86	1	$1.25	1	49.3	$2.29			$8.41
Briquettes	$5.17	1.06	$2.19	1	52.6	-	$1.16	-	$8.52
Bio-liquid	$8.84	1.82	$2.27	1	40.4	$0.20	$1.27	$0.20	$12.78
Methanol	$12.63	2.60	$10.77	1	44.1	-	$0.88	(buyer)	$24.29
Meth. (H_2)	$5.16	1.06	$5.44	1	44.1	-	$0.88	(buyer)	$11.48
Ethanol	$4.23	0.87	$19.94	1	33.7	-	$0.67	(buyer)	$24.84
SNG	$7.25	1.49	$9.84	1	-	0	0	0	$17.09

* Chipping: cost is assumed to be $5/m³. Note that chipping would only take place AFTER transportation to the coal plant, as the density of trees is higher than that of chips.

** Not de-barked, hence same HHV as wood feedstock.

*** Salaries, O&M, utilities, plus capital cost, amortized over 10 years at 10% interest.

Table 5.2.2 Cost Comparison of 1 GJ Delivered by Train at a Distance of 1,000 km (+150 km Feedstock Transport to Plant by Truck)

Product	Harvesting & Transport	GJ HHV	Processing Cost***	GJ HHV	Kg bdt	Loading	Transport	Unloading	Total
Wood	$4.86	1	$0.65	1	49.3	0.49	$1.33	(buyer)	$7.33
Pellets**	$4.86	1	$1.25	1	49.3	-	$1.23	(buyer)	$7.35
Briquettes	$5.17	1.06	$2.19	1	52.6	-	$1.68	(buyer)	$9.04
Ethanol	$4.23	0.87	$19.94	1	33.7	-	$1.52	(buyer)	$25.69
SNG	$7.25	1.49	$9.84	1	-	0	0	0	$17.09

Figure 5.2.1 compares the costs of the bugwood processing technology options included in this study. The left bars show the ROI achieved at a feedstock cost of $68.55/bdt, and the right ones show the ROI achieved at a harvesting cost of $106/bdt. The ROI deemed necessary to attract private investment is 10%. Processes with an ROI below 10% would require an incentive (or feedstocks at a reduced cost) to become economically viable. At the assumed plant sizes, several technologies can achieve the required ROI at the lower feedstock cost. However, especially the results for ethanol and methanol production (based on the Indirect Fluidized Gasification and hydrogen process options) are still preliminary and would need to be confirmed through technology demonstration. At the higher feedstock cost, only methanol with hydrogen enrichment and off-grid CHP seem to be able to generate the required return, with ethanol coming close at 7% ROI. However, there are a few remote (off-grid) communities in the BC Interior (i.e., the bugwood application in off-grid systems is not likely to be implemented in many places). Briquettes and on-grid CHP can achieve and ROI of around zero percent at the high feedstock cost (-0.7% for CHP), but economics are insufficient to attract private investment.

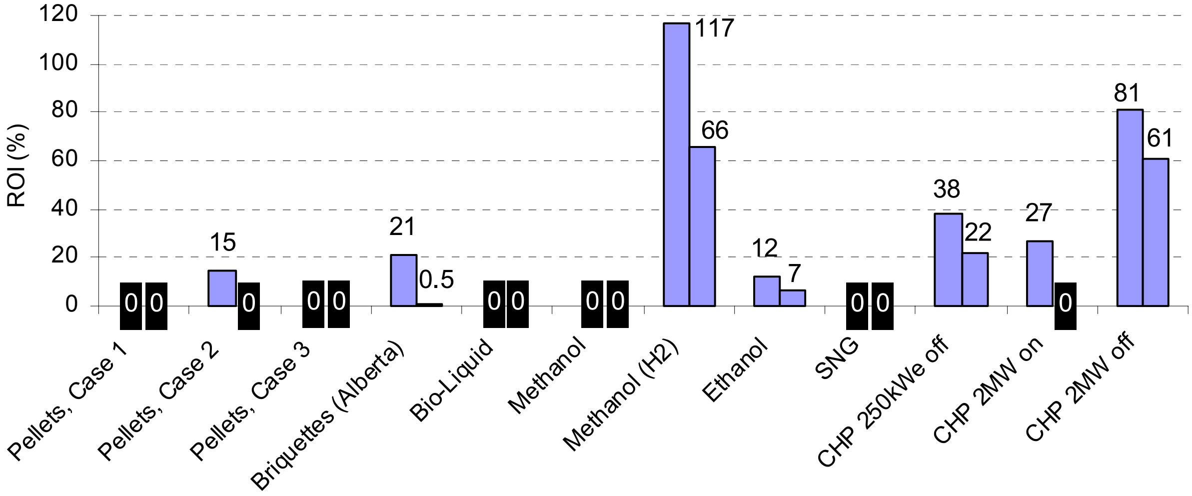


Figure 5.2.1 **Comparison of Plant Economics at a Harvesting Cost of $68.55/bdt (left bars) and $40/m³ (right bars)**

Figure 5.2.2 shows the incentives required per m³ of bugwood processed for each technology to reach a 10% ROI, again for both the lower and higher harvesting costs. Subtracting these numbers from the assumed harvesting cost of $26.05 or $40.50 per m³ reveals the harvesting cost at which the process would become profitable. For example, at a feedstock harvesting cost of $40.50/m³ ($106/bdt), Case 2 of pellet production would require a $13/m³ incentive, equivalent to a 30% cost reduction in feedstock harvesting cost, to achieve a desirable ROI; the ethanol requires a 20% reduction in harvesting cost. CHP (on-grid) processes would require 8% improved feedstock economics (full cost for a CHP district heat system is not included as it is dependent on the local need and specific installation). This suggests that in such cases, mixing the bugwood with other, low-costs feedstocks, such as sawmill waste or hog fuel, may enable such technologies to operate profitably using a feedstock predominantly consisting of bugwood.

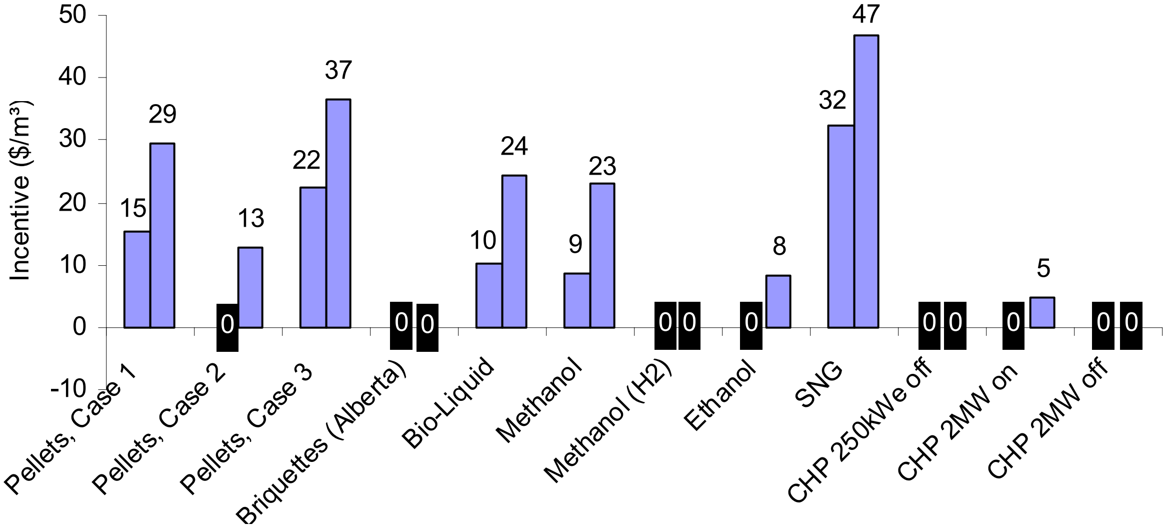


Figure 5.2.2 **Feedstock Incentive Required to Generate 10% ROI for Different Technologies at Harvesting Cost of $68.55/bdt (left bars) and $40/m³ (right bars)**

Figure 5.2.3 makes a comparison of life-cycle GHG emission reductions for each technology. Note that the pine beetle kills are decreasing Canada's carbon inventory, and not using the wood will mean that carbon stored in these trees will eventually be released through gradual decay. Using this biomass for energy purposes will displace fossil fuels, thus creating permanent emission reductions that can be counted towards Canada's Kyoto target. Emission reductions from co-products (CHP: electricity; ethanol: acetic acid and lignin) are accounted for as described in the pertinent chapters. Carbon credits flowing from the net reductions were accounted for in the cost calculations above.

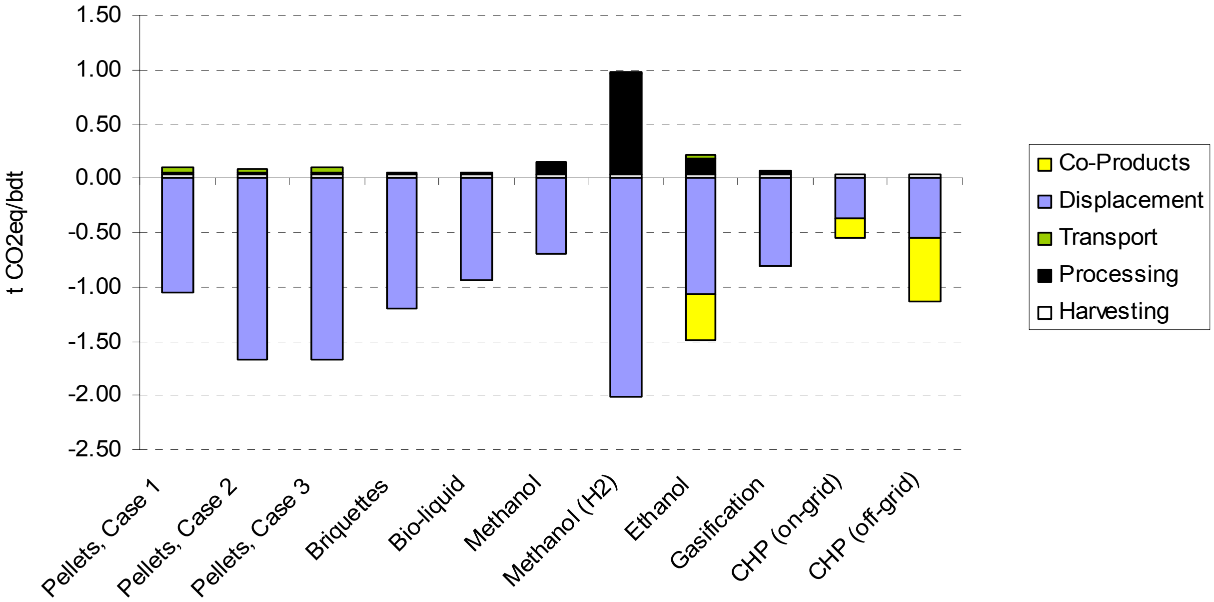


Figure 5.2.3 GHG Process Emissions and Displacements

The CHP emission reductions vary between on-grid and off-grid conditions because different energy sources are used on-grid (i.e. grid electricity and natural gas) from off-grid (i.e. heating oil and diesel-electricity). An interesting result of the analysis for methanol is that adding hydrogen to the process to increase methanol output greatly increases the GHG benefits. However, this result only applies because BC grid electricity emissions are very low, whereas in other regions using more electricity for the process might eliminate all the GHG benefits from displacing diesel in the automotive sector. **Table 5.2.3** shows the net emission reductions and resulting carbon credits for each technology. Remarkably, ethanol from the Lignol process, which only contains 41% of the original feedstock energy, still achieves higher emission reductions than the CHP plant, which uses the entire feedstock material. This shows that displacing gasoline on a 1:1 basis has a far larger impact than displacing natural gas-heat and BC electricity. As cellulignin briquettes are assumed to displace natural gas heating in Alberta, they are also less effective in terms of emission reductions than pellets displacing coal in an Alberta coal fired power plant – GHG results for cellulignin would therefore improve when used in coal plants, or would displace heating oil. However, displacing natural gas is seen as a higher-value applications for CL.

Table 5.2.3 Net GHG Emission Reductions and Resulting Carbon Credits

Technology	Net CO_2 Emission Reductions	Carbon Credits (\$15/t of CO_2)
Pellets, Case 1*	0.96 t/bdt	$14.36/bdt
Pellets, Case 2**	1.58 t/bdt	$23.67/bdt
Briquettes (to Alberta)*	1.15 t/bdt	$17.20/bdt
Bio-Liquid	0.90 t/bdt	$13.48/bdt
Methanol	0.54 t/bdt	$8.14/bdt
Methanol (H_2)	1.04 t/bdt	$15.54/bdt
Ethanol	1.27 t/bdt	$19.07/bdt
SNG	0.73 t/bdt	$11.04/bdt
CHP (on-grid)	0.51 t/bdt	$7.66/bdt
CHP (off-grid)	1.10 t/bdt	$16.52/bdt

* Displaces natural gas for heat. ** Displaces coal in co-firing.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Evaluation

6.1.1 Summary of Findings

The aim of this study was to assess seven technologies that could be used to convert BC bugwood into energy. The review evaluated the technologies based on their economics, suitability and technology readiness, and their GHG emission reduction potentials.

Bugwood resource: Bugwood will most likely not remain a resource for longer than 10 to 15 years. By 2025, most dead trees older than 10 years may have fallen, been destroyed by wildfires or otherwise be of sufficiently poor quality to make harvesting uneconomic. It is therefore necessary to devise processes that can amortize in a short time, or are able to process other feedstocks once the bugwood is used up.

Moisture content: The average moisture content of bugwood is not known with certainty. Estimates are that moisture content decreases quickly after death, and that older trees (four years or older) have a moisture content of no more than 19 to 25%. An average moisture content of 20% was assumed to apply for old and very old (10 years or older) wood, which is the feedstock modelled in this study.

Harvesting: Harvesting is most likely to occur not as a separate operation to salvage bugwood, rather the bugwood will be co-harvested with more valuable types of wood (including bugwood sawlogs). A large-scale harvesting operation can produce up to 8,000 m^3 of wood a day, and a large percentage thereof may be bugwood. Processing capacities should be able to cope with these amounts of feedstock. Harvesting activities are also limited by seasonal issues such as soil moisture, fire hazard and access.

Small-scale approach: The initial approach of this work was to assess small-scale, decentralised plants which could be operated at the harvesting site, at the local log sorts or other nearby locations. Reducing log transport distances and concentrating the energy contained in wood as bio-liquid, methanol etc. was thought to reduce costs enough to make small-scale technologies more viable, and would allow them to follow the harvesting operation if devised as mobile or semi-mobile plants. However, due mainly to the scale of harvesting operations in BC (up to several thousand m^3 per day), the amounts of bugwood expected to be processed and the energy needs linked to their processing do generally not allow for processing in remote locations. Some applications, such as bio-oil or cellulignin briquettes, may be successfully run in remote locations (with diesel engines or small CHP systems to provide electricity), but may then not be adequate to link in with larger harvesting operations.

Harvesting vs. transport cost: It was also found that the main factor influencing plant economics is not transport cost, but the harvesting cost, which was estimated to be $106 per bdt ($40.50 per m^3), and also modelled as $68.55/bdt in order to allow for a comparison of the results with the BIOCAP study. Harvesting cost is increased due to weather-related interruptions of harvesting operations, and the complexities of bugwood as compared to healthy trees, such as increased dampness of the soil.

Transport cost for logs up to 100 km represents only 20-25% of delivered cost. Longer distances are not anticipated for energy uses due to the abundance of bugwood and economic restraints that do not allow for higher transportation costs. Likewise, the transport of pellets, bio-liquid and other energy products does usually not make or break plant economics if compared to the high cost of harvesting. An exception is the transport to Europe by train and/or ship, which adds a significant financial burden to the processes examined.

Concentration of energy to reduce transport costs: It was hoped that conversion of wood to liquid fuels or gases would reduce the cost of transporting energy to the end user. This is indeed the case; for example, transport costs are reduced considerably when transporting ethanol instead of logs. On the other hand, a quote obtained for pellet transport showed no significantly improved economics compared to log transport, although pellet transport charges can be overrated (i.e., high freight rate in comparison to log transport). Counting in the cost of harvesting and processing, the conversion into more condensed fuels does not necessarily make economic sense. For the option examined (500 km truck transport), logging trucks remain one of the least-cost options to deliver a given amount of energy to the user, even if chipping cost is included. However, there are other benefits in energy conversions, such as the opening up of different markets, and possibly the sale of co-products, such as in the case of the Lignol process. As transportation is not the only factor, conversion into more condensed biofuels may be an attractive option to open up new markets for wood-derived products.

Economics: Economics were assessed based on preliminary data from the literature for several processes that are not yet commercial. Several scenarios (bio-liquid, overseas pellet and briquette sale) do not break even with the full cost of bugwood as a feedstock. Especially at the higher feedstock cost modelled, only methanol with hydrogen enrichment or off-grid CHP appear to yield an ROI high enough to justify using bugwood. The other options would require a subsidy to achieve a 10% ROI, or would have to source cheaper feedstocks to supplement bugwood and reduce overall feedstock costs.

GHG emission reductions: The amount that GHG emissions are reduced by each bugwood use depends on two factors – the energetic efficiency of the process, and the type of fuel that is displaced. Despite its efficient use of biomass, a CHP plant will only displace slightly over 0.5 t of GHG per bdt of bugwood feedstock. Several other options, which displace either gasoline, diesel or natural gas, will achieve a displacement of about 1 tonne of CO_2e per tonne of bugwood. Only when bugwood is (directly, as pellets or as briquettes) used to displace coal in cofiring, the benefits can grow to over 1.5 tonnes of CO_2e per tonne of bugwood. Ethanol (Lignol Process) achieves emission reductions of about 1.25 t of CO_2e/bdt, mainly due to the fact that it displaces gasoline and also due to the lignin, which displaces resins in wood products manufacturing that require a lot of energy to produce. Note that the above calculations are reasonably precise, but would not be detailed enough to claim carbon credits in a sales agreement, i.e. a more detailed life-cycle analysis would be required.

6.1.2 Evaluation of the Technologies Examined

The following paragraphs discuss the main issues for each of the technologies examined. Beyond the immediate results obtained in previous chapters, this chapter looks at the larger issues and assesses the overall feasibility and long-term viability of each technology option (summarized in **Table 6.1.1**).

Pellets: A pellet plant only relying on bugwood for its feedstock will find it difficult to break even. Using the parameters of \$106/bdt harvesting cost and \$156/t market value for pellets (\$170/t for Europe), none of the pellet plant scenarios were able to reach an ROI of at least 10%. In the most favourable scenario, which is the use of pellets in an Alberta coal plant, the incentive required to break even is \$8 per m^3 of bugwood harvested. Exporting the pellets to Alberta for co-firing in coal plants will only work if the coal plants are ready to pay the full price for this feedstock, but the economics are very tight. There is no economic motivation for coal plants to use pellets as a feedstock at a price of over \$150 per tonne. However, counting in benefits such as the Renewable Power Production Incentive and carbon credits may reduce the price of power enough to break even with electricity from combined cycle natural gas turbines. Debarking is most likely not necessary for bugwood use in coal plants, which would reduce the costs of pellets somewhat. However, shipping entire logs for chipping at the plant may be cheaper than shipping pellets, depending on the type of pre-processing required to use the wood in the coal plant.

The domestic market for wood pellets seems limited: many BC communities do discourage or prohibit the use of wood pellets due to the environmental implications (particulate emissions). There may be some more market potential in the greenhouse sector, as well as some pulp & paper plants, but the larger market seems to lie overseas in Europe. It is not expected that China will become a market anytime soon due to the very high cost of pellets as compared to coal.

However, the overseas market is limited by the very high shipping price (over $50 per tonne). This shipping cost brings the price of pellets over the market price of $170 that can be achieved in Europe. The reason why one BC pellet manufacturer exports pellets overseas is not known with certainty, but is presumably either that

- they can sell pellets to Britain, where a higher than usual price can be paid for pellets than in other countries, due to the “Renewable Obligation Certificates”, which create considerable additional income for renewable power producers, but only exist due to a particular trading mechanism created by the British government to support renewables, or
- because their cut license also includes other species than pine, as well as sawlog quality bugwood (at the same low stumpage fee), the amount of high-quality logs harvested and sold to other companies may provide a high enough return to counterbalance the high cost of bugwood as a feedstock through this second source of income.

There is on-going investment in several pellet plants in BC, based on the bugwood resource. It is currently not known if the market in the UK or other European countries would allow for an expansion of this industry in BC. It is, however, possible to combine bugwood with other feedstocks, such as sawmill waste and bark residues. BC has large amounts of these biomass residues available, and co-processing of such free feedstocks with bugwood would reduce the average feedstock costs enough to achieve the commercial break-even point. It was also shown that an advanced (Entropic System) CHP plant can reach an ROI of 10% using bugwood. If such plants were built in BC, they could therefore process pellets that cost no more than $106 per tonne. Using low-value bark pellets, or mixed pellets, could therefore be an option to use this resource. Alternatively, chipping of logs at the CHP plant and mixing them with other low-cost forest residues could be an option. Producing lower-end industrial pellets that contain bark could also reduce prices enough to sell such pellets to Alberta coal plants for co-firing (note that such pellets are currently not accepted by industry). Industry could negotiate with Alberta utilities to determine the maximum price that could be obtained for such pellets. If long-term contracts can be obtained, then the viability of such production based on residues from smaller sawmills and bark residues in BC could sustain production even when the bugwood resource is diminished in 10-15 years. Note that much of the equipment is written off after ten years, allowing a somewhat increased margin for feedstock costs.

Cellulignin: Cellulignin (CL) briquettes were developed as a means to process the biomass into a renewable fuel with high energy density but without significant ash and inorganics. Once compacted, it has the energy density of bituminous coal, but with much better burning characteristics as the particles are very small (less than 250 microns and burn quickly). This technology is promising as the briquettes can be transformed into a cellulignin powder, which can displace natural gas in many applications. This creates a high value for the biomass and could solve the many issues related to the thermal biomass conversion, such as particulate emissions. Prehydrolysis of biomass to produce furfural and CL is economically attractive at the lower feedstock cost, but not at a harvesting cost of $106 per bdt. Briquetting using prehydrolysis is a technology that can also work at the small-scale, decentralised level. Like distributed CHP systems, these applications may find possible investment for their development, provided a stable market can be developed for the briquettes. Addressing biomass handling and impurities upstream of any process may prove to be strategically better in the long run as Canada tries to emerge a leader in the bioproducts and bioenergy economy.

Bio-Liquid: The ABRI bio-liquid system was selected for review because it has been developed specifically to be modular, sized suitable for relocation and designed to meet the flexibility requirements that bugwood applications would demand. Design details that are developed for the Ontario demonstration plant may clarify its suitability for use with BC bugwood.

The bio-liquid production approach was unable to show profitability of at least 10% under the costing scenarios of this study. As with other technologies, this is largely due to the very high cost attributed to bugwood harvesting. Without the inclusion of harvesting costs, the bio-liquid facility shows a strong ROI. If the ABRI system were implemented in a situation where harvesting costs were attributed to an alternate operation (such as a sawmill), then it may show itself to be a profitable technology to implement. Likewise, if it becomes feasible to extract high-value chemicals from bio-liquid to increase plant revenues with additional streams of income, this technology may fare better in comparison to the other options examined.

CHP: Combined heat and power systems will find bugwood to be feasible as a feedstock in many situations. Unlike higher-end uses such as lumber or pulp chips, the heat content of bugwood remains available through combustion unless or until the material decays. Moreover the same systems that would combust bugwood can be used to combust other materials such as green wood, underbrush, construction waste and refuse derived fuels as well as non-renewable fuels. Thus CHP systems that are commissioned to use bugwood can continue to be used in the future if the bugwood resource is eventually consumed. Investments into CHP systems are not limited to the continued existence of bugwood.

Box 3 Oujé-Bougoumou District Heat

In the early 1990s the Cree of Oujé-Bougoumou built a new community designed to include a biomass-fired district heating system. Although a combined heat and power system was not then available and cost-effective, the heat only system proved effective. Currently the village proudly publicizes its history, culture, people and home; including details of their community energy system.

Source:www.ouje.ca/content/our-story/energy.php

CHP systems have limited application suitability. They offer the greatest benefit for off-grid communities where they are used to displace diesel generated power and where they feed a district heat system that displaces heating oil. For on-grid communities, CHP increases the stability of power and its security of supply. For most communities CHP would introduce a new concept of energy planning. It would offer extensive benefits of reduced pollution (smell, noise, spill and emissions of diesels), reduced cost (removing subsidies), affordable new community services and business ventures, added employment (related to harvesting bugwood, to new services and new ventures) and reduced wildfire threat (preferential mechanical treatment of forest interface land). Such communities may not consume vast quantities of bugwood but will clear and reforest the nearest bugwood to restore the surrounding lands. Box 3 discusses the community systems approach to energy.

Alternate scenarios may take advantage of existing infrastructure to implement CHP systems. Sawmills can use their existing biomass waste to operate a CHP system that produces both mill power and dry kiln heat. These sawmills may find it attractive to oversize such CHP operations to combust available bugwood while supplying the excess power to the grid. However, similar attempts have proven difficult in BC as many sawmills prefer to shut down for extended periods of time whenever market conditions for their products are insufficient. Such shutdowns would mean that the economics of the CHP plant are negatively affected.

CHP systems are noted in the financial comparisons to be very attractive in off-grid applications. They are very sensitive to harvesting costs if applied to on-grid power production. For on-grid applications the CHP application must include a suitable heat user or more favoured power sell value as well as contained harvesting costs to generate a satisfactory ROI. Note that the cost for district heat distribution systems is not fully included in the cost calculations and can be significant.

Ethanol: BC-based Lignol Innovations is developing a promising process that can extract ethanol from softwood using a fermentation process (Organosolv). This process could break even at a gasoline rack price of about $0.50 per litre, as it is seen today (assuming an ethanol value of $0.45/l). However, the fairly good economic return from this process (ROI of 12%) depends on the successful, long-term sale of the co-products, with the related price uncertainties. The process is not commercial yet, but with a pilot plant expected to be running by 2007, the process may be ready for the coming decade, in time to utilize the bugwood resource for this high-value application. Demonstration is crucial to confirm both capital and operational costs for this technology, and to confirm projected product yields with bugwood as a resource.

The market potential for ethanol is very large, as it can be mixed with gasoline. Nevertheless, a legislative obligation may be required to force refineries to accept ethanol in order to mix it with gasoline. At the current cost of oil-based products, the Lignol process should be able to sell ethanol for about 45 cents per litre, which would represent a significant revenue stream. The market for the other products of this process may be more limited and a more detailed feasibility study would have to assess market potentials and expected revenues from these materials with much certainty, as they account for a major part of expected plant revenues.

While the Lignol process can use bark for process heat, it cannot process the bark itself and therefore has no alternative feedstocks in the forestry industry, other than sawmill residues. There may be competition for these residues in the coming decades as other technologies, such as pellet plants, source more and more of them. It appears, though, that the Lignol process may result in high-end products that will allow it to successfully compete for these feeedstocks. The process can also use other lignocellulosic feedstocks, such as straw, but would most likely depend on forest residues if a plant is located in the BC Interior. Being a BC technology, the Lignol process has some export potential which could be developed, creating a local manufacturing industry.

Methanol: Methanol production technology from syngas is still in the development stage and may take significant time to develop commercially. The methanol yield is significantly affected by syngas composition and requires an optimum molecular ratio for the process to become feasible. Indirect fluidized gasification seems to be the best choice for methanol production from bugwood in BC. The addition of hydrogen instead of CO_2 removal dramatically increases the methanol yield. The economics are determined both by the bulk selling price of methanol and by the cost of biomass feedstocks, and only the hydrogen enrichment scenario seems economic under the assumptions made, although increasing fuel prices may change this outcome. Demonstrations of gasification systems using biomass to create syngas for power generation in engines and turbines have not been successful in the past. They have been hindered by issues surrounding flue gas clean-up and process economics. There is no commercial technology today that can cost-effectively generate clean syngas by gasification of biomass. Cleaning the syngas remains a major technological challenge. A possible modification of the process would be to use cleaner cellulignin (see section on briquettes) to produce the required syngas.

Synthetic Natural Gas: While it seems technically feasible to convert wood to pipeline standard natural gas, the technology is not available and no demonstration plants can be expected before 2010. Also, reaching a percentage of 2% CO_2 in the gas – one of the quality criteria for natural gas in BC pipelines - does not seem technically feasibly at this point in time. The process cannot break even at the high feedstock costs modelled. Low-cost biomass residues, such as sawmill waste, may take such a plant to profitability while using a small portion of bugwood as a feedstock (less than 25%). Gasification is possible with a variety of feedstocks, but some wood (such as sawmill waste) may have to be pre-dried. A plant would have to be situated both near a gas pipeline that can accommodate its output, and also needs some process water and electricity. The subsidy per m^3 required to make the process profitable is otherwise one of the largest among the technologies examined. In the end, the most important factor when considering gasification is the absence of any demonstrated technology that would allow for its implementation. Major breakthroughs in gasification technology are required to make this technology commercial. Using wood gas in vehicles instead of feeding it into a pipeline would require less extensive syngas processing, and would also displace more GHG emissions as it displaces gasoline and diesel instead of natural gas. However, this option would require that users modify their vehicles so they are able to use wood gas as a fuel and be prepared to absorb the increased maintenance and fuel handling costs (activities). This is only likely for local use as prepared biomass fuel is unlikely to be widely available.

Table 6.1.1 Feasibility of Bugwood-to-Energy Technologies

Technology	Cost-effective	Comments
Pellets	Some scenarios work, but not at high feedstock costs.	**Commercial.** Limited domestic market due to concerns about particulate emissions. Potential in UK at high prices, but un-quantified. Coal plant may want to buy pellets for image reasons; biomass is competitive with natural gas as a fuel
Cellulignin Briquettes	Local use works at lower feedstock cost	**Commercial in Brazil.** Depends on whether CL can be accepted as a substitute to natural gas in industrial and residential applications, and on natural gas prices.
CHP	Yes: off-grid, under 2 MW	**Pre-commercial.** Costing depends on technology; small CHP reviewed is a new BC technology
	On-grid: Yes, at lower feedstock cost; marginal at $40/m³	Depends on emission credits and RPP Incentive, as well as power sales price.
Bio-Liquid	No	**Pre-commercial.** High harvesting costs negate ROI; Bio-liquid market needs to be developed
Ethanol	Yes, at lower feedstock cost	**Pre-commercial.** High uncertainty with respect to production cost and value of co-products; first demonstration plant in BC expected by 2007
Methanol	Yes, with H_2 addition	**Conceptual.**
SNG	No	**Conceptual**; requires higher natural gas price to break even.

6.1.3 Considerations about Residues and Harvesting

Bark residues: The pelletizing process cannot use the bark of the wood feedstock to produce so-called “premium” pellets, which have low ash content and achieve a market price of $156 per tonne. Sometimes part or all of the bark can be used within the process for heat or steam production, such as in ethanol production. However, the increased use of these technologies would lead to increased production of bark residues. One possibility to deal with this residue would be to build a medium-scale power plant in the BC Interior that would use up this low-value feedstock. Being a waste product, it could be removed at no cost, only incurring transportation and handling costs for the power plant. Another possibility would be to use the bark in pellets, which could be sold at a lower price to industrial users. However, this would require a higher incentive payment as the market price for such pellets is lower.

Harvesting cost: The high harvesting cost was singled out as the main cost component for bugwood processing, apart from capital investment. With such high feedstock costs, it is not possible for all technologies to reach a break-even point under the conditions used for financial modelling in this study. Reducing delivered feedstock costs by reducing transport distances, or pre-processing, will only have minor effects on overall economic performance if most of the bugwood can be sourced within an average distance of 150 km. One other way of reducing feedstock costs would be to mix in low-cost feedstocks, such as (hitherto unused) sawmill waste or hog fuel. In addition, harvesting costs could be reduced by increasing the amount of bugwood harvested. As suggested in the BIOCAP study [BIOCAP 2005], the amount of wood recovered could be increased by 20% if not only roundwood, but also branches were harvested. While it is likely that the branches will cost more than $16 per m^3 to harvest (falling and skidding only, not including overhead), their recovery will not increase overhead and other harvest-related costs. , This will tend to reduce the average costs per m^3 harvested. The exact parameters would have to be confirmed in a more detailed analysis, but assuming that including non-stem in the harvest operation wood would cost $20/m^3, and would increase the total harvest by 20%, then average harvesting costs for bugwood could be reduced substantially. In the Vanderhoof example given in **Table 6.1.2**, a total harvest of 8,000 m^3 per day includes, on average, 3,400 m^3 of low-value bugwood. Using the standing volume of sawlog quality pine and other species [Eng 2004], **Table 6.1.2** estimates (in a simplified way) the cost savings potential from harvesting the non-stem biomass from these trees, averaging the combined surplus harvest and the low-quality bugwood harvest over the combined costs. The resulting cost is $31.82 (i.e., a 21% cost reduction over the harvest of roundwood alone). This does not include any other non-merchantable wood that is not picked up by sawmills, but is usually burned on-site.

Table 6.1.2 Example of Potential Cost Reduction from the Collection of Non-Stem Wood in the Quesnel Area (simplified, year 2011)

	Harvestable volume (at $40/km^3)	20% increase	Extra harvest (at $20/m^3)	Average harvesting cost
Low-value bugwood	3,680 m^3 (46%)	736 m^3	1,600 m^3 Cost: $32,000	$136,000 + $32,000 = $168,000 : 4,944 m^3 = $31.82/m^3
Pine Sawlogs	1,680 m^3 (21%)	336 m^3		
Other Species	2,640 m^3 (33%)	528 m^3		

However, not all technologies discussed above can actually use this extra wood. Any technology that requires de-barking cannot use this extra feedstock (only “premium” pellets, among the technologies examined). It may also be that processing branches will require new investment and slight modifications of the equipment or logistics to pre-process the wood feedstock. Premium pellets cannot use bark, i.e. only lower-quality, industrial heat pellets could be made with non-stem wood. Likewise, ethanol requires de-barking, but could use some of the branches to provide extra process heat. Cellulignin, bio-liquid production, CHP and gasification (methanol or pipeline gas) can use the non-stem wood. While harvesting costs may be reduced, a specific analysis would have to account for changes in transportation and logistics as well. Transporting smaller branches may require special equipment (on-site chipping may be the preferred option), and the average truck payload may be reduced, increasing transportation cost. In addition, collecting branches from both bugwood and green trees may require (increased) pre-drying of the feedstock in some cases.

Harvesting cost reductions are also likely from the use of non-merchantable wood usually logged and skidded by forestry operations. Logging companies will generally sort the stems harvested into two groups, i.e. those that can be used in their operations and those that cannot because they are different tree species etc. If, for example, 10% of the wood harvested would be non-merchantable and 20% would be low-quality bugwood, the combined harvest of wood for energy purposes would increase by 50%, reducing harvesting cost for the energy operation by one-third.

6.2 Recommendations

Bugwood on public lands is a potential liability and responsibility for the province. It has become a major issue for the provincial government to address and represents a significant cost, whether it is addressed or ignored. Leaving the problem unaddressed will lead to long-term loss of healthy forests because the regeneration of new forests in areas with standing dead trees is inhibited, and will result in markedly reduced harvests of merchantable wood after about 15 years. This would inevitably lead to job and government revenue losses from the forest resources industry. In addition, old bugwood stands represent a wildfire risk. Forest fires are very expensive to control, endanger communities and pollute the environment. Wildfires result in the loss of carbon contained in the wood, making it unavailable for energy uses to displace fossil fuels and their associated GHG emissions. Controlled combustion and energy capture provide a useful and valuable alternative for the bugwood but without the particulate and other emissions of wildfires. There is thus a public cost involved with the bugwood problem, either now or in the future.

However, the bugwood liability can be turned into an opportunity for economic development. This study has determined that several technologies exist or are emerging that can convert bugwood into an energy and/or chemical resource. The application of these technologies could create a new industry, employment, and export opportunities for both the wood-derived products and the related technologies.

6.2.1 Technologies

Some of the technologies examined are able to yield returns on investment that should be sufficient, with limited incentives, to attract private investment provided that a suitable policy in regards to harvesting bugwood is established in BC. This is true in particular for

- Small-scale combined heat and power (CHP) plants;
- The Lignol (ethanol and lignin) process; and
- Wood pellets or cellulignin.

Wood pellets could achieve sufficient economic returns under certain circumstances, such as the sale to Alberta coal (or other solid fuel) fired power plants if a high enough price can be negotiated and the federal RPPI incentive and carbon credits can be secured. Cellulignin replacing natural gas as a fuel also shows good economic potential if used in BC or Alberta. They can also make economic sense if truck transport distances to users in BC are relatively short or if acceptable sales prices can be achieved in European (e.g. the U.K.) or other foreign markets.

Other options, including gasification to produce synthetic natural gas (SNG) or methanol, do not appear to break even unless very high market prices are available and very low harvest costs can be implemented by policies. In addition the technologies required are not yet commercial especially at the smaller scale and short term time frames required for bugwood. Bio-liquid production does not perform well economically under the scenarios developed in this report unless the bugwood is readily available at minimal cost. These insights, which are based on general economic data averages, should be confirmed for a specific plant location and technology. Some strategies are available to the provincial government which could encourage the conversion of bugwood into energy.

6.2.2 Strategies

The basic strategies presented below are designed to encourage the development of industries based on the bugwood and other biomass resources in BC, and to use the management of the bugwood resource itself to enable new growth and sustainability of the BC pine forests and the associated forestry industry.

1. **Encourage Biomass Technology Development:** Within the provincial Alternative Energy and Power Technology Strategy, encourage and support the demonstration of emerging technologies, such as ethanol, cellulignin, and small-scale CHP.

   These technologies were shown to have economic potential using bugwood as a feedstock, and could improve the BC Interior's energy and economic infrastructure while creating a lasting benefit for the province as a whole. Tax benefits for bugwood related technologies, such as those provided for the mining sector, may enable the development of a new industry in BC. This strategy will also help the province to hedge against increasing natural gas prices, as wood may become a competitive fuel if the price of natural gas continues to increase. Investments in bugwood technologies can be used to lever the development of a larger biomass industry in BC.

Box 4: The Forest Industry Competitiveness Strategy

This five-year initiative, led by Natural Resources Canada, was announced in November 2005 and addresses a wide range of issues and opportunities currently facing the Canadian forest industry. This includes diversifying the economies of forest-dependent communities, enhancing skills of forestry workers, investigating new markets for wood products, developing innovative technologies and supporting the domestic industry in the face of the continuing softwood lumber dispute.

The strategy provides $581 million to support forest-dependent communities, market diversification and incentives for innovation in the forest industry, including incentives for bioenergy production. In addition, the Government of Canada's November 2005 Economic and Fiscal Update proposes to accelerate the capital cost allowance for forest bioenergy. This would mean the industry would realize up to $110 million in tax savings. The Strategy also sets aside funds to facilitate up to $800 million in loan insurance and provides $100 million for a repayable contribution program for firms affected by the unique circumstances of the softwood lumber dispute.

Source: NRCan press release, Oct. 24, 2005

2. **Encourage Biomass Industry Development:** The government should support private investment in energy related to the commercial application of new technologies. Using

mechanisms for reducing investor risk that would allow small and medium-scale projects to move ahead quickly are potential tools to achieve industrial development. Some possible economic instruments or mechanisms are outlined below.

- i. Providing loan guarantees, grants, long-term or low-interest financing, or public-private partnerships could reduce the business risks associated with investing in new technologies related to bugwood and biomass in general.
- ii. Concentrating on small-scale systems will increase the number of installations and potential investors compared to large-scale centralized systems. In addition, once the bugwood resource is used up, smaller facilities will also find it easier to relocate and/or source alternative feedstocks. It is anticipated that most small-scale plants, having repaid their initial investment, will be able to justify higher feedstock costs and maybe use alternate biomass sources such as hog fuel, non-stem wood, sawmill waste, or even wood from energy crop plantations.
- iii. Subsidizing the cost of the bugwood feedstock (e.g. \$X per m^3 based on the volume of bugwood harvested) would improve the financial viability of the technologies. The subsidy could also be used to favour or target specific technologies or applications. Instead of subsidies, the cost of co-harvesting bugwood can be counterbalanced by decreased bid prices for merchantable wood.
- iv. Providing a premium or set purchasing tariff for the biomass (renewable) energy and/or products produced would help the technologies commercialize.

3. **Encourage the Harvesting, Removal and Utilization of the Bugwood Biomass**. Efforts should be made to favour the removal and utilization of the bugwood, subject to silviculture considerations. The bugwood should not be left in the forest where it may create a potential fire hazard with the attendant management and environmental costs, nor should it be burned in slash or wood-waste burners that have no energy recovery and higher environmental impacts. Some options to encourage bugwood removal and utilization are discussed below. As the co-harvesting of bugwood that cannot be used in sawmill or pulp mill operations increases overall delivered feedstock costs for these mills, it is likely that the bidding cost for merchantable wood cut licenses in areas affected by the pine beetle has to decrease in order to allow the co-harvest of bugwood. It may be possible for large-scale harvesting operations to accommodate a certain percentage of co-harvested bugwood, but large amounts of wood that has no value for their operations will certainly jeopardize profitability in the BC forestry sector unless costs can be saved elsewhere. The specific combination of options chosen therefore depends on a variety of considerations, including the portion of bugwood in the cut block, the harvesting costs, and transport costs:
    - i. Forest companies could co-harvest the NRL bugwood with merchantable wood. In-forest, staging area, or mill site separation of bugwood would follow the harvesting of merchantable wood. The silviculture and infrastructure costs (roads, camps, reforestation etc.) could be absorbed by (or assigned to) the merchantable portion of the wood harvested, thus reducing the "overhead" costs for the bugwood.
    - ii. Harvest obligations could be tied to cutting rights to require bugwood cut blocks to be co-harvested with higher value (less bugwood) cut blocks. This would encourage logging of the lower value bugwood areas in order to access the higher value fibre.
    - iii. Staged harvesting of merchantable wood and then bugwood could reduce overhead costs attributable to bugwood: if harvesting of cutblocks with predominantly merchantable wood precedes the harvest of bugwood by another cutting crew, the costs for road and camp construction to recover the bugwood could be reduced. Although this option is generally seen as more costly and has

therefore not been practiced in BC, it could encourage bugwood harvest by an energy industry able to process it if at the same time increased costs to recover the merchantable wood first are mitigated by cheaper cut licenses.

iv. Reduce or assign low or no stumpage fees to the bugwood or the cut block as a whole. Depending on NAFTA trade restrictions, even a negative stumpage fee may have to be assigned to the bugwood (i.e. paying to have it removed). If the bugwood is perceived by the forestry companies to have no value, controls must be put in place to ensure its removal and utilization, rather than leaving it in the forest, as discussed above. On the other hand, maintaining a moderate stumpage price for bugwood has the advantage of encouraging forestry companies to investigate options to recover their costs incurred by co-harvesting bugwood, such as maximizing use as sawlogs or chips, or even a CHP plant integrated with their mill and dry kilns. This would be more of an option for the early phase of bugwood removal.

v. The harvested bugwood would be made available at a value pre-determined by government policy (possibly free) to third parties with the harvesting company allowed preference for their own consumption. The province would then have to make concessions on the cut license bidding price for high-quality wood in areas with large amounts of bugwood to be co-harvested (as discussed above under low stumpage). This would effectively place bugwood harvesting costs onto merchantable wood and separate it from value recovery of the energy resource. This suggestion is based on the premise that bugwood removal is necessary for forest rehabilitation while value recovery is only a method to mitigate the removal costs. The approach would serve to encourage forest industry participation in bugwood conversion technologies by giving them preference in realizing the economic returns of value recovery.

vi. Harvesting rights could be modeled after the existing Small Business Forest Enterprise Program. Owners of bugwood conversion facilities could be awarded forest licences to bugwood areas. They could then subcontract the harvesting to large forestry companies who would harvest all of the wood and use the merchantable portion for their own purposes (sawmills, paper mills, etc.). Contractual agreements would specify at which price the license holder can buy back the NRL bugwood from the harvesting company. Harvesting methods and costs may be adjusted to match the local situation and requirements.

In any event, the BC government is urged to develop a clear policy as to how the bugwood harvest will be tied to existing harvesting of good wood to allow potential users of the bugwood to properly predict their delivered feedstock cost. Not doing so will translate in very little use of the bugwood as few would bid to harvest dead bugwood at its full cost when waste wood residues are available in the province.

6.2.3 Synergies

There are obvious synergies between the technologies examined, and between the bugwood problem and other BC forestry issues, such as beehive burners. A small CHP plant can deliver energy to municipalities in the BC Interior or create an integrated sawmill producing power and kiln heat from mill residues, or feed power and heat to related technologies, such as ethanol production. Likewise, cellulignin could be used instead of natural gas to heat greenhouses, commercial/institutional and residential buildings, providing a low-carbon, clean energy source to replace natural gas. The increased use of older bugwood saw logs will create additional biomass waste in sawmill operations that can be fed to the systems presented. Implementing such plants near sawmills, hog fuel piles, wood waste landfills[8], etc. would address several problems together and feedstock costs would at the same time be reduced to improve plant economics. CL briquettes create the possibility of a much lower capital cost gas turbine for power generation, which could then supply a gasification plant with a much cleaner feedstock for the creation of syngas. Greenhouses in the Lower Mainland could use small CHP plants that can control particulate emissions while delivering electricity in an area where demand is highest, providing substantial value for BC Hydro's power planning.

Based on the above results, some technologies can operate profitably even with expensive bugwood as their feedstock. This means that the existence of such plants in BC is very likely to reduce existing wood waste problems seen in many areas. With wood waste being a free feedstock, and transport costs being less important than harvesting costs, these additional feedstocks are more than likely to be utilised once the infrastructure for their energy conversion is in place.

6.2.4 Further Work and Research

The following areas are recommended for further investigation:

- Investigate technologies or strategies for reducing the high cost of bugwood harvesting.
- Confirm the cost of harvesting bugwood and resolve discrepancies between various studies quoting different costs.
- Assess market value and potentials for products made from bugwood in domestic and foreign markets, and identify possible sites and/or partners for community or industry CHP installations.
- Develop a bugwood-for-energy strategy that links in with BC's Alternative Energy Strategy, and analyse how several plants of various technologies could work together synergetically to use this resource cost-efficiently.
- The harvesting of non-stem wood or forest fire fuel load reduction may present an economic opportunity for BC that has so far been ignored. In Scandinavia, special processors collect branches, and small diameter stems to form bundles which are then utilised in energy conversion plants. According to FERIC, the density of non-stemwood is still low even if bundled, and the cost of bundlers is high (i.e., on-site chipping of such wood may be another option to be considered for BC).
- Detailed economic and feasibility studies should be encouraged, possibly through public private partnerships, for specific locations and applications as some of the assumptions in this report (e.g. averaging transport distance), the availability of waste fibre, and local community and/or industry needs for energy may have masked a site-specific economic opportunity.
- The feasibility of micro or small community-scale wood gas systems, such as mobile self powered whole log or branch chippers could be evaluated.

Most of the technologies presented in this report and other reports concerning bugwood require further development and refinement of expertise and knowledge to bring them to commercialization. Information has been presented to suggest the most promising opportunities. Further research and support is required to bring them to commercial reality in the reduced time-frame available to meet the BC bugwood issue.

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[8] Wood waste landfills in BC frequently contain other non-wood items, such as car wrecks or concrete, which may make their "mining" for energy purposes difficult, or uneconomic.

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