Liquid Fuel from Wood

Can it be Done on a Small Scale in the New Zealand Wood Processing Industry?

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Introduction

This article discusses the feasibility of producing liquid fuels in New Zealand using waste wood as a feedstock. There are strong reasons to investigate and develop plants to produce biofuels from wood in New Zealand with the first being the significant forestry based activity in our country. New Zealand's large annual wood harvest produces significant residues and it is estimated there are around 5 million m^3 available per year that is not already used for energy (Hall & Gifford, 2007).

The use of wood as a feedstock for making liquid fuel is ultimately driven by the need to reduce fossil fuel use. The government has signalled this need through different policies relating to liquid biofuel. A biodiesel grant scheme was recently implemented starting on 1 July 2009 with a grant of up to 42.5 c/L for biodiesel for biodiesel producers. The companies that have signed up to the scheme base their feedstock on tallow, cooking oil, or rapeseed oil. Although this is a different base feedstock to wood residue one would be hopeful the grant would still apply. New Zealand has also introduced an Emissions Trading Scheme (ETS) that currently caps the cost of emissions at a maximum of $NZ25/tonne of CO_2 equivalent emitted. On its own this is too low to influence decision making on renewable fuels projects. It is also not entirely clear how it would be applied to a wood to biofuels project, apart from a potential carbon cost associated with some fossil fuel use in the supply chain. However, in conjunction with the biodiesel grant, a cost on emissions from fossil carbon may considerably offset biofuel costs in the future if fossil fuel prices increase as a result. Biofuels from woody biomass also has the potential to replace some of our importation of fossil fuel. This has benefits in terms of local revenue generation and job creation within New Zealand. It also disconnects us from the damaging sharp rises in international oil prices that can occur. All these factors make producing liquid fuel from wood in New Zealand a topic well worth investigating further.

How can we turn wood into liquid fuel?

The process discussed in this article is called Fischer-Tropsch synthesis. The Fisher-Tropsch process was originally discovered in the 1920's by Professor Franz Fischer and Dr. Hans Tropsch. The Fischer-Tropsch (FT) process is a means of converting synthesis gas (ideally a 2:1 ratio of hydrogen to carbon monoxide) into long chain hydrocarbons.

The overall reaction commonly used to describe the FT process is

$$CO + \left(1 + \frac{m}{2n}\right) H_2 \rightarrow \frac{1}{n} C_n H_m + H_2O \qquad \Delta H_{FT} = -165\ KJmol^{-1} \qquad (1)$$

This process was widely used in Germany in WWII and in South Africa during oil embargos (Dry, 2002). Historically the FT process has been based on natural gas and syngas from coal gasification as a feedstock with around 320,000 barrels per day of worldwide production. The process with coal or gas as a feedstock is therefore very mature, however, to the author's knowledge there are no large commercial plants producing biodiesel from biomass via the FT process. There are a small number of small to medium scale projects with one of the most notable being the Choren plant in Germany which is a 45 MW plant producing 18 million litres of fuel per annum (Choren, 2011). There are other technologies for converting biomass to liquid fuels that are also receiving significant attention such as biological processes, flash pyrolysis and catalytic depolymerisation methods. These technologies are outside the scope of this article, however, the reader may want to investigate these further to generate their own comparison.

The challenge realised in this study is the production of liquid fuels at a suitable scale that meets the balance between production cost and biomass availability. Traditional FT fuel plants rely heavily on economies of scale to remain viable i.e the bigger the plant is the cheaper you can make the product per litre. Using either natural gas or coal allows a very concentrated source of feedstock. In the case of a biomass fed FT plant there is not the same density of feedstock, therefore a different

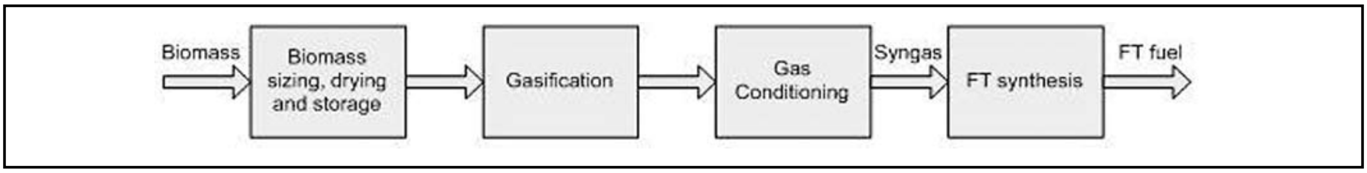

Figure 1: Block diagram of the Fischer-Tropsch process

set of constraints apply compared to traditional plants. Economy of scale becomes a balance with the availability of feedstock at an appropriate price. While a larger plant will produce fuel at a lower price per litre the cost of delivered biomass will increase as the transportation cost increases. Overseas researchers (Searcy & Flynn, 2009) have looked into the optimum size of a plant taking into account scale and biomass cost and this could be applied to the New Zealand scenario. However, this study suggests a different philosophy of plant sizing which involves integration with a sawmill. This study is not an attempt to maximise profit in a balance between plant size and biomass cost in a stand alone fuel plant. Instead the synergy between heat and power requirements of a sawmill being met from an FT fuels plant has been explored.

Overall Process

The FT synthesis process is only one step to creating FT products from biomass. The FT synthesis needs gas as its feed, therefore the process of converting wood into a usable gas is shown briefly in a typical block diagram of the process in Figure 1.

Biomass sizing, drying and storage will not be discussed in detail in this article due to the knowledge already available on commercial technology.

Gasification

Gasification is a process where wood is heated up in limited oxygen to produce a synthesis gas product. It is similar to combustion but with less oxygen so instead of only getting carbon dioxide as a product carbon monoxide and hydrogen are produced in significant quantities – the gases needed for FT synthesis.

The gasifier design selected for this analysis is of a twin fluidised bed type. Figure 2 is a simple representation of the operation of the gasifier. Sand is circulated between the two columns as a heat carrying medium. Combustion of char as a byproduct of gasification and additional fuel (recycled synthesis gas in this case) within the combustion column (a circulating fluidised bed - CFB) provides the heat for the sand (to a temperature of around 800^{o}C) before the sand is circulated back into the gasification column to provide heat for the gasification reactions. The gasification column is a bubbling fluidised bed (BFB) where steam is used to fluidise the bed as well as taking part in the gasification reactions. The advantage of this system is there is no nitrogen dilution of the synthesis gas

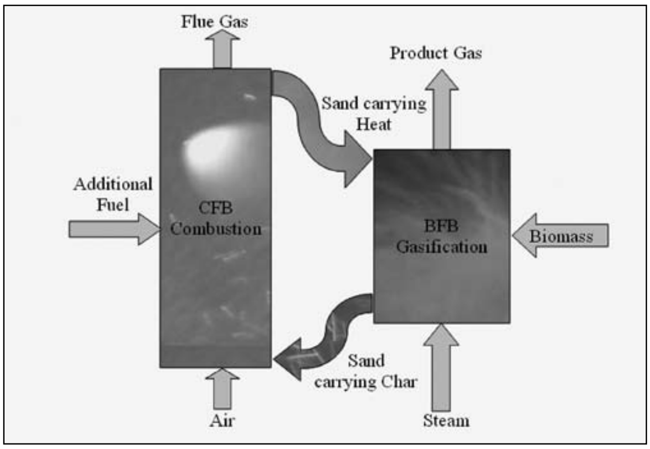

Figure 2: Simple schematic of twin fluidised bed gasifier operation (Rutherford & Williamson, 2006)

as occurs in traditional air blown gasifiers. This results in a synthesis gas with more usable energy, or for the case of use as a syngas for FT, higher concentrations of the reacting components. Fluidisation of the gasification bed with steam also promotes a higher fraction of hydrogen within the synthesis gas, ideal for the 2:1 ratio of hydrogen to carbon monoxide preferred for FT synthesis. A large amount of research on this type of gasifier has been undertaken at the University of Canterbury so there is plenty of information available to anyone who is interested (Brown, Dobbs, Devenish, & Gilmour, 2006).

Gas Conditioning

One of the significant and often overlooked parts of a biomass to liquids plant is the gas cleaning step. FT catalysts are very sensitive to poisoning and require a very clean syngas. Sulphur is the main contaminant of concern and very low concentrations will poison the catalyst and reduce or stop the FT reaction. A biodiesel scrubber and guard beds have been used in this study to deal with the contaminant problems. The gas also needs to be compressed requiring a significant amount of electricity which is accounted for in the modelling.

FT Synthesis

There are two main options for the FT reactor either fixed bed or slurry bed as shown in Figure 3. In the biomass gasification based small scale scenario the slurry bed is more appropriate. Slurry bed reactors have high average single pass conversions (up to 80%) allowing a simpler once through process. They are also less maintenance and labour intensive than fixed beds because the catalyst can be replaced without shutting down.

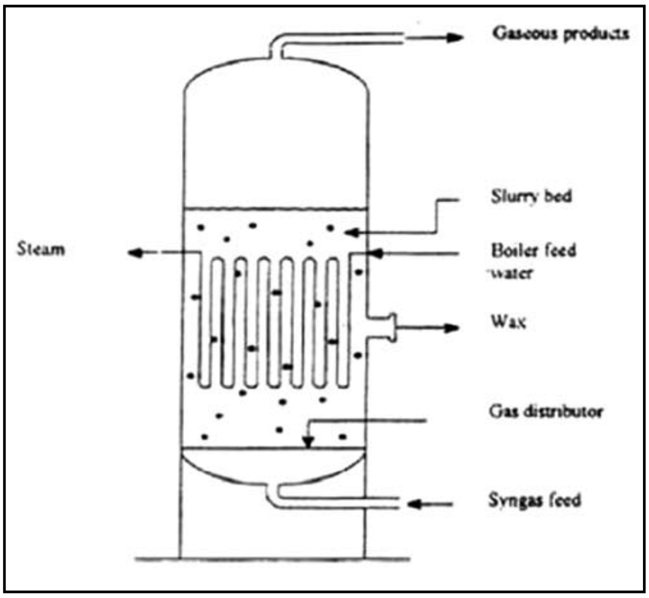

Figure 3: Slurry bed FT reactor (Tijmensen, Faaij, Hamelinck, & Van Hardeveld, 2002)

Recently there has been progress made on microchannel reactor technology which has great potential to operate effectively on a smaller scale with lower capital cost and maximisation of catalyst. This technology is very promising for the small scale required in New Zealand and is the focus of FT reactor research at the University of Canterbury. However, due to a lack of reliable costing data for proven designs the slurry bed reactor will be chosen as the basis for this study.

It should be noted that this study does not incorporate any plant for upgrading the liquid fuel product, rather the product is conservatively considered to have the same value as crude oil and breakeven calculations are based on this assumption. It is assumed this is a likely future scenario for such a plant as the added complication of a 'mini refinery' may be beyond the resources of a sawmill. An ideal situation would allow a simple process to separate the diesel fraction for local use while the remaining products are transported to an existing refinery with some modifications to accept FT syncrude, or potentially a dedicated mini refinery within a cluster of small FT plants if transport distances to an existing refinery are unrealistic.

Combined heat, power and liquid fuels concept

As discussed in the introduction, the philosophy of this study in selection of scale is to take advantage of the heat and power requirements of a sawmill with kiln drying facilities. Figure 4 shows a schematic for the base case design that allows integration with a sawmill. For a simpler diagram showing major components and key mass and energy flows refer to Figure 5. The advantages of a system such as this revolve mainly around the sawmill drying requirements as a sink for the heat produced in the process since the FT reaction releases a lot of energy. Heat can be recovered in the form of steam which when combined with supplementary steam from a boiler running off producer gas can meet the heat requirement for the timber kiln drying process. The other benefit of integration with a sawmill is the potential for meeting the electrical needs of the plant. Having a gas engine utilising the off gas of the FT process allows the plant to be run in a once through process reducing complexity and making use of the unwanted gaseous products, such as methane, produced in the FT reaction.

Results and Discussion

There are a number of different strategies for sizing the combined heat, power, and liquid fuels plant based around the varying electrical demand of the sawmill. Typically a sawmill will mill for 8 hours during the day with the associated electrical demand, while drying continues 24 hours per day with a continual heat and electrical demand. The energy plant must meet the heat requirement of the drying process, however, the electrical production of the energy centre has more flexibility as there will still be grid connection. For this article the scenario is considered where the energy centre will supply all heat that is required for kiln drying in the form of steam and all on peak electrical requirements of the mill (including parasitic use in the liquid fuels operation – mainly for compression). This means the plant would sell power back onto the grid for the times when only the drying component of the mill is operating. The Fischer Tropsch component of the plant will be sized as large as possible limited by the heat generated by the process to balance with mill requirements. The model was based on a mill producing 300m^3 per day (approx 100,000 m^3/yr) of timber with an associated residue stream of approximately 100 oven dry tonnes (odt) per day of sawmill chip, sawdust and bark. While this is considered to be at the larger end of sawmills in New Zealand it is unrealistic to assume a significantly smaller sawmill could, or would invest the capital necessary for such a significant energy centre. Based on the energy demand model the sawmill has an electrical demand on peak of 1,400 kW, while the off peak electrical demand is 360 kW. There is a continual need for 7800 kW of heat energy (in the form of steam) for drying and a varying heat requirement to dry the biomass fed to the energy plant. The energy centre is assumed to have an availability of 95%.

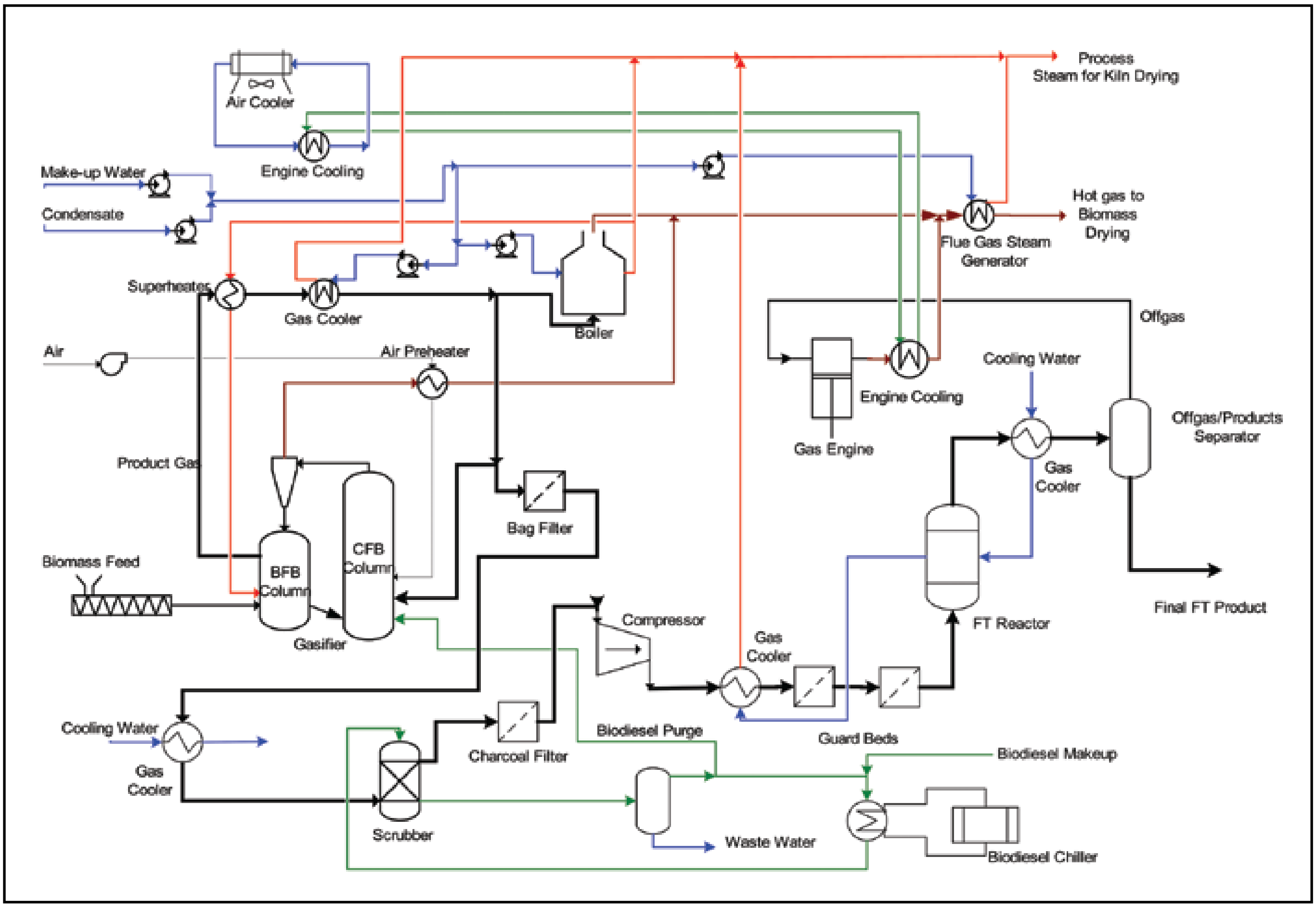

Figure 4: Schematic of combined heat, power and liquid fuels process

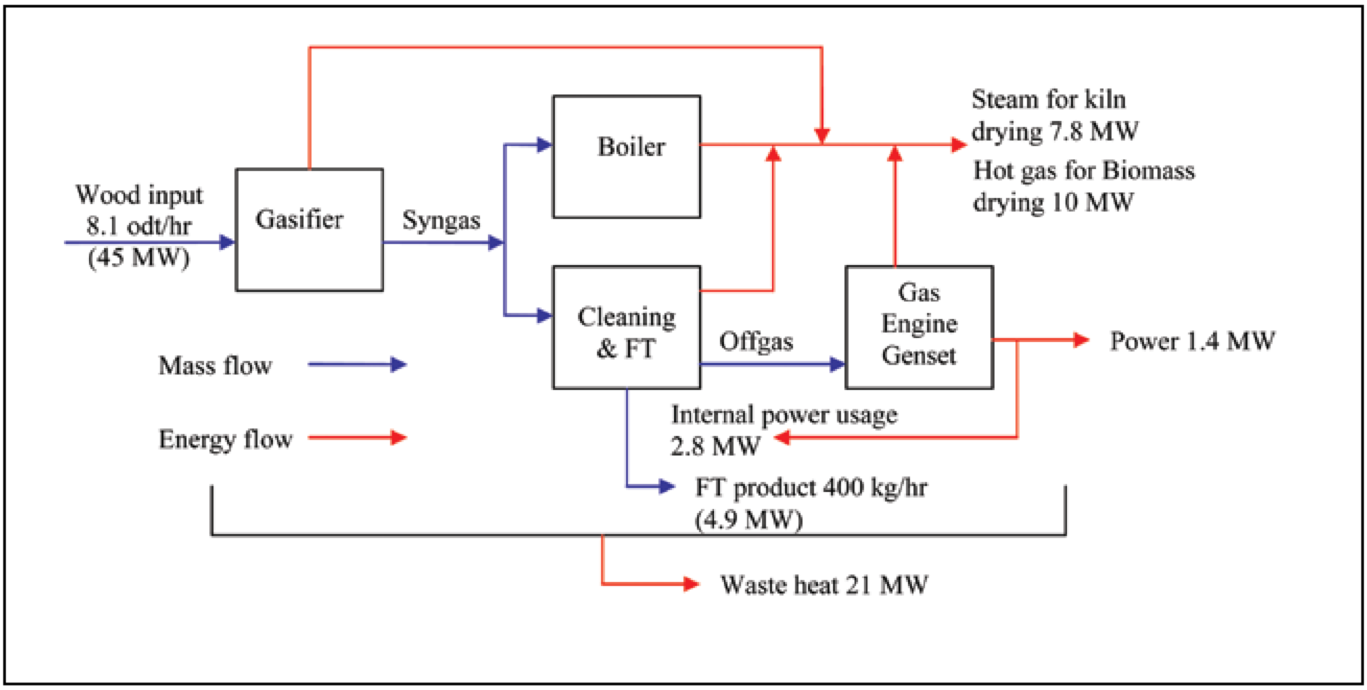

Figure 5: Simplified layout and flows for modelled scenario

Capital Cost

Capital cost was calculated based on values from literature or suppliers with an assumed accuracy of ± 25 %. The breakdown of capital cost is shown in Table 1.

Table 1: Economic breakdown for modelled scenario

		Capital Cost ($NZ)
Biomass Drying		3,100,000
Feed Handling		2,600,000
Gasifier		2,900,000
Gas Engine		7,300,000
Boiler		350,000
Misc.		160,000
Gas Scrubber		1,200,000
Gas filters and Guard Beds		190,000
Compressor		2,300,000
Heat exchange		640,000
FT slurry reactor		7,400,000
Contingency and Fee		4,200,000
Working Capital		3,200,000
Total		**36,000,000**
Breakeven price	$NZ/barrel	202
	$US/barrel	167
Fuel production	kg/yr	3,300,000
	barrel/yr	27,000
	barrel/day	74
Engine power	kW	4,300
Biomass requirement (dry T/yr)		68,000

Operating cost

Operating cost was calculated using typical values from literature (Ulrich & Vasudevan, 2004) or typical assumed values that are applicable to New Zealand. The value for heat the energy centre would 'sell' to the mill was $8/GJ (Rutherford & Williamson, 2006). The electricity value had a split value depending on whether the energy centre was offsetting power purchased by the mill, or whether the mill was selling power back onto the grid. The values were 9.8 c/kWh to buy, 8.13 c/kWh to sell based on what the wood processing industry paid on average in 2008 (Ministry of Economic Development, 2010). Table 2 shows an operating cost and profit breakdown. Note this is with the product value adjusted to achieve breakeven over a 30 year plant lifetime with a 10% discount factor (11 years to breakeven with zero discount factor). Worth comment, however, is the value chosen for the wood cost. A value of $20/odt has been selected. This may seem low compared to the typical sale value of wood chip for instance, however, the rationale is this plant would not get installed in a scenario where substantial amounts of biomass would need to be purchased at a premium or transported large distances. Rather, it would suit a scenario where there may be excess biomass and low opportunity cost for selling sawmill chip and other waste biomass. Of note is that the mill could supply approximately half the biomass feed requirements for the energy centre with the other half needing to be sourced externally.

The breakeven fuel price quoted in Table 1 is the value the FT product would have to sell at for the plant to pay itself off within a 30 year lifetime.

The modelling results are encouraging with a breakeven price for the FT syncrude of $NZ 202 per barrel ($US 167) which isn't significantly above historic crude price trends (Ministry of Economic Development, 2011). This figure also doesn't incorporate any biodiesel grant subsidy which would have a further positive effect on the economics. As a comparison for completeness a breakeven price for a scenario where wood feed to the plant will cost $40 per odt is $NZ 253 per barrel ($US 209). This would represent a more realistic scenario if a mill was unable to find a cheap source of biomass, or was not constrained in selling its chip or other waste biomass.

Conclusion

The primary advantage offered by this system is that the sizing is not based on a compromise of feedstock cost vs. economies of scale, but rather the sizing is based on what meets the heat and power requirements of the associated mill. The sizing and design is configured specifically to suit the scenario, instead of, at least in part, mimicking the design of a plant many orders of magnitude larger. Because of this design principle and the synergy created between the energy plant and the associated mill the breakeven price per barrel for the FT crude of $NZ 202 ($US167) excluding subsidies is not an unrealistic figure in light of trends in crude oil price. The peak in July 2008 of $US148 per barrel of fossil crude demonstrates this technology is not far from being competitive, but it is acknowledged that volatility in the market price of fossil crude is probably the biggest single barrier to uptake, so government underwriting of investment in an FT plant may be necessary to get the first few sawmill installations over the line. Also to be considered is that FT product will be of higher value and quality than regular crude, but for conservatism is compared directly. It can be concluded that if oil price does in fact trend up as is expected, and scenarios can be found where a lower than average biomass supply cost is available, the technology may be appropriate for New Zealand scenarios.

It should be noted this study incorporated analysis of further configuration scenarios within a sawmill and sensitivity analysis of input/output cost variations. For further information on this study please contact Chris Penniall – clp29@uclive.ac.nz.

Table 2: Operating cost and profit breakdown

	Annual Use		$/unit		$/yr
Raw Materials					
Wood	68000	odt	20		1,360,000
Utilities					
Electricity	0	kWh	0.098	kWh	0
Diesel	540000	L	1	L	540,000
Labour and Maintenance					
Process Operation	13000	hrs	20	hr	260,000
Supervision	15	% of operating labour			39,000
Administrative and General Overhead	60	% of labour + maintenance			610,000
Maintenance	2	% of capital cost			720,000
Local taxes	1	% of capital cost			360,000
Insurance	1.5	% of capital cost			540,000
Operating Supplies	15	% of maintenance cost			54,000
Total Operating Costs ($NZ)					4,500,000
Revenue from sales					
Product sales					5,500,000
Heat revenue					1,700,000
Electricity revenue					1,100,000
Net Annual Profit					
Sales revenue					8,300,000
Less Operating Costs					4,500,000
Net Annual Profit after operating costs, before tax					3,800,000
Less depreciation on fixed capital	10	years straight line			3,200,000
Net annual profit after depreciation					570,000
Less tax	33	c/$			190,000
Net Annual Profit after tax ($NZ)					380,000
Add back depreciation					3,200,000
Total Net Annual Cashflow ($NZ)					**3,600,000**
% return on capital investment					10

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