DEVELOPMENT OF A PYROLYSIS PROCESS FOR ON-SITE UTILISATION OF SAWMILL RESIDUES

By

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SUMMARY

A description of the pilot plant pyrolysis process currently being installed by Lakeland Steel Products Ltd is provided. The process is designed to use green or partially dried sawdust and operate at temperatures 600–850°C to maximise gas and minimize oil production. The process produces a high hydrogen content fuel suitable for production of electricity in a diesel generator. The rationale for adopting these process parameters is discussed, with respect to site specific factors, capital and operating costs, process efficiency, end product utilisation and environmental factors.

INTRODUCTION

Lakeland Steel Products Ltd (LSP) in Rotorua, New Zealand will in the next 2-3 months commission a pyrolysis pilot plant for the production of electrical energy and biochar from sawmill residues. The unit, which will accommodate sawdust feed rates up to 200kg/hour, is designed to operate under conditions which extend to the boundary between pyrolysis and gasification processes.

This presentation outlines the background to the selected Lakeland Steel Process and how this process may serve niche markets in the NZ and Australian sawmill industries.

UTILISATION OF WOOD RESIDUES

A comparison of the range of processes existing or proposed for converting wood residues into higher value products is shown in Table 1.

Obviously the principal driver for the implementation of any process is the economic return. Nevertheless, attempts to provide general cost benefit comparisons of these processes, and therefore pick a clear winner, may meet with little success because of site specific factors. In particular, available quantities and costs of wood residues and demands for energy or other product outputs vary considerably from site to site.

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The requirement to provide process steam for drying kilns dictates the decisions by sawmills to combust residues in boilers. The Bioenergy Association of NZ (www.bioenergy.org.nz) lists over one hundred wood residue fired boiler installations in sawmills or other wood processing plants in NZ.

### Table 1. Processes to Convert Wood Residues to Higher value Products.

<table>
<thead>
<tr>
<th>Process</th>
<th>Type</th>
<th>Primary Inputs</th>
<th>Main Outputs</th>
<th>End Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler</td>
<td>Combustion</td>
<td>Wood residue</td>
<td>Thermal energy</td>
<td>Process heat</td>
</tr>
<tr>
<td>CHP (combined heat and power)</td>
<td>Gasification Turbine</td>
<td>Wood residue</td>
<td>Thermal energy</td>
<td>Process heat</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Electricity</td>
<td>Electricity</td>
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<tr>
<td>Pelletisation</td>
<td>Agglomeration densification</td>
<td>Wood residue electricity</td>
<td>Solid fuel</td>
<td>Process heat</td>
</tr>
<tr>
<td>Ethanol manufacture</td>
<td>Fermentation</td>
<td>Wood residue process heat</td>
<td>Liquid fuel</td>
<td>Transport fuel</td>
</tr>
<tr>
<td>Biochar manufacture</td>
<td>Microwave pyrolysis</td>
<td>Wood residue electricity</td>
<td>Char</td>
<td>Soil conditioner</td>
</tr>
<tr>
<td>Biochar manufacture</td>
<td>Conventional pyrolysis</td>
<td>Wood residue by-product gas</td>
<td>Oil, Char</td>
<td>Liquid fuel, Soil conditioner</td>
</tr>
<tr>
<td>Bio-oil manufacture</td>
<td>Fast pyrolysis</td>
<td>Wood residue process heat</td>
<td>Oil</td>
<td>Liquid fuel</td>
</tr>
</tbody>
</table>

Generally sawmills have residues surplus to requirements for steam generation and the decision often facing the sawmiller is how to dispose of excess residues. In some cases bark may be screened and sold for landscape purposes. Fibrous material may be utilised in composite board or wood pellet manufacture. Low bulk densities and low value end uses of these residues denote low prices for these residues ex the sawmill gate. However if the alternative is the cost of disposal in a landfill any sales value may be justifiable.

A few larger sawmills, utilise combined heat and power plants (CHP) incorporating cogeneration of electricity via steam or gas turbines. High capital costs of such installations require high throughputs to be justifiable and most NZ sawmills do not generate sufficient residues for consideration of CHP plants.

Although sawmills have potentially surplus thermal energy capacity (many boilers run at 50 - 75% load factors) they also have significant electrical energy demands. High energy requirements result primarily from the sawing processes and the kiln recirculation fans.

This background of surplus thermal and a deficit of electrical energy in sawmills provided the incentive for LSP to investigate potential of generation of electricity from sawmill wastes.
GENERAL COMPARISON OF PYROLYSIS PROCESSES

The LSP process may be classed as a pyrolysis process insofar as the wood residue is heated to wood decomposition temperatures in the (virtual) absence of air.

A definition of terms recently published by the International Biochar Initiative: www.biochar-international.org categorises pyrolysis conditions as follows:

**Slow pyrolysis** – Temperatures < 400°C and heating rates < 2°C/s

**Conventional** - Temperatures< 450°C and heating rates 2-10°C/s.

**Fast pyrolysis** – Temperatures 400 – 600°C, heating rates > 10,000°C/s and rapid product quenching.

These classifications may not have been intended to be absolute but they give indications of typical conditions for pyrolysis where the emphasis is in the production of char or bio-oil.

These definitions suggest there may be no economic benefits from carrying out pyrolysis at temperatures higher than 600°C, although it is noted that fast pyrolysis may be carried at higher temperatures, where increased gas yields are desired. At temperatures higher than 800°C, the realm of gasification processes is entered with commercial production of producer gas.

THE LAKELAND STEEL PRODUCTS PROCESS

A description of the LSP process is as follows:

Feedstock containing moisture in the range 40 – 100% is transported through a heat exchanger utilizing hot gases (up to 1000°C) from an existing boiler. Typical residence times at pyrolysis temperatures (i.e. above 400°C) are 10 -30 minutes and maximum temperatures between 600 -850°C. The water vapour, gas, tar and oils are separated from the char in a char separator where the char is collected at the bottom outlet and the other products pass through a condenser with separation of water vapour. The remaining gas and oil mixture is separated in a water absorption tower and the demisted gas is collected for storage. The gas is used in a modified diesel engine for production of electricity.

The distinguishing features of the LSP process are:

- Scale to suit on-site utilization by medium to large sawmills.
- Use of an existing boiler facility as the primary heat source.
- Reaction at higher temperatures compared to other pyrolysis processes.
- High moisture feedstocks instead of dry fibre as with other processes.
- Emphasis on gas production and electricity generation.

These features are discussed in the following sections.
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PLANT SCALE

As previously mentioned there are over one hundred wood fired boilers at NZ wood processing sites. Such units are required to produce process steam for on-site kiln drying at sawmills.

Efficient sawmills in NZ yield about 60 -65% sawn product from incoming (unbarked) logs. Residue products include bark (5-10%) chips (15-30%) and sawdust (12-15%). Further re-processing of timber may generate shavings, sander dust and off-cuts totalling about 20% of infeed.

The amount of residue surplus to steam generation requirements depends on the relative quantity of sawn timber required to be kiln dried, nature of the sawmill cuts, the amount of timber finishing and importantly, the moisture content of the boiler feed, which largely determines the heat output per unit of feed. Some sawmills have no excess of residues which may be due to the relatively high moisture contents of the boiler fuel. Other mills may have to dispose of 30% or more of their generated fibrous wastes.

In targeting the LSP process it is clear that the quantities of residues available at many sawmills are insufficient to warrant implementation of such a process. Even where sufficient quantities of residues are available it must also be acknowledged that the sawmilling industry over the past decade has experienced difficult trading conditions, which affect the ability of some mills to consider expenditure of this type.

Thus in an initial screening of process options it was decided to self impose guidelines that plant capital cost should be less than (NZ$) one million and a simple payback should calculate at no more than three to four years. These preliminary calculations suggested that a continuously running plant (8000h/year) would need to process at least 300kg/h of wet (100% moisture) to warrant consideration.

The full scale plant as designed to be incorporated into an existing sawmill boiler plant is based on a wet sawdust feed rate of 500kg/h. We believe that there may be some 10-20 sawmills in NZ which could suitably integrate such a process into their operations.

The LSP plant may not seem large compared to other proposed pyrolysis processes but the LSP process is matched to the available quantities of residues at medium to larger size sawmills. Other studies of pyrolysis processes have indicated that plants should be larger by a factor of five or more to achieve suitable economies of scale. The competitiveness of the LSP process is to a large extent due to the low capital cost, maybe 10% or less of other proposed plants. The capital cost savings relate to absence of a major pre-drying facility, integration of a relatively low cost heat exchanger into an existing boiler heat source and adoption of an off-the-shelf diesel generator for electricity production.
COST CONSIDERATIONS

Apart from capital costs discussed above, there are a number of other cost factors which influenced the decision by LSP to proceed down the particular pathway. These include:

**Raw material costs** – The LSP process is designed to utilize green sawdust which is the lowest value fibrous residue available. Sawdust, which is wetted from the sawing process has the highest moisture of the residues and is comparatively difficult to dry. In many cases this product has a negative value where disposal is accomplished in landfills.

**Primary Energy Costs** – The heat energy for pyrolysis is provided by the existing boiler which utilizes wood waste. The relatively constant boiler energy demand from an integrated pyrolysis process may be advantageous in terms of buffering the fluctuating requirements for steam in kiln drying. These factors contribute to a low primary fuel cost for the LSP process.

**Labour Costs** – The pyrolysis process can conveniently be controlled in association with the boiler operation leading to efficient use of labour. Operation of the diesel generator would also be included as part of this combined process.

EFFICIENCY OF THE PROCESS

Two features which distinguish LSP pyrolysis from other processes are high moisture contents of the feedstock and relatively high pyrolysis temperatures. The impacts that these parameters have on energy inputs and yields are discussed in this section.

A large number of studies have been carried out on the pyrolysis of air or kiln (oven) dried wood fibre and these processes, aimed at maximising char or oil yields, require no detailed discussion here. However, with the objective of the LSP process to maximise gas and to minimise oil yield, the following general relationships should be highlighted:

- Higher temperatures (in the range 500-900°C) and or longer reaction times decrease oil and char and increase gas yields.
- The gas composition changes with more hydrogen and carbon monoxide and less methane at higher temperatures. However the heating value of the gas remains relatively constant.

Fewer studies of the effects of high feedstock moisture on the pyrolysis reactions have been carried out. Interest in this aspect was generated early in LSP's experimentation whereby comparative trials using wet and dry sawdust pyrolysed under the same conditions (600°C maximum over one hour) showed considerably greater gas yields from the sample of wet sawdust. Complete mass balances were not carried out in these initial experiments and it was possible that the residual char was incompletely carbonised in the pyrolysis of the dry material.

Nevertheless the presence of water in the feedstock undoubtedly had a beneficial effect, either by enhancing the rate or by changing the chemistry of the pyrolysis reactions. The question to be addressed was whether the penalty of extra heat required to heat (vaporise) the additional water in...
the sawdust could be offset against the potential benefits of either additional gas yield or increased rate of reaction.

A high temperature “wet” pyrolysis process has much in common with steam gasification processes, for which the gas composition is rich in hydrogen and carbon monoxide.

Study of thermodynamic relationships indicates that methane formed in early stages of pyrolysis becomes increasingly converted to hydrogen at temperatures in excess of 600°C due to the steam-methane reforming reaction:

\[ CH_4 + H_2O = CO_2 + 3H_2 \]

This equilibrium reaction is endothermic and favours formation of hydrogen at higher temperatures (Le Chatelier principle). The heat value of one mole of methane is similar to the total of three moles of hydrogen and therefore there is no net energy gain in the formation of hydrogen at the expense of methane.

Other significant chemical changes in the pyrolysis of wet sawdust are the so-called water gas reactions. In the case of cellulose these reactions may be represented as:

\[ C_6H_{10}O_5 \text{ (cellulose)} + H_2O = 6CO + 6H_2 \]
\[ C_6H_{10}O_5 \text{ (cellulose)} + 7H_2O = 6CO_2 + 12H_2 \]

The presence of high water contents may be expected to promote either of these reactions. There may be some energy advantage in the formation of higher CO contents at the expense of hydrogen (LHV of CO = 283kg/mol: LHV H₂ = 241kg/mol). However the actual quantities of hydrogen, carbon monoxide and carbon dioxide in the gas will be determined by the equilibrium of the exothermic watergas shift reaction:

\[ CO + H_2O = CO_2 + H_2 \]

It should be noted that these reactions are idealised “bulk” reactions, useful in modelling various thermodynamic relationships, but do not reveal the mechanisms of the breakdown of organic matter to the various end products.

A general conclusion from the above chemical relationships is that the presence of excess water may change the equilibria between the various gaseous species formed. However the thermal energy value of the product gas is likely to be relatively independent of water content. Therefore if there is any advantage in utilising high moisture feedstock it would relate to the kinetics rather than the thermodynamics of pyrolysis.

The batch trials carried out by LSP have yielded results showing increased rate of pyrolysis with high moisture feedstock. The trials yield only limited information for the specification of operating conditions of a scaled up continuous plant. However an important objective in the pilot plant programme will be to determine optimum moisture content, i.e. the minimum moisture that will suitably enhance the reaction rate at the specified time and temperature conditions.
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Optimisation of the moisture content is also desired to minimize thermal energy to heat and evaporate sawdust moisture. The magnitude of this energy requirement is illustrated by the following batch trial carried out by LSP. The trial involved pyrolysis at 600°C of sawdust containing 92% moisture. The following yields by weight were obtained:

Oil – 2.6%; Char – 8.6%, Gas – 43%

The composition of the gas (by volume) was:

$\text{CH}_4$ (and other hydrocarbons)-22%; $\text{CO}_2$ – 25%; $\text{H}_2$ – 20%; $\text{CO}$ – 32%

The measured LHV of the gas produced was 15MJ/dscm and it was calculated that the required thermal energy to heat and vaporize the water contained in the sawdust was 18% of the total thermal energy of the output gas.

This value of 18% of the generated thermal energy, representing the additional load from heating wet sawdust may be towards the upper end of the scale. Lower feedstock moistures are anticipated and thermal transfer and partial heat recovery in the designed continuous process would lead to minimization of this moisture penalty.

**UTILISATION OF THE GAS, OIL AND CHAR**

The LSP process is designed to combust the gas in a diesel engine to generate electricity. Diesel engines have reasonably high conversion efficiencies (30 -35%) even on partial load; low quality fuels may be used; and diesel engines have low capital and operating costs.

Char is of secondary importance in the LSP process which is tailored to maximum gas production. However the carbonaceous product has potential to make a useful contribution to the economics of the process from sales, of say, 300 tonne per year of biochar. There is no developed market for biochar in NZ but volumes as above can be blended into the existing garden (nursery) products range or marketed as specialty products. The low mineral matter char has also prompted assessment of this material as a commercial activated carbon source.

An objective of the LSP process is to minimise oil production. As previously discussed oil yields of 2-3% by weight were obtained by pyrolysis at 600°C. At higher temperatures yields are lower but it is not yet determined if operating times/temperatures, optimized for other factors, will produce significant quantities oil. It is intended that any oil produced will be used either directly as boiler fuel or recycled in the sawdust feedstock.

**ENVIRONMENTAL**

Processes which utilize agricultural crops for product of biofuels are generally considered carbon neutral, as the amount of carbon dioxide absorbed from the atmosphere in plant growth equals the amount released in energy generation. Similarly the LSP process which utilises waste sawdust for energy production is carbon neutral because non-utilisation (e.g. dumping in a landfill), with
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subsequent decomposition by micro-organisms and chemical oxidation, leads to almost the same quantity of CO₂ released into the atmosphere as for the energy generation process.

A process which generates biochar for soil conditioning is regarded as carbon negative as it there is a net loss of atmospheric CO₂ from fixation of the carbon. The LSP process is expected to generate about 8-10% by weight of char which is equivalent to 25% of the input carbon. Other environmental benefits from biochar production may relate to fixation of nutrients and nitrogen in the soil which would otherwise be released as nitrous oxide gases.

In these respects the LSP pyrolysis process should comply with environmental expectations of new technologies.

CONCLUSIONS

Raw material availability and capital cost considerations have been the primary determinants of the design of the LSP pyrolysis process for on-site utilization of sawmill wastes. Other site specific factors, such as existing heat sources of wood waste fired boilers and large requirements to purchase electricity, provide special opportunities for a process designed to generate electricity from pyrolysis gas.

Whereas many pyrolysis processes seek to maximise oil production for liquid fuels, the LSP process is intended to maximise gas production by pyrolysis at higher temperatures or longer times. In this respect the LSP process has elements in common with lower temperature steam gasification processes. In the case of the LSP process the steam is generated in-situ from the relatively high moisture content of the sawdust feedstock.

Improved gas yields from batch pyrolysis tests using green sawdust (rather than dry sawdust) are thought to relate to kinetic rather than thermodynamic factors. Determination of the optimum wood moisture and temperature/ time conditions awaits construction of a pilot plant, about one-third scale of a planned commercial unit.

The LSP process is planned to generate a high hydrogen containing fuel capable of combustion in a diesel engine which should meet environmental standards required of new technologies.