

Overview of Potential Conversion Technologies for Forest Thinnings

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Abstract

The thinning of forests promotes higher value growth, increases disease resistance, and reduces the potential for catastrophic wild-fire. However, the size and quantity of these thinned trees is such that they are of little value to traditional forest industries. In order to improve the economics of thinning, methods must be identified for upgrading this low-quality feedstock to a higher value product. This document considers three wood conversion technologies: pelletization to densified wood pellets, fast pyrolysis to bio-oil, and gasification to methanol.

1.0 Introduction

As the human fingerprint on climate change comes under increasing scrutiny, efforts are being made to develop more sustainable energy practices. Among renewable energy sources, such as wind and solar, biomass has the sole distinction in that it may be easily stored and used in a manner similar to conventional fossil fuels. Solid biomass may be burned like coal, gasified biomass may be used in gas turbines like natural gas, and liquefied biomass could replace petroleum. Also, as with fossil fuels, processing or combusting biomass releases fuel bound carbon as carbon dioxide (CO₂). However, provided biomass is replanted at the same rate it is harvested, CO₂ emitted by combustion will be taken back up by new growth. As a result, biomass to energy conversion may be considered carbon neutral and does not contribute to increased atmospheric concentrations of greenhouse gases. Of course, some fossil fuel carbon may be emitted during harvesting and transport.

A challenge to the wider use of biomass for energy production has been the availability of low-cost feedstock. One potential source of low-cost biomass would be thinnings from sustainable forestry practices. Thinning involves removing some fraction of the small diameter (4-8") trees from a stand, allowing those remaining to mature more readily into valuable timber. Furthermore, thinning improves disease resistance and reduces the risk of catastrophic wild-fire [1]. However, thinned trees are too small to be of value to traditional forest industries and the resource base is insufficient to profitably operate a chip-mill for the pulp and paper industry [2]. Additionally, once thinned biomass has been chipped for transport, its density is too low to be economically carried a great distance [1], reducing the possibility of traditional combustion for power generation. Furthermore, a significant fraction of the material transported is moisture in the wood.

The challenge is to convert low quality, low density thinnings into a product with higher value and density. This conversion should be carried out as close to the logging bed as possible to minimize aforementioned transportation penalties. However, some transportation may be necessary to achieve reasonable scale of operations at an intermediate processing point. Three conversion technologies considered in order of increasing complexity are: pelletization, fast pyrolysis, and gasification. The products of these processes are, respectively, wood pellets, bio-oil, and methanol. Table 1 provides a summary of these technologies and their saleable products, as well as economic and technical hurdles to their use in the field.

Conversion Process	Product (Energy Density)¹	Product Use	Technical Hurdles to Field Use	Economic Hurdles to Field Use
Pelletization	Densified, uniform wood pellets (12.2 GJ/m ³) [10]	Fluidized bed power generation Residential heating	Feedstock grinding and drying requirements	More expensive when compared to pellets from mill sawdust
Fast Pyrolysis	Bio-oil (21.6 GJ/m ³) [4]	Bio-oil combustion in furnace for heat or steam Bio-oil combustion in industrial turbine for power generation Refining to recover valuable chemicals and/or generate H ₂	Feedstock grinding and drying requirements Reactors best suited for field use currently under development, rather than reactors in commercial demonstration	Marginal economics as a low-grade heating fuel Economics of bio-refining unproven
Gasification	Methanol (17.9 GJ/m ³) [12]	Commodity use of methanol Reforming to H ₂ for use in fuel cell vehicles	Feedstock drying requirements Significant infrastructure required External inputs required (e.g. steam, electricity)	Methanol derived from biomass does not compete economically with methanol from natural gas

Table 1 – Conversion Technologies for Forest Thinnings

This is by no means an exhaustive list of biomass conversion technologies, but rather those that would be most readily modified for field use, or for use at an intermediate processing point.

¹ For comparison, wood residue bundles have an energy density of $4.1 \text{ GJ/m}^3 = 450 \text{ m}^3/\text{kg} \times 9 \text{ MJ/kg}$ [11]

2.0 Feedstock

Chipping at the logging bed is usually accomplished with a disk chipper, producing wood chips roughly 25mm x 25mm x 6mm. If the entire tree – bark, limbs, and trunk – is chipped, the product is referred to as whole tree chips and may contain slivers or splinters longer than the nominal chip size [13]. Moisture content varies between 40-60% and is usually around 50% for thinnings [13]. Each of the three conversion processes has different chip size and moisture limits, as shown in Table 2. Feeding chips with a higher size or moisture content may significantly reduce process yield, alter the characteristics of the product, or damage equipment.

Conversion Process	Chip Size Limit	Moisture Limit
Pelletization [3,15]	3-6 mm	0-10%
Fast Pyrolysis [4]	>6 mm ¹ / 2mm ²	10-15%
Gasification [5]	50 mm	15-20%

¹ Ablative pyrolysis

² Bubbling fluidized bed pyrolysis

Table 2 – Feedstock Size and Moisture Limits

For all three conversion processes, additional drying is required. The energy for drying may be obtained either through the burning of some of the wood or cooling of available flue gases (in the case of gasification). Alternatively, the chipped wood may be “seasoned”, that is, left to age for up to a year. Seasoning can reduce moisture content to 35% [6], reducing the drying energy. Rotary drum dryers are most commonly used for drying raw chips [13].

Both pelletization and fast pyrolysis require additional grinding to reduce chips to an acceptable size. For fast pyrolysis, the power for grinding may constitute the highest variable cost for the overall process [7]. In all cases, wood should be screened for over-sized slivers and splinters to prevent damage to feeding systems [13].

3.0 Pelletization

Pelletization is a process by which ground wood is densified to uniform pellets. These pellets are ideal for residential wood stoves and their uniformity also makes them an attractive feedstock for large fluidized bed combustors for power generation. In the case of thinning, the quantity of pellets produced will likely be more appropriate for the residential heating market.

3.1 Process

Finely ground wood is extruded through a die at high pressure to form pellets. Sufficiently high temperatures (90-95°C) are achieved by extrusion for the lignin fraction of the wood to soften, forming a glue-like bond which maintains pellet cohesion [3]. In order for the extrusion mill to operate properly, the characteristic size of the feedstock should be between one-half and unity of the diameter of the final pellet. For U.S. pellet standards (6-7.5 mm diameter), this implies a characteristic feedstock size of 3 – 6 mm [3].

3.2 Field Readiness

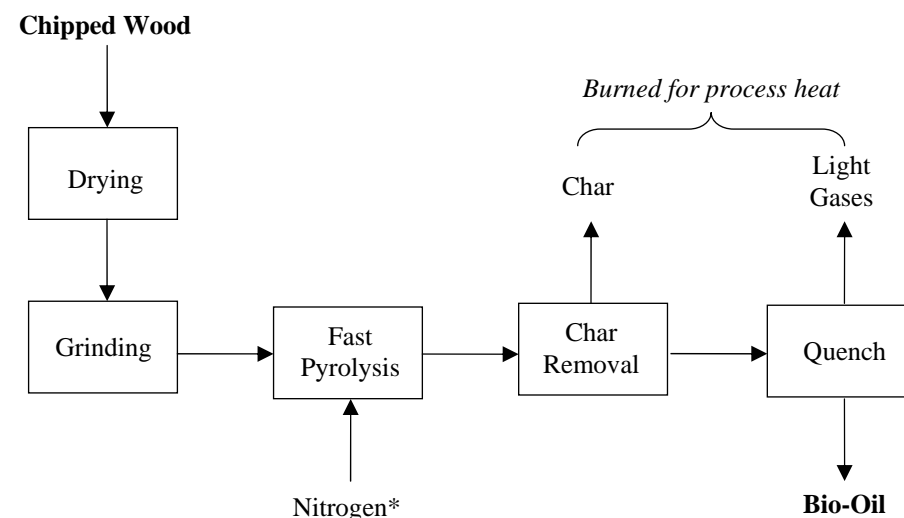
There do not appear to be any significant technical barriers to creating a mobile pellet mill – though the economics will likely favor pellets produced from mill sawdust due to additional grinding and drying costs for fresh biomass. Furthermore, pellets produced from whole tree chips tend to have higher ash contents – owing to the high ash content of bark. Pellet standards mandate maximum allowable ash contents, which may act to restrict the market for pellets produced from thinnings. For example, in a Canadian study, pellets produced from short rotation willow contained 1.54% ash by weight [14], which exceeds the U.S. premium pellet ash limit of 1% [10]. Additionally, pellets with bark in the feedstock have been reported to experience a higher rate of biodegradation [15], further reducing market value.

4.0 Fast Pyrolysis

If woody biomass is brought rapidly to a mid-range temperature (e.g. 500°C) in the absence of oxygen, its primary decomposition product will be a liquid, termed bio-oil [4]. This bio-oil is a complex mixture of oxygenated hydrocarbons that may be burned in a furnace, or with some modification, combusted in industrial turbines for power generation [16]. Further upgrading bio-oil in a “bio-refinery” to produce valuable chemicals for purposes other than combustion is an ongoing research concern [8] and may have strong economic potential. Raw bio-oil has a number of unique characteristics, including high density (specific gravity of 1.2), low pH (2.5), a moderate heating value (18 MJ/kg), and a high water content (15-30%). For reference, heavy fuel oil – the nearest market analogue – has a lower density (specific gravity of 0.94), very low water content (0.1%), and substantially higher heating value (40 MJ/kg) [16]. A further drawback relating to its high water content is that bio-oil will not form a stable emulsion with other hydrocarbon fuels without the addition of an emulsifier [4]. Thus, it cannot be easily blended with other petroleum fuels.

4.1 Process

Figure 1 gives a schematic for bio-oil production. The major components are drying, grinding, the fast pyrolysis reactor itself, char removal, and vapor quench to separate condensable liquids from light gases.



*Fluidized bed pyrolysis only

Figure 1 – Fast Pyrolysis of Biomass

As previously stated, the maximum feedstock moisture content allowable for fast pyrolysis is 10-15% by weight. The moisture content of bio-oil (15-30%) is a combination of moisture present in the feedstock and moisture generated by condensation reactions during fast pyrolysis. If feedstock moisture is higher than 10-15%, the final water content of the bio-oil will be high enough to result in rapid phase separation, rendering the bio-oil of little commercial value. Additional grinding in a hammer-mill and screen filtration [7] is also necessary to reduce feedstock to a size amenable for fast pyrolysis. For bubbling fluidized bed reactors (currently in the commercializing phase) this is 2 mm or less. For ablative reactors (currently in the research phase) this may be larger, up to 6 mm.

Once fed into the reactor, wood temperature is rapidly elevated ($>100^{\circ}\text{C/s}$), bringing wood to pyrolysis conditions ($450\text{-}550^{\circ}\text{C}$) [9]. In fast pyrolysis, wood decomposes to yield condensable organic vapors (70%), char (15%), and light gases (15%) [4]. Two approaches are used to minimize time spent below 500°C , where char formation is kinetically favored [4]. In fluidized bed reactors, the particles of biomass are small enough that the entire particle is rapidly, uniformly brought to pyrolysis temperature. In

ablative reactors, the feedstock surface is brought to reaction temperature, then mechanically removed (ablated) by friction, exposing the next layer directly to the high temperature environment. This is accomplished rapidly enough so that the bulk of the biomass stays below 100°C and does not thermally decompose. Vapor residence time in reactors is normally less than one second [9] in order to discourage secondary reactions.

Char exits the reactor along with light gases and condensable vapors and must be rapidly filtered out for two reasons. First, at pyrolysis temperature, the char particles will crack the condensable vapors to light gases, reducing bio-oil yield. Second, if char fines are entrained in the condensed bio-oil they will accelerate “aging” as discussed later [4]. Char removal is accomplished either through cyclone separation or hot gas filtration. Hot gas filtration is more effective at removing char, but char build-up on the filter effectively creates a vapor cracking bed that reduces bio-oil yield by 10-20% [4].

The quench stage rapidly cools bio-oil to ambient temperature (200°C/s) [4], condensing the volatile organic fraction to a liquid oil. However, the components of quenched bio-oil continue to react with each other at a slow, temperature sensitive rate. Over several months of storage, bio-oil viscosity increases, flammability decreases, and water content increases. This effect is known as “aging” and is an impediment to storing unstabilized bio-oil for extended periods of time [9].

4.2 Field Readiness

Bubbling fluidized bed fast pyrolysis appears unsuitable for field use, due to the need for an inert fluidizing gas (air may not be used) and very small feedstock sizes. Generally, these units have been commercialized where sawdust is available as a feedstock. Ablative pyrolysis would clearly be preferable for field use, as it does not require a fluidizing inert gas and is tolerant of larger feed sizes. However, this technology has not been commercially demonstrated to date. The rotating cone fluidized bed reactor developed by BTG may offer the best workable solution in the small term. This reactor design, which does not require an external fluidizing gas, has been shown to produce high yields (70-75%) of bio-oil for feedstock up to 3 mm in diameter [7].

A joint project between VTT and Fortum in Finland has shown that processing forest residues (i.e. residues with substantial bark and needles) results in decreased yields (60-65% by weight) of lower quality bio-oil. This oil tends to separate into a phase rich in extractives (10-20%) and a second phase

closely resembling conventional bio-oil [6]. This may imply a need to debark thinnings before processing. However, debarking is not usually carried out at the logging bed [2].

Bio-oil stabilization (which reduces the aging rate) has been demonstrated by diluting raw bio-oil with 10% methanol by weight [9]. Methanol addition is superior to other stabilizing agents (e.g. ethanol, water, acetone), altering bio-oil characteristics in ways not attributable to a simple dilution effect [9]. If stabilization is required for extended storage then this methanol requirement will increase the final cost of the bio-oil.

5.0 Gasification

Gasification converts solid biomass to gas by heating it to 800-900°C in an oxidative environment [5]. It is possible, through gasification and subsequent reforming, to produce methanol, a commodity chemical with high energy density. Methanol is an attractive product because, in addition to use as a commodity chemical, it is easily reformed to produce hydrogen, which may be used in a fuel cell.

5.1 Process

Figure 2 gives a schematic diagram of the production of methanol from biomass. The main steps are drying, gasification, gas cleaning, reforming, and methanol synthesis.

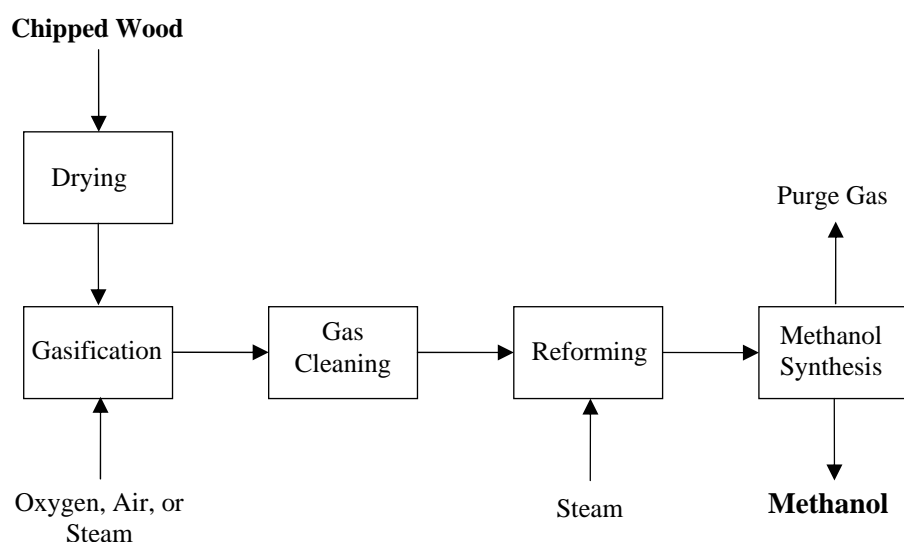


Figure 2 - Methanol Synthesis from Biomass

Biomass gasifiers are fluidized bed reactors. There are two types of fluidized bed gasifiers – directly heated and indirectly heated. In directed heated gasifiers, air or oxygen serves as a fluidizing gas and oxidizes part of the fuel to provide process heat. If air is used, the product gas is referred to as producer gas and has a low heating value owing to significant nitrogen dilution. If oxygen is used, the product is a medium BTU gas referred to as synthetic gas, or syngas. Syngas is primarily composed of CO, CO₂, H₂, and H₂O. Indirectly heated gasifiers, such as the one designed by Battelle-Columbus Labs, fluidize the reaction bed with steam. Heat is supplied by combusting char in a separate reactor. Indirectly heated gasifiers are capable of producing an undiluted, medium BTU gas without the need for potentially costly air separation.

Syngas also contains small quantities of acid gases, tars, and particulates. These must be reduced to acceptable concentrations prior to methanol synthesis. Gas cleaning has historically been one of the most challenging aspects to application of gasification technology, on-par or exceeding feedstock handling issues. While tars constitute the desired product of fast pyrolysis, in gasification they are considered a contaminant as they tend to foul downstream equipment (e.g. heat exchangers) or deactivate catalysts. Economic removal of tars produced in the gasifier remains problematic. In order to capture the significant energy content of the tars, catalytic conversion is preferred to removal, but the most effective catalysts have unacceptably short lifetimes, either due to deactivation or sintering. Research is ongoing in this area [17] and breakthroughs may be possible.

Once impurities have been minimized, the gas is further reformed via a water-gas shift to achieve a 2:1 ratio of H₂ to CO for methanol synthesis. This synthesis is performed over a copper catalyst to form methanol (CH₃OH) from CO and H₂. Remaining gas, primarily CO₂ with some residual H₂ and CO, is rejected from the cycle and may be burned to provide process heat if the energy content is high enough [5].

5.2 Field Readiness

Producing methanol in the field may be technically challenging. The gasification and subsequent reforming require significant infrastructure (using current technology). Of the gasifier types considered, a steam blown indirectly heated gasifier would be most appropriate for field use. This is because the nitrogen dilution of the product gas of air blown gasifiers renders the gas unsuitable for downstream reforming. Furthermore, air separation to produce pure oxygen is a very scale intensive process and will be economically prohibitive at small scale [5], thus removing oxygen blown, directly heated gasifiers

from consideration. However, even in the case of a steam blown, indirectly heated gasifier, steam and electricity will be needed as process inputs. Both may be challenging to supply at the logging bed [2].

6.0 Conclusion

Of the three conversion technologies available, pelletization would likely present the lowest technical challenge. Wood pellets have an energy density three times higher than raw wood chips, which allows them to be economically transported over greater distances than the raw material. However, methanol and bio-oil have energy densities more than four times higher than raw wood chips. This implies a potentially larger geographic market for methanol and bio-oil than for pellets.

Bio-oil produced by fast pyrolysis could be transported significant distances and potentially upgraded to more valuable fuels and chemicals. However, the appropriate technology requires additional research prior to commercialization and the economics are uncertain.

Gasification to produce methanol would be technically challenging with economics unfavorable when compared to traditional forms of methanol synthesis. However, unlike pellets and bio-oil, methanol is readily reformed to H_2 for use in fuel cells, and may command a premium in a hydrogen economy.

While it may not be economic to produce methanol, bio-oil, or pellets at the logging bed, economics may be more favorable at an intermediate processing point. This would potentially allow for an optimization between increased transportation costs and decreased equipment costs due to scale effects. An intermediate processing point would also not need to be as mobile as a field unit placed at the logging bed [2].

In the end, the economics of any of these three processes may not prove out. However, if conversion costs are lower than disposal costs for thinnings then a least cost approach may be indicated. Modeling of process economics at various scales will be required, as will a consideration of mobile versus quasi-stationary processing facilities.

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