

Use of Wood as a Fuel in Combined Heat and Power

By

Nupur Sengupta

**Thesis presented for the Degree of Master of Science in
Energy Systems and the Environment**

**University of Strathclyde
Department of Mechanical Engineering**

September 2002

Declaration of author's rights

The copyright of this thesis belongs to the author under the terms of the United Kingdom Copyright Acts as qualified by the University of Strathclyde Regulation 3.49. Due acknowledgements must always be made of the use of any material contained in, or derived from, this thesis.

Acknowledgements

I would like to express my deep gratitude to my supervisor, Mr. R C McLean for his expert knowledge and guidance throughout the course.

I would also like to extend my gratitude to the entire people respondent to my emails and letters providing valuable information on my project.

Finally thanks to all the staff at ESRU for their support and help throughout the course of my study.

Abstract

The study looks into the application of wood as a fuel in a combined heat and power plant with particular focus on a sawmill. The sawmill produces woodchips as a byproduct, which can be utilized to produce energy in a CHP plant. The heat and electrical energy thus produced can be used by the sawmill for their process operation or can be sold to the grid at a very competitive price.

Through literature survey, the technologies currently available have been studied and applied to the case of the sawmill. The study mainly focuses on two available technologies: Organic Rankine Cycle technology and the Wood Gasification technology.

A cost comparison has been done for the two available technologies and also for the two options of end use of the energy generated. It was finally concluded that the Organic Rankine Cycle technology would be more reliable at this scale of operation at present. Also if grid connection to the site is sufficient to allow the electricity generated to be sold to the grid, it will be more profitable to sell the renewable electricity generated under the Renewable Obligation.

Apart from the economic viability, the social and environmental benefits of the project; for example safeguarding the existing jobs in the saw milling and forestry industry and using a 'carbon neutral fuel' and thus reducing the green house gas emissions, have also been studied.

List of Symbols and Abbreviations

CV	Calorific value
C_p	Specific Heat at Constant Pressure
C_v	Specific Heat at Constant Volume
γ	C_p / C_v
T	Temperature
P	Pressure
S	Entropy
m	Mass flow rate
J	Joules
s	second
Pa	Pascal
K	Kelvin
C	Centigrade
KWh	Kilo Watt Hours
W	Watts
G	Giga
M	Mega
K	Kilo

LIST OF CONTENTS

Chapter 1 Introduction

1.1 Bio Energy and Sustainable Development	1
1.2 Background and Purpose of the Project	2
1.3 Wood Residues Available from the Sawmill	3
1.4 Demand of Heat Energy and Electrical Energy for the Saw Mill	4

Chapter 2 Literature Review

2.1 Principal Types of CHP Systems	6
2.2 Fuel used in Different Types of CHP	7
2.3 CHP performance	9
2.4 Properties of Wood as a Fuel in CHP	11
2.4.1 Moisture content (abbreviated to MC)	11
2.4.2 Size or “Quality”	12
2.5 Viable Technologies for the Utilisation of Wood as a Fuel	12
2.5.1 Wood Combustion	14
2.5.2 Wood Gasification	15
2.5.3 Pyrolysis of wood	32
2.6 Examples of using Woodchips as Fuel	32

Chapter 3 Calculations for the Proposed Technology

3.1 The Organic Rankine Cycle (ORC) Technology	36
3.1.1 Calculation of amount of wood fuel required	41
3.1.2 Calculation of the size of fuel hopper required	42
3.1.3 Heat Recovery and Use	42

3.2 Biomass Gasification	42
3.2.1 Gas Clean-up	47
3.2.2 Calculations for Biomass Gasification, Gas Turbine Cycle	48
Chapter 4 The Economics of CHP	
4.1 Cost Calculations	51
4.1.1 CHP to Replace the Existing System of Energy Consumption of the Sawmill	52
4.1.2 Selling the Renewable Energy under the NFFO Obligation	56
Chapter 5 Conclusions and Recommendations	
5.1 Summary of Results	57
5.2 Direction for Future Work	58
References	59

Chapter 1 Introduction

1.1 Bio Energy and Sustainable Development

Global energy supply is continually evolving in response to the changing needs of industry and consumers. The pace of change is accelerating as energy markets open to competition and new technologies challenge energy supply conventions. Countries are just beginning to address the overriding reality of the need to exploit more sustainable and secure energy resources.

Biomass was the first fuel mankind learned to use for energy. Worldwide bio energy, much of it traditional wood fuel, is still by far the most important source of non fossil fuel energy, meeting 13% of the primary energy demand. Bio energy provides over five times as much energy in the UK as large-scale hydroelectricity; in 1997 bio energy accounted for 81% of all renewable energy generation in the UK.

Properly managed biomass resources are renewable and sustainable. Modern bio energy technologies are clean and efficient. Burning biomass rather than fossil fuels can reduce emissions of the gasses responsible for acid rain as well as cut down fossil carbon dioxide emissions, the main gas responsible for global climate change. Biomass is the only source of renewable fixed carbon. It has extremely low sulphur content and for every 2 tonnes of biomass, 1 tonne of oil or 1½ tonnes of coal can be left in the ground. Biomass as a fuel is 'Carbon Neutral'. Even allowing for emissions of CO₂ in planting, harvesting, processing and transporting the fuel, replacing fossil fuel energy with bio energy will typically reduce net CO₂ emissions by over 90%.

Bio energy addresses the four core themes of sustainable development; protection of the environment, economic growth, social equity and prudent use of natural resources.

Energy markets are now changing at an alarming rate as new automated energy technologies and liberalised energy markets create the opportunity for widespread application of high efficiency, local and on-site generation of heat and power. Competitiveness in these markets will be about flexibility, integrated development, environmental protection and embedded and on-site generation. Therefore bio energy

stands competitive in the future energy market.

The UK Government is committed to 20% reduction in CO₂ emissions by 2010. The Government continues to assert that it is committed to 'a new and strong drive to encourage renewable technologies and has set a target of 10% of electricity from these sources by the year 2010'. This target will be achieved through obligations laid with electricity suppliers or distributors and supported by an invigorated Research, Development and Demonstration programme.

The Climate Change Levy, a UK tax on non-domestic energy supplies has already come into force. On-site heat and power generation running on renewable biomass fuels and renewable electricity are exempt from the levy. This will substantially improve the competitiveness of bioenergy. Bioenergy addresses these new priorities and will thrive in the developing carbon-trading-driven commercial climate

The need for action over Greenhouse Gas emissions to tackle the dangers of Global Climate Change is now being translated into real political action and economic instruments. Emission reduction targets, carbon and energy taxes, carbon trading and the new economics of privatised energy markets and new energy technologies are now commercial realities.

Electricity generation from biomass is being encouraged in the UK through the Government's Non Fossil Fuel Obligation (NFFO) scheme. Also, on-site heat and power generation running on renewable biomass fuels and renewable electricity will be exempt from the Climate Change Levy. This will substantially improve the competitiveness of bio energy.

1.2 Background and Purpose of the Project

In a sawmill, the process of manufacturing solid wood products from logs produces a variety of wood fibre by-products e.g. wood chips, saw dust and barks, which are sold to a number of different customers and industries. The market for these by-products is becoming increasingly competitive and in certain cases close to saturation. Using these wood by-products as a bio energy fuel can provide a competitive edge, and therefore the

proposal for a Combined Heat and Power plant using the wood by-products comes in. In this way the project would also safeguard existing local jobs in the saw milling and forestry industry.

A Combined Heat and Power or CHP plant simultaneously generates usable heat and power (usually electricity) in a single process. CHP provides a secure and efficient method of generating both electricity and heat at the point of use. By utilising the heat from electricity generation and avoiding the transmission losses, (because electricity is generated on-site), a CHP typically achieves a 35 per cent reduction in primary energy usage compared with electricity power stations and heat only boilers. Biomass is ideally suited to CHP, either as a low calorific fuel gas to be used in a gas turbine or as a fuel in a boiler to drive a steam turbine.

The heat and power produced from such wood by-products in saw milling operation can be used for the internal consumption of the sawmill or can be sold at a very competitive price under the NFFO. In this report, two different technologies of using the wood by-products for generating power in a CHP plant in a cost effective way, has been explored. A case study of a sawmill located near Fort William has been taken up to evaluate the various technologies currently available.

1.3 Wood Residues Available from the Sawmill

The sawmill which forms the focus of this study, processes logs obtained mostly from west coast of Scotland, from Aryle, Fort William and Skye. Wood is mainly spruce, a kind of softwood, sometimes Norwegian Sitka spruce is also imported. The main product is sawn timber, which is sold to the construction industry or for fencing or pallets. The by-products are

- Chips (thickness 8 mm and diameter 8-45 mm mostly), currently sold to fibre board manufacturers and paper industry;
- Sawdust, currently sold to fibre board manufacturer or for agricultural use
- Barks currently sold as a gardening product

The total quantity of each of the by-products available for use in the CHP plant is detailed below:

Type of by-product	Green Tonnes available (Thousand)	Moisture Content (%)	Oven Dry Tonnes (Thousand)
Chips	55.0	50	23.7
Sawdust	10.0	57	4.3
Bark Spruce	9.0	65	3.2

The chips will be used as a fuel for generation of bio energy.

1.4 Demand of Heat Energy and Electrical Energy for the Saw Mill

Preliminary energy demand information obtained during site visit is summarised as follows:

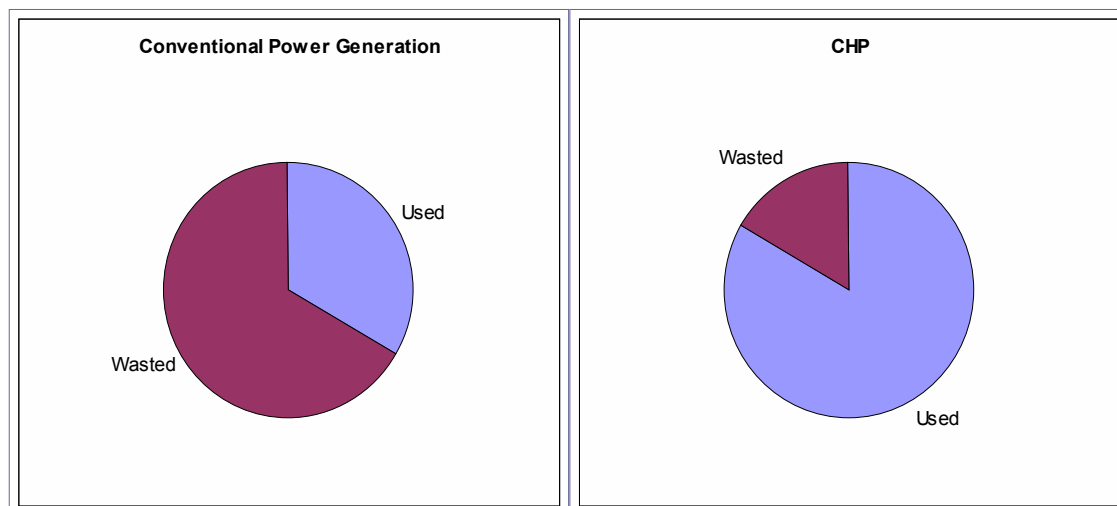
- Current Maximum Power Consumption: 3 MW_e
- Current Typical Power Consumption: 2.25 MW_e
- Current continuous heat demand: 3 MW_t of hot water at 110°C presently provided by onsite waste wood fired boiler
- Anticipated Future Maximum Power Consumption: 3.5 MW_e
- Anticipated Future Typical Power Consumption: 2.5 MW_e
- Anticipated Future continuous heat demand: 5.2 MW_t

In this report, the scale of CHP plant proposed will meet the current heat and electricity demand.

Chapter 2 Literature Review

The UK Government's has a target of installation of Good-Quality CHP of 10 GWe by 2010 as part of its Climate Change Programme [2]. CHP is a very efficient technology for generating electricity and heat together. A CHP plant is an installation where there is simultaneous generation of usable heat and power (usually electricity) in a single process. The term CHP is synonymous with 'cogeneration' and 'total energy'. The basic elements of a CHP plant comprise one or more prime movers usually driving electrical generators, where the heat generated in the process is utilised via suitable heat recovery equipment for a variety of purposes including industrial processes, community heating and space heating. More energy of a fuel is utilised in a CHP compared to a conventional power generation plant. Figure 2.1 illustrates this.

Figure 2.1 Comparison of Energy used and wasted in Conventional Power Generation and a CHP



CHP can provide a secure and highly efficient method of generating electricity and heat at the point of use. Due to the utilisation of heat from generation of electricity and the avoidance of transmission losses because electricity is generated on site, CHP typically achieves a 35% reduction in primary energy usage compared with power stations and heat only boilers. This allows the host organisation to make economic savings where there is a suitable balance between the heat and power loads. The current mix of CHP installations achieves a reduction of over 30 % in CO₂ emissions in comparison with

generation from coal-fired power stations, and over 10 per cent in comparison with gas fired combined cycle gas turbines. The newest installations achieve a reduction of over 50 per cent compared with generation from coal-fired power stations.

57 per cent of CHP electrical capacity is now either simple cycle or combined cycle gas turbine. In terms of heat capacity, steam turbines and gas turbines (in simple or combined cycle) each account for just under half of capacity, with reciprocating engines accounting for only a few per cent. In terms of numbers of installations, the dominant technology is reciprocating engines, though the average size of these installations is less than 0.5 MWe. The majority of these schemes have been installed in the last ten years.

2.1 Principal Types of CHP Systems ^{[2][16]}

There are four principal types of CHP system, steam turbine, gas turbine, combined cycle systems and reciprocating engines. Each of these is defined below.

Steam turbine, where steam at high pressure is generated in a boiler. In back pressure steam turbine systems, the steam passes through a turbine before being exhausted from the turbine at the required pressure for the site. In pass-out condensing steam turbine systems, a proportion of the steam used by the turbine is extracted at an intermediate pressure from the turbine with the exhaust being condensed. (Condensing steam turbines without pass out and which do not utilize steam are not included in these statistics as they are not CHP.) The boilers used in steam turbine schemes can burn a wide variety of fuels including coal, gas, oil, and waste-derived fuels. With the exception of waste-fired schemes, steam turbine plant has often been in service for several decades. Steam turbine plants capable of supplying useful steam have electrical efficiencies between 5 and 15 per cent, depending on size, and thus between 70 per cent and 30 per cent of the fuel input is available as useful heat. Steam turbines used in CHP applications typically range in size from a few MW_e to over 100 MW_e.

Gas turbine systems, often aero-engine derivatives, where fuel (gas, or gas-oil) is combusted in the gas turbine and the exhaust gases are normally used in a waste heat boiler to produce usable steam, though the exhaust gases may be used directly in some process applications. Gas turbines typically range from 1 MWe upwards (although micro

turbines of down to 30 kW_e are being installed), achieving electrical efficiency of 23 to 30 per cent (depending on size) and with the potential to recover up to 50 per cent of the fuel input as useful heat. They have been common in CHP since the mid 1980's. The waste heat boiler can include supplementary or auxiliary firing using a wide range of fuels, and thus the heat to power ratio of the scheme can vary.

Combined cycle systems, where the plant comprises more than one prime mover. These are usually gas turbines where the exhaust gases are utilised in a waste heat recovery boiler, the steam from which is passed wholly or in part into one or more steam turbines. Additional boilers often supplement this heat. In rare cases reciprocating engines may be linked with steam turbines. Combined cycle is suited to larger installations of 7 MWe and over. They achieve higher electrical efficiency and a lower heat to power ratio than steam turbines or gas turbines used alone. Recently installed combined cycle gas turbine (CCGT) schemes have achieved an electrical efficiency approaching 45 per cent (GCV), with 20 per cent heat recovery, and a heat to power ratio of less than 1:1.

Reciprocating engine systems range from less than 100 kW_e up to around 5 MW_e, and are found on smaller industrial sites as well as in buildings. They are based on auto engine or marine engine derivatives converted to run on gas. Both compression ignition and spark ignition firing is used. Reciprocating engines operate at around 28 to 33 per cent electrical efficiency with around 50 per cent to 33 per cent of the fuel input available as useful heat. Reciprocating engines produce two grades of waste heat: high-grade heat from the engine exhaust and low-grade heat from the engine cooling circuits. Steam generation from reciprocating engines is comparatively rare. Commonly, schemes of less than 800 kW_e have no heat dump facility and if heat demand falls both electrical and thermal outputs are reduced.

2.2 Fuel used by Different Types of CHP

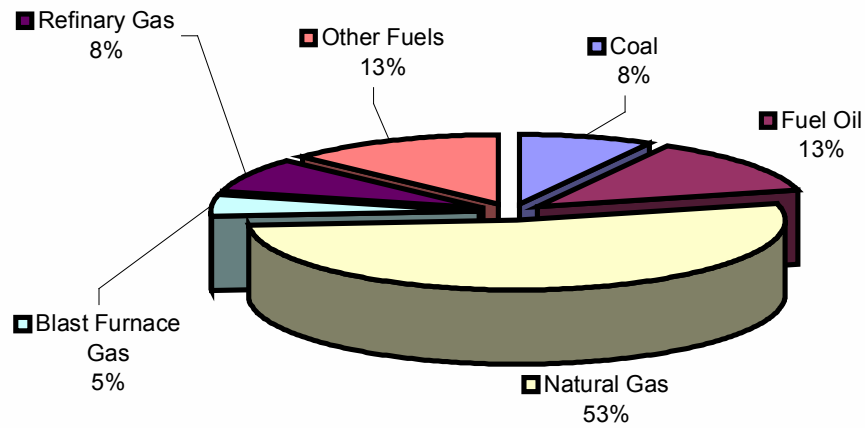
Table 2.1 shows the fuel used in different types of CHP installation using renewable fuels. Also CHPs using all types of fuels including coal, oil and natural gas are also presented for comparison purpose. Figure 2.2 shows the types of fuel used by CHP plants in the year 1999.

Table 2.1 Fuel used by Types of CHP installation (GWh)

	1995	1996	1997	1998	1999
Renewable fuels (a)					
Back pressure steam turbine	719	776	776	761	746
Gas turbine	23	-	-	-	-
Combined cycle	-	-	-	-	-
Reciprocating engine	1,545	1,714	1,699	1,655	1,641
Pass out condensing steam turbine	302	302	126	473	661
Total renewable fuels	2,589	2,792	2,601	2,889	3,048
Other fuels (b)					
Back pressure steam turbine	11,585	11,722	10,861	10,988	10,810
Gas turbine	6,362	6,460	6,120	5,624	5,640
Combined cycle	2,585	2,967	4,014	3,804	3,672
Reciprocating engine	280	342	309	293	335
Pass out condensing steam turbine	8,179	8,384	5,892	6,131	5,847
Total other fuels	28,991	29,875	27,196	26,840	26,304
Total - all fuels					
Back pressure steam turbine	42,014	39,274	35,133	31,208	25,307
Gas turbine	16,087	17,641	19,810	20,709	22,597
Combined cycle	16,391	17,044	22,331	26,011	30,445
Reciprocating engine	4,711	5,291	5,657	6,868	7,493
Pass out condensing steam turbine	27,809	27,593	23,847	23,817	24,052
Total all fuels	107,012	106,843	106,778	108,613	109,894

(a) Renewable fuels include: sewage gas; other biogases; clinical waste; municipal waste.

(b) Other fuels include: process by-products, coke oven gas, blast furnace gas, gas oil and uranium.

Figure 2.2 Types of Fuel used by CHP Plants in 1999

(a) Back pressure steam turbines account for over 90% of coal use and over 90% of blast furnace gas use.

(b) Other fuels include coke oven gas, gas oil, renewable fuels and process by-products.

2.3 CHP Performance

Detailed performance statistics are available for 67 per cent of the surveyed CHP capacity in 1999. These are summarised in Table 2.2.

Table 2.2 A summary of performance of CHP schemes surveyed in 1999 (a)

Main prime mover in CHP plant	Typical operating hours per annum (Full load equivalent)	Average electrical efficiency (% GCV)	Average heat efficiency (% GCV)	Average overall efficiency (% GCV)
Back pressure steam turbine	5,007	12.1	54.4	66.5
Pass out condensing steam turbine	4,139	14.2	54.3	68.5
Combined Cycle	3,823	20.9	46.9	67.8
Gas Turbine	5,676	23.4	41.0	64.4
Reciprocating engine	4,617	29.9	31.1	61.1

(a) Includes CHP element of partial CHP schemes.

Electrical efficiency of reciprocating engines is typically 28-33 per cent (GCV). If only high-grade heat is recovered overall efficiency is around 50 per cent. If low-grade heat is recovered as well, efficiency exceeds 70 per cent. New combined cycle gas turbine CHP schemes have a large gas turbine and small steam turbine and may achieve electrical efficiencies of 45 per cent (GCV). Many existing CCGT CHP schemes have a small gas turbine, and large steam turbine. Here steam generated in the waste heat recovery boiler of the gas turbine is frequently supplemented with steam from additional boilers. The overall electrical efficiency of such schemes can be as low as 12 per cent. In some cases, these additional boilers use non-conventional fuels. In other cases, these schemes represent prime candidates for upgrade. In aggregate, however, the electrical efficiency of CCGT CHP is currently lower than gas turbine based CHP, which achieve electrical efficiencies in the range 22 to 36 per cent. Steam turbines achieve electrical efficiencies in the range 5 to 20 per cent.

2.4 Properties of Wood as a Fuel in CHP

In the energy market wood can make a substantial contribution as an electricity generation fuel or as a heating fuel replacing electric heating, coal, gas or oil. Some properties of wood as a fuel are described below ^[6]

2.4.1 Moisture content (abbreviated to MC)

Wood combustion plant is commercially available, and operating, on a range of wood fuels with moisture contents varying from 5% to over 50%. In general, for automatic plant, lower the fuel quality, i.e. the coarser and wetter it is, the more expensive the combustion equipment will be. Wet fuel has a lower energy content than dry fuel.

The Moisture Content is described as a percentage, for example MC 30%. No more than 10% of a load should exceed the moisture content (by weight on a wet basis) specified for that load. e.g. MC35%; implies that no more than 10% of the load should exceed 35% moisture content.

Standard test sample: Four one litre samples are taken from different points (one top, one bottom, two middle) in a chipped load (of at least 3 m³), mixed thoroughly and divided in two to give a two litre test sample.

Standard definition of Moisture content ^[6]: Test sample weighed, dried (24 hrs, 105°C) to 0% MC, and re-weighed; MC then is given by:

$$\text{MC (\% weight on wet basis)} = \frac{(\text{Fresh Weight} - \text{Dry Weight}) \times 100\%}{\text{Fresh Weight}}$$

Chipped wood does not dry well if simply left in a pile, except in very specific climatic and soil circumstances, with expert management. Piles of wet wood chip will start to compost, heating the pile and reducing dry matter content and thus the value of the wood fuel. Fungal spores from composting piles may pose a health hazard. Very large stacks (>3m high) may heat up enough to spontaneously combust and should therefore

be avoided. Blowing air up through a pile of wood chips will help drying; the natural heating of the pile may be used with controlled air blowing to speed up the drying process. Blowing warm air, from an engine exhaust or insulated boiler house can further speed the drying rate.

2.4.2 Size or “Quality”

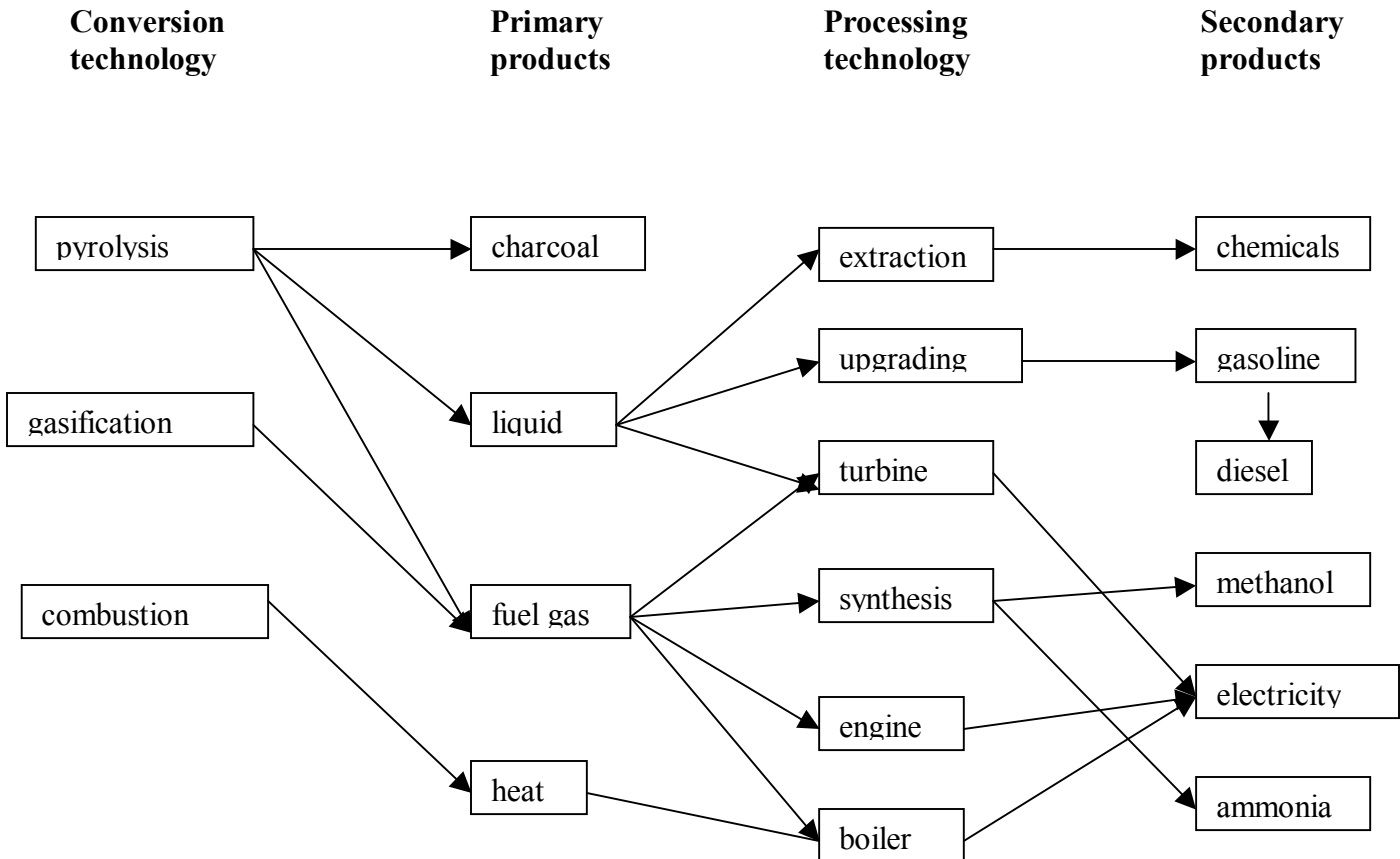
Wood chip burning plant will generally operate best on material between 2 and 25mm maximum dimension. Regarding particle size, the principal constraint is the maximum dimension in any direction of the woodchip. Oversize particles can be tolerated, provided they are few in number, and do not exceed the quoted maximum for that combustion equipment. Long stringy material can cause blockages where chips need to fall by gravity, as in hoppers and drops in the fuel feed mechanism, requiring manual intervention. Very fine material also poses difficulties, in that it is difficult to force sufficient air through the fuel to promote efficient combustion.

In case of gasification and pyrolysis due to the nature of the process a more stringent fuel specification may be required. In order to produce gas or oil useable in an engine, the process must be closely controlled. Big variations in chip size will make this difficult, so a tight grading is likely. Moisture content is also tightly controlled. For power production on a larger scale fuel drying, screening and even re-chipping equipment on site is necessary.

2.5 Viable Technologies for the Utilisation of Wood as a Fuel

Wood combustion is the process in which wood is exposed to high temperature and air supply and decomposes to give heat. The simplest ones are open fires and the most sophisticated circulating fluid bed combustors. The exploitation of wood for the production of electric energy can be done mainly in the following ways:

- A. Combustion in Wood fired boilers aimed at:
 - i. Production of steam to feed a traditional steam turbine
 - ii. Production of hot thermal oil to be used as hot source in Organic Rankine Cycle turbo generators

Figure 2.3 Conversion technologies and their products

B. Gasification and the use of the gas as a fuel in gas turbines, for internal combustion engines (Otto cycles), or Stirling engines

Gasification plants with gas turbines will be economically feasible only in medium-large scale (installed electric power above 1-5 MW) due to complexity of the gasification process and because the gas turbine exhibits a low efficiency below 1MWe

C. Production of Bio-oil from pyrolysis, which can be used as a fuel in a diesel engine or gas turbine. This is achieved by heating the wood in a special piece of equipment with/ without air.

The combustion routes use well proven technology, however the efficiency is limited, especially at small sizes. The gasification or the pyrolysis route is more efficient, but less well proven.

2.5.1 Wood Combustion

Direct combustion is the simplest method for the conversion of fuel into heat and is a viable option for most biomass. There are advantages, however, to conversion of the fuel into a gas or a liquid by gasification or pyrolysis. Particulates and chemical pollutants can be removed during these processes, together with the inert matter, which produces particulates (smoke) when the fuel is burnt.

The resulting gas can be burnt directly or used in internal combustion engines or gas turbines. Biomass gasification processes are generally designed to produce low-to-medium-energy gases, synthesis gases for the manufacture of chemicals, or hydrogen. They are also be used as the energy source in turbines, engines and boilers for the production of electricity. Possible routes between the processes of gasification and electricity generation are illustrated in Figure 2.3.

Pyrolysis has the added advantage that the fuels produced can be easily stored and transported to where they are required.

The biomass combustion systems associated with steam boilers and steam turbines are disadvantages due to:

1. Involve very high pressure steam,
2. Conversion efficiency is low,
3. Require careful control of water quality,
4. Must be operated by skilled personnel.
5. The steam cycle requires a super heater, which is a delicate component in association with biomass.
6. Pure water as used in steam turbines has the risk of freezing; hence the equipment must be drained very carefully, when not in operation

Therefore, Organic Rankine Cycle (ORC) operating with a high molecular mass organic fluid, similar to the cycle of a conventional steam turbine, has been applied to the case study. The working principles of ORC are detailed in Chapter 3.

2.5.2 Wood Gasification ^[3]

Fuel Storage and Handling

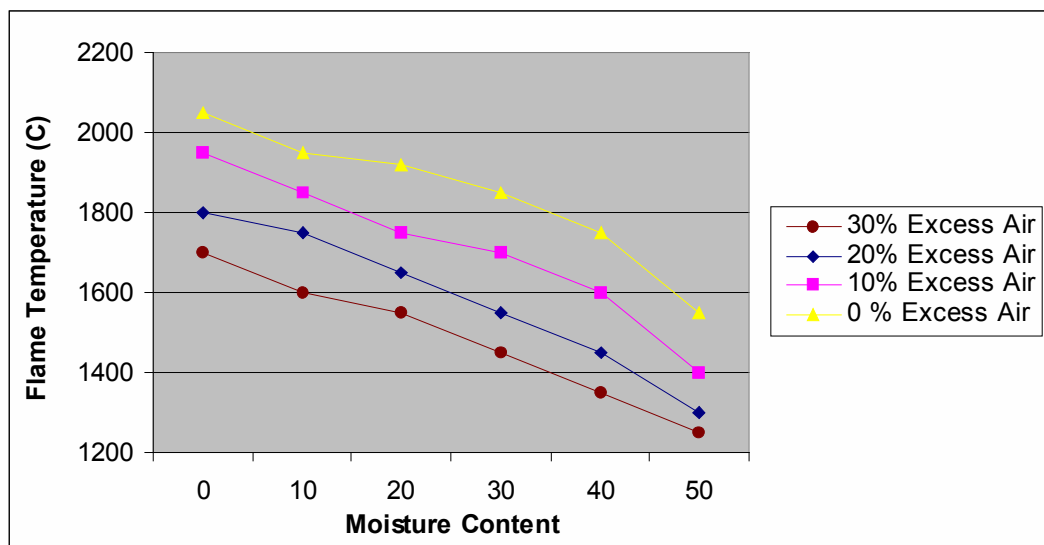
There are no perceived problems in handling or storing wood apart from that of degradation. Degradation happens very quickly for chips.

Drying

The drying requirement depends on the gasifier feed specification. Wet wood at typically 50% (wet basis) is generally considered too wet, affecting the gas quality and, giving rise to condensation problems and lower efficiencies. This, however, depends on the conversion technology used as 50% is suitable for combustion and some gasifiers and 5 Wt % for a pyrolysis plant. Some gasifiers will not work unless the feedstock is dried.

Drying may be carried out in the field and in the storage pile, but this is slow, unreliable, causes loss of material from biological degradation and can cause fires. Rotary kilns are widely specified as dryers using waste heat and/or combustion of biomass feed. The feed used for the latter may be that rejected as screenings or fines, again depending on the gasifier feed specification. Fluid bed, silo and steam dryers have all been used successfully for biomass. None is very efficient, however, and the energy and economic costs are high. However, a consequence of not drying is higher downstream gas clean requirements which also have energy and economic cost attached. Therefore a balance needs to be struck between drying and gas cleaning.

The Figure 2.4 shows the dependence of flame temperature during combustion on the moisture content of the wood and the excess air available.

Figure 2.4 Dependence of Flame Temperature on Moisture Content and Excess Air

Particle Size Control and Feed Specification

In the case of gasification, different gasifiers have different feed requirements. Fluid bed and circulating fluid bed gasifiers are the most tolerant to particle size within their specified range. Fixed bed gasifiers require a regularly sized and relatively large particle with a minimum of fines.

With regard to the process of gasification, the feedstock size specification for different types of gasifiers is as follows:

- Fixed bed 10-100mm
- Fluid bed 1-10mm

Direct Combustion of Solid Fuels and gasification

A series of processes are involved in the combustion of a solid fuel and not all of these give out energy in the form of heat (i.e. are exothermic). The first process is the evaporation of any water in the fuel. If the fuel has high water content, energy is used up

in this part of the combustion process. Therefore the lower the moisture content of a fuel, the better.

As the temperature increases, volatile matter in the form of mixed vapours or vaporized tars and oils is released. Little spurts of flame seen when wood or coal is burnt are the combustion of these vapours. The solid left behind is char and inert matter. Char is composed mainly of carbon and burns to produce CO_2 . The inert matter is made up of materials that are non-combustible and becomes clinker, slag or ashes.

Three quarters or more of the energy of bio fuels is in the volatile matter compared to less than half for coal. Any stove, furnace or boiler is designed to ensure that these vapours burn. Air must reach all of the char for its complete combustion and so the fuel should be in as small particles as possible. This has the disadvantage of producing finer particulates that need to be removed from the flue gases. Airflow needs to be carefully controlled because too little oxygen results in the production of carbon monoxide, which is a poison. Too much air can carry the heat away in the flue gases.

Gasification is a process in which a solid fuel is reacted with air or oxygen and sometimes steam to produce a gaseous fuel. The resulting gas is a mixture of carbon monoxide, hydrogen and methane together with carbon dioxide and nitrogen. The proportions of which depend on the type of feedstock, the processing conditions and whether air or oxygen is used.

Processes using oxygen instead of air are capable of producing higher quality gas products, which can then be used to make synthesis gas (used in methanol production) and gaseous and liquid fuels. The basic product gas here is a Medium Heat Value (MHV) gas.

Partial oxidation takes place when there isn't enough oxygen present for full oxidation to occur i.e. when less than the stoichiometric amounts of oxygen needed for complete combustion are present. As a result of this, partially oxidised products are formed. If the temperature is sufficient, then the primary products from the gasification of biomass are gases. These gases are:

- carbon monoxide (CO)
- carbon dioxide (CO₂)
- hydrogen
- methane
- trace amounts of higher hydrocarbons such as ethane and ethene
- water
- nitrogen (if air is used as the oxidising agent)

Various contaminants such as small char particles, ash, tars and oils are also present with the gases. At high temperatures, charcoal and liquids are either minor products or not present in the product mixture. The partial oxidation can be carried out using air, oxygen, steam or a mixture of these. The addition of co-reactants, such as oxygen or steam, to the biomass system can result in large changes in reaction rates, product gas compositions and yields.

The simplest process uses air instead of oxygen (Air gasification involving direct contact of biomass feedstock and air). This results in gas containing up to 50% by volume of nitrogen and CO₂, and as these have no fuel value, its energy may be only a few megajoules (MJ) per cubic metre –about a tenth of that of methane. However, it is a clean fuel and although transporting such a dilute energy carrier may not be worthwhile, its improved qualities, in terms of cleanliness, may make it worth using where it is produced. This type of fuel is a Low Heat Value (LHV) gas. The heating value is 4-12 MJ/m³ [Klass, 1998] and is suitable for boiler, engine, and turbine operation.

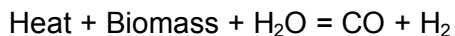
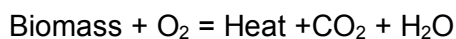
Oxygen gasification results in the production of a MHV gas. This occurs in directly heated biomass gasifiers when oxygen is used. The heating value of 12-27 MJ/m³ [Klass,1998] is suitable for pipeline distribution and as synthesis gas for conversion, for example, to methanol and gasoline.

Gasification with air is a much more widely used technology. This is because oxygen production and usage incurs an extra cost and hazard. It also involves the complexity of having multiple reactors. Pyrolytic gasification (from indirectly heated biomass gasifiers when air is used and heat transfer occurs via an inert solid medium) or steam gasification will also produce the same MHV gas.

The feedstock will contain a certain amount of moisture and so steam will always be present during the gasification even if it isn't added. This causes a type of reforming to take place. For biomass gasification, reforming refers to gasification in the presence of another reactant e.g. steam, steam-oxygen or steam-air.

Steam reforming processes involve reactions of biomass and steam and of the secondary products formed from biomass and steam. Steam-oxygen or steam-air gasification of biomass often includes combustion of a residual char from the gasifier, of a portion of the product gas, or of a portion of the biomass feedstock to supply the heat. The process can be carried out with or without the use of catalysts. The addition of steam increases the amount of hydrogen in the product gas.

A general description of the overall process of gasification is:



Gasification occurs in a number of sequential steps:

1. Drying to evaporate moisture
2. Pyrolysis to give gas, vaporised tars or oils and a solid char residue
3. Gasification or partial oxidation of the solid char, pyrolysis tars and pyrolysis gases.

When a solid fuel is heated to 300-500°C in the absence of an oxidising agent, it pyrolyses (physically or chemically breaks down by heating in the absence of air) to solid char, condensable hydrocarbons or tar, and gases. The relative yields of gas, liquid and char depend mostly on the rate of heating and the final temperature.

The gas, liquid and solid products of pyrolysis then react with the oxidising agent – usually air – to give permanent gases of CO, CO₂, H₂ and lesser quantities of hydrocarbon gases.

Char gasification is the interactive combination of several gas-solid and gas-gas reactions in which solid carbon is oxidised to carbon monoxide and carbon dioxide, and

hydrogen is generated through the steam reforming reaction. The gas-solid reactions of char oxidation are the slowest and limit the overall rate of the gasification process. Many of the reactions are catalysed by the alkali metals present in wood ash, but still do not reach equilibrium.

The final gas composition is influenced by many factors such as:

- feed composition
- water content of fuel
- reaction temperature
- the extent of oxidation of the pyrolysis products

In summary, there are three types of biomass gasification process - pyrolysis, partial oxidation and reforming. Using cellulose ($C_6H_{10}O_5$) as a representative feedstock, examples of some of the reactions are as follows:

Pyrolysis: $C_6H_{10}O_5 = 5CO + 5H_2 + C$

Partial oxidation: $C_6H_{10}O_5 + O_2 = 5CO + CO_2 + 5H_2$

Steam reforming: $C_6H_{10}O_5 + H_2O = 6CO + 6H_2$

Gasification is a series of reactions occurring simultaneously. Gases are not only produced directly from the feedstock but also from the products of the feedstock reactions (e.g. the char produced during pyrolysis will further react to form gases and carbon dioxide will react with oxygen to produce carbon monoxide).

Not all the liquid products from the pyrolysis step are completely converted due to the physical or geometrical limitations of the reactions involved, and these give rise to contaminant tars in the final product gas. Due to the higher temperatures involved in gasification compared to pyrolysis, these tars tend to be refractory and are difficult to remove by thermal, catalytic or physical processes. This aspect of tar cracking/removal in gas clean up is one of the most important technical uncertainties in implementation of gasification technologies.

Types of gasification- Pressurised and Atmospheric

Gasifier operating conditions vary over a range of temperatures from a few hundred to over a thousand degrees Celsius, and pressures from near atmospheric to as much as 30 atmospheres. Both pressurised and atmospheric operations of gasifiers have advantages and disadvantages.

Pressurised gasifiers have the following features:

- Feeding is more complex and very costly, as the feedstock has to be supplied at pressure.
- The system has to be cleaned out by blowing it through (purging) with inert gas
- Capital costs of pressure equipment are much higher than atmospheric equipment although sizes are much smaller.
- Gas is supplied to the turbine at pressure removing the need for gas compression before use in a gas turbine and also allowing relatively high tar contents in the gas.
- Overall system efficiency is higher due to retention of sensible heat (i.e. that already acquired by the gas) and chemical energy of tars in the products.

Atmospheric gasifiers have the following features:

- For gas turbine applications the product gas is required to be sufficiently clean for compression prior to the turbine. For engine applications the gas quality requirements are less onerous and pressure is not required.
- Atmospheric applications have a potentially much lower capital cost at smaller capacities of below around 30 MW_e.

Gas compositions and heating values are not significantly different for either system.

Changing the pressure and temperature at which the reactions take place affects the composition of the product gas. Increasing the temperature of the process (at constant pressure) increases the amounts of carbon monoxide and hydrogen produced. Increasing the pressure (at constant temperature) increases the amount of methane produced. Methane is the main constituent of natural gas and has a HHV of 40 MJ/m³.

Of all the available gasifier types, the downdraft gasifier has received the most attention and is suited for smaller power levels (i.e. ~100kW_e). The updraft gasifier is preferred for ~MW_e power levels. The fluidised bed is best suited for 10MW_e and above.

The common reactor configurations are outline in Table 2.3.

Table 2.3 Common Reactor Configurations

Fixed bed gasifier	Uses a bed of solid fuel particles through which the air and gas pass either up or down. They are the simplest type of gasifiers and are the only ones suitable for small-scale application
Downdraft gasifier	Developed to convert high volatile fuels (wood, biomass) to low tar gas and therefore has proven to be the most successful design for power generation.
Updraft gasifier	Widely used for coal gasification and non-volatile fuels such as charcoal. However, the high rate of tar production (5%-20%) makes them impractical for high volatile fuels where a clean gas is required.
Fluidised bed gasifiers	Favoured by many designers for gasifiers producing more than 40GJ/h and for gasifiers using smaller particle feedstock sizes. In a fluidised bed, air rises through a grate covered in sand at high enough velocity to levitate the particles above the grate, thus forming a “fluidised bed”. Above the bed itself the vessel increases in diameter, lowering the gas velocity and causing particles to recirculate within the bed itself. The recirculation results in high heat and mass transfer between particle and gas stream.

Downdraft

In this type of gasifier a descending packed bed of biomass is supported across a constriction known as a throat. A co-current of gases and solids flows through this bed i.e. both gases and solid flow through the gasifier in the same direction. The throat is where most of the gasification reactions occur. There is a turbulent high temperature region around the throat where the reaction products are intimately mixed.

This mixing aids the tar cracking. Some tar cracking also takes place below the throat on a residual charcoal bed where the gasification is completed. This configuration is simple, reliable and proven for certain fuels and results in a high conversion of pyrolysis intermediates and hence a relatively clean gas.

The fuels suitable for use in this type of gasifier include relatively dry (up to about 30 % (wet basis)) blocks or lumps and containing a low proportion of fine and coarse particles (i.e. not smaller than about 1cm and not bigger than 30cm in the longest dimension). The gas produced has a low content of tars. Because of this, the downdraft configuration is generally favoured for small-scale electricity generation with an internal combustion engine.

The practical upper limit to the capacity of this configuration is around 50kg/h of feedstock or 500kW_e. The limit is set by the physical limitations of the diameter of the gasifier throat and the size of the particles.

A relatively new concept of stratified or open core downdraft gasifier has been developed in which there is no throat and the bed is supported on a grate. This was first devised by the Chinese for rice husk gasification and has subsequently been used in India. The National Renewable Energy Laboratory (then known as the Solar Energy Research Institute) designed, built and operated a 0.9t/day prototype, downdraft biomass gasifier between 1980 and 1985 [Klass, 1998].

In 1985, Syn-Gas, Inc., scaled this process to a 22t/day plant to develop the concept for commercial production of methanol. Feedstock included wood chips, urban wood waste and densified RDF. Tests in the 22t/day plant at 870 to 930°C with cedar wood

feedstock and oxygen gave 87 to 91% carbon conversions. The product gas had a lower heating value (wet) of 8.3 to 9.8 MJ/m³.

Updraft

The biomass is downward moving and is first dried by the up-flowing hot product gas. Once dry, the fuel is pyrolysed. This gives a char, which continues to be moved down to be gasified. Pyrolysis vapours are carried upward by the up-flowing hot product gas. The tars in the vapour are either carried out of the reactor with the product gas (thereby contributing to the high tar content) or condense on the cool descending fuel. It is estimated that up to 20% of the pyrolysis products in the form of tars “bypass” the gasification process in this way. The condensed tars are recycled back to the reaction zones where they are further cracked to gas and char. In the bottom gasification zone the solid char from pyrolysis and tar cracking is partially oxidised with the incoming air or oxygen. Steam may also be added to provide a higher level of hydrogen in the gas.

A feature of the updraft gasifier is that the product gas has a significant tar and hydrocarbon content which contributes to its high heating value. Thorough clean up of the product gas has to be performed before it can be used to generate electricity. Updraft gasifiers have the advantage that their construction is simple and they have a high thermal efficiency. The latter is due to the fact that the heat of the gas produced is recovered by direct heat exchange with the entering feed. The entering feed is thus dried, preheated and pyrolysed prior to entering the gasification zone. In principle, there is no scaling limitation, although no very large updraft biomass gasifiers have been built.

A recent example of this technology was built in Mississippi in 1995 for the gasification of 300t/day of rice hulls [Klass, 1998]. An air blown updraft gasifier converts unground rice hulls to fuel gas (121GJ/h) for an existing boiler-power island, which supplies 5MW electric power and 6800 kg/h of process steam for parboiling rice. Several small-scale, fixed-bed, updraft gasifiers are operated commercially in Sweden and Finland for the gasification of a wide range of biomass feedstocks, including wood chips, saw mill residues, straw and RDF. The moisture content of the feeds can range from 0 to 45% and the corresponding heating values of the product gas are about 5.5 to 3.8 MJ/m³.

The gasifiers can be connected to a hot water or steam boiler depending on whether heat or electric power is required. Alternatively the product gas can be used for hot gas generation for kilns and dryers.

Fluid Bed

This type of gasifier is also referred to as a bubbling fluid bed gasifier. The air bubbling upwards through the feedstock results in a method of solid-gas contacting that has excellent mixing characteristics and high reaction rates. As the gas passes upwards through the packed bed of particles (coarse sand is commonly used) a pressure drop is formed across the bed. This pressure drop increases as the gas velocity increases until the bed of solid particles expands slightly. At this point the individual particles become supported in the gas stream with freedom of movement relative to one another. The bed is then said to be fluidised and has the appearance of a boiling liquid with a well-defined free surface. Higher gas velocities result in entrainment of the solid particles and the surface loses its well-defined interface.

Fluid bed gasifiers are the only gasifiers with isothermal bed operation i.e. the whole bed is at the same temperature. Their typical operating temperature is at 800-850°C.

Most of the conversion of the feedstock takes place within the bed. Some conversion does, however, continue to take place in the freeboard section above the fluid bed as some pyrolysis products are swept out of the fluid bed by gasification products. These are converted by further thermal cracking.

In most cases, carbon conversion approaches 100%. This is not the case if excessive carry over of fines takes place. This occurs with a top-feeding configuration. The gas produced by the bubbling fluid bed gasifiers tends to have a tar content somewhere between that of the updraft and downdraft gasifiers.

The bed can lose its fluidity due to sintering, which is when the solid feedstock fuses together without melting. Alkali metals from the biomass ash form low melting point substances (eutectics) with the silica in the sand of the bed. This results in the eventual loss of bed fluidity. This is quite a common problem but its occurrence depends on the

thermal characteristics of the ash. The inherently lower operating temperature and better temperature control of a fluid bed provide an acceptable control measure. With biomass of high ash/inerts content it is better to use alumina or even metallic sand such as chromite sand in the fluid bed itself.

The carbon loss with entrained ash can be significant. This means that fluidised beds are uneconomical for small-scale applications. They also incur higher operating costs. This type of gasifier can be readily scaled up. Multiple feeding is used in large beds where fuel distribution can become a problem. Alternative configurations such as twin bed systems and circulating fluidised beds are available. As a result, there are processes to suit almost every type of feedstock or thermochemical process.

Fluidised beds can provide high rates of heat and mass transfer and good mixing of the solid phase. Relatively high reaction rates are possible and the temperature is more or less constant in the bed. The particles need to be in the range of 1-10mm in diameter and so the feedstock may need to be reduced in size to meet the particle requirements of the fluidised bed. The ash is elutriated (separated by washing into coarser and finer portions) and removed as fine particles entrained in the product gas.

Circulating Fluid Bed (CFB)

In this type of gasifier the air velocity through the fluid bed is high. Because of this, large amounts of solids are entrained with the product gas. The system is designed so that these solids are recycled back to the fluid bed. This improves the carbon conversion efficiency and makes it greater than that for the single fluid bed design. The product is a raw, hot gas. Britain's first commercial gasification project 'Project Arbre' is an Air Blown CFB gasifier.

Twin Fluid Bed

The use of two fluid bed gasifiers gives a higher heating value product gas than a single air blown gasifier. The gasifier is in effect a pyrolyser. It is heated with hot sand from the second fluid bed. This second fluid bed is heated by burning the product char in air before recirculating it back to the first reactor. Hydrogen is generated when a shift

reaction occurs. This shift reaction occurs upon the addition of steam to the gasifier. The presence of steam also encourages carbon-steam reactions. The product gas has a fairly high heating value but contains tars from the pyrolysis process.

A summary of gasifier characteristics is given in Table 2.4 and Table 2.5 compares the gasification product gas characteristics

Table 2.4 Summary Of Gasifier Characteristics

Gasifier Type	Characteristics
Downdraft	<ul style="list-style-type: none"> Simple, reliable and proven for certain fuels Relatively simple construction Close specification on feedstock characteristics Uniform sized feed required Very limited scale-up potential Possible ash fusion and clinker formation on the grate High residence time of solids Needs low moisture fuels High carbon conversion Low ash carry over Fairly clean gas is produced Low specific capacity
Updraft	<ul style="list-style-type: none"> Product gas is very dirty with high levels of tars Very simple and robust construction Good scale up potential Suitable for direct firing High residence time of solids Relatively simple construction Low exit gas temperature High thermal efficiency High carbon conversion Low ash carry over
Bubbling Fluid Bed	<ul style="list-style-type: none"> Good temperature control High reaction rates In-bed catalytic processing is possible Greater tolerance to particle size range Moderate tar levels in product gas Higher particulates in the product gas Good gas-solid contact and mixing Tolerates variations in fuel quality Easily started and stopped Good scale-up potential Low feedstock inventory Carbon loss with ash High specific capacity Can operate at partial load
Circulating Fluid Bed	<ul style="list-style-type: none"> Good temperature control and high reaction rates In-bed catalytic processing not possible Greater tolerance to particle size range Moderate tar levels in product gas Relatively simple construction and operation High specific capacity Very good scale-up potential High carbon conversion Good gas-solid contact

Table 2.5 Gasification Product Gas Characteristics

Gasifier	Capacity t/h	Capacity MW_e(a)	Feed(b)	HHV MJ/m³	Gas Quality (c)	Outlet Temp °C
Downdraft, air	0.1-0.7	0.2-1.4	1	4-6	4	700-1000
Downdraft, oxygen	1-5	2-10	1	9-11	4	700-1100
Updraft, air	0.5-10	1-20	2	4-6	3	100-400
Updraft, oxygen	1-10	2-20	2	8-14	3	100-700
Single fluid bed, air	0.5-15	1-30	4	4-6	3	500-900
Single fluid bed, oxygen	2-10	4-20	4	8-14	3	700-1100
Single fluid bed, steam	1-10	2-20	4	12-18	3	700-900
Circulating fluid bed, air	2-20	4-40	3	5-6.5	2	700-1100
Circulating fluid bed, oxygen	2-20	4-40	3	10-13	3	800-1200
Twin fluid bed	1-10	2-20	4	13-20	3	750-1000
Secondary processing	-	-	-	-	5	1000-1200

(a) conversion at 36% overall efficiency

(b) specificity: most specific – 1; least specific – 5

(c) relative assessment in terms of tars and particulates in raw gas: worst – 1; best – 5

The gas and tar content of the gases produced by the different gasifiers are outlined in Table 2.6.

Table 2.6. Gas Quality for each Gasifier Type

Gasifier Type	Gas Quality	
	Tars	Dust
Fluid bed air-blown	fair	poor
Updraft air-blown	poor	good
Downdraft air-blown	good	fair
Downdraft oxygen-blown	good	good
Multi-solid fluid bed	fair	poor
Twin fluidised bed	fair	poor
Pyrolysis (for comparison)	poor	good

Gas Clean Up

Gases that are formed by gasification will contain some or all of the contaminants listed (with their concomitant problems) in Table 2.7

Table 2.7 Product Gas Contents and Associated Problems

Contaminant	Examples	Problems
Particulates .	Ash, char, fluidised bed material	Erosion
Alkali metals	Sodium, potassium compounds .	Hot erosion
Fuel-bound nitrogen	Mainly ammonia and HCN	NO _x formation
Tars	Refractive aromatics	Clogs filters Difficult to burn Deposits internally Corrosion
Sulphur, chlorine	HCl, H ₂ S	Corrosion Emissions

The level of contamination depends mainly on two factors:

- The type of gasification process employed

- The type of feedstock used

If gas cleaning is not carried out, there will be erosion, corrosion and environmental problems in the downstream equipment. Table 2.8 gives a summary of the main contaminants in gasification product gases and methods for their removal

Table 2.8 A Summary of the Main Contaminants in Gasification Product Gases and Methods for their Removal

Contaminants	Clean-up method
Ash	Filtration, Scrubbing
Char	Filtration, Scrubbing
Inerts	Filtration, Scrubbing
NH ₃	Scrubbing, SCR
HCl	Lime or Dolomite, Scrubbing, Absorption
SO ₂	Lime or Dolomite, Scrubbing, Absorption
Tar	Tar cracking, Tar removal
Na	Cooling, Condensation, Filtration, Adsorption
K	Cooling, Condensation, Filtration, Adsorption
Other metals	Cooling, Condensation, Filtration, Adsorption

2.5.3 Pyrolysis of Wood

From the literature survey, it was observed that commercially proven pyrolysis technology at this scale of operation is not very common though several companies are trying to bring such technology to the market.

2.6 Examples of using Woodchips as Fuel

Biomass Integrated Gasification/Combined Cycle (BIG/CC) demonstration projects are underway in Brazil, Denmark, Finland, Italy, The Netherlands, Sweden, the United Kingdom, and the United States (Williams and Larson, 1996). The largest is a 30 MW_e

unit in Brazil that will be fuelled by wood chips from an existing eucalyptus plantation; this project is being supported by the Global Environment Facility (Elliott and Booth, 1993) ^[4]. The goal of this project is to confirm the commercial viability of producing electricity from wood through the use of BIG/CC technology. The wood will first be converted to a gas, known as syngas, which has a calorific value of around 5 MJ per cubic metre. The syngas will be combusted in a combined cycle plant that contains a gas turbine and a steam turbine to maximise efficiency. This system is termed Biomass Integrated Gasification Combined Cycle (BIG/CC). TPS Termiska Processor AB, of Sweden is performing the experimental work, engineering studies and basic engineering of the phase two of this GEF project. The gas turbine proposed for the plant is GE LM-2500 ^[5].

In the UK, electricity generation from biomass is being encouraged through the Government's Non Fossil Fuel Obligation (NFFO) scheme. Over 80 MW_e of bio energy projects having NFFO or SRO contracts are under development ^[1]. Over the next ten years many more of these relatively small power stations spring up all across the country using local fuel and supplying electricity and, in many cases, heat to local markets.

Some of the current successes in UK include:

ARBRE project

A new generating plant for 'Green' electricity is being built in Yorkshire. The first commercial plant of its type in Europe, it will produce enough electricity for the domestic electricity consumption of 33,500 people from clean and sustainable wood fuel sources.

First Renewables, a Kelda Group company, is leading this renewable energy development with a Swedish company under the name of ARBRE Energy- ARable Biomass Renewable Energy. *The* other partner is TPS of Sweden, developers of gasification technology to be employed in the plant.

The ARBRE plant will generate 10 MW_e of electricity from wood chips provided from forest and coppice sources. BIG/CC technology will be used to generate electricity - the

wood is converted into a gas which fuels a high efficiency combined cycle generating process.

The fuel sources are mostly Short Rotation Coppice primarily of densely planted willow shrubs harvested on a three-year cycle and forestry sources - materials derived from forest and woodland management.

Carlisle Project

A 225,000 tonne per year pyrolysis plant under development in Carlisle will fuel 20 MW_e of electricity generation on-site; supply district heating to nearby industrial units and supply bio-oil to two satellite CHP plants.

Blackwater Valley Museum - from B9 Energy Biomass

Sited at the Blackwater Valley Museum, Benburb, this 200kW plant uses sawmill wood chips to provide heating for the museum and clean, green electricity for 400 homes. Designed and manufactured in Northern Ireland, the plant is the world's first downdraft, combined heat and power unit to operate on a continuous feed system.

Wood chips are gasified in presence of air to produce hydrogen carbon dioxide and nitrogen. The gas is then cleaned, cooled, mixed with air and fed into the engine. 10% of the engine fuel is diesel supplied for ignition purposes. The internal combustion of the gas rotates the engine shaft. This shaft is coupled to a generator, which produces electricity. The engine exhausts contain a considerable amount of heat that is recovered by diverting them through heat exchangers. The resulting hot water is then pumped to the radiators in the museum for space heating via an underground heating network.

Boughton Pumping Station

Boughton Pumping Station has a biomass visitors centre, offices, and a conference centre. It was opened in April 1998 as part of a developing scheme for a renewable energy village. The site is heated and powered by a CHP plant, installed in 1999. Wood

chips are heated in a gasifier producing a combustible gas, which is then used to fuel a stirling engine producing both heat and electricity.

The wood chips are supplied from local forestry operations, are used as fuel in the short term. In the longer term, the fuel supply will come from energy crops, which have been planted on-site.

Chapter 3 Calculations for the Proposed Technology

From the literature survey and information received from various manufacturers about conversion of biomass into energy, the following combined heat and power schemes are proposed for the sawmill.

1. Organic Rankine Cycle (ORC) Technology
2. Wood gasification- Gas Turbine Technology

3.1 The Organic Rankine Cycle (ORC) Technology ^[7]

The Organic Rankine Cycle (ORC) is similar to the cycle of a conventional steam turbine, except for the fluid, which operates in the turbine is a high molecular mass organic fluid e.g. di-phenol oxide. Figure 3.1 shows a schematic diagram of the Organic Rankine Cycle (ORC).

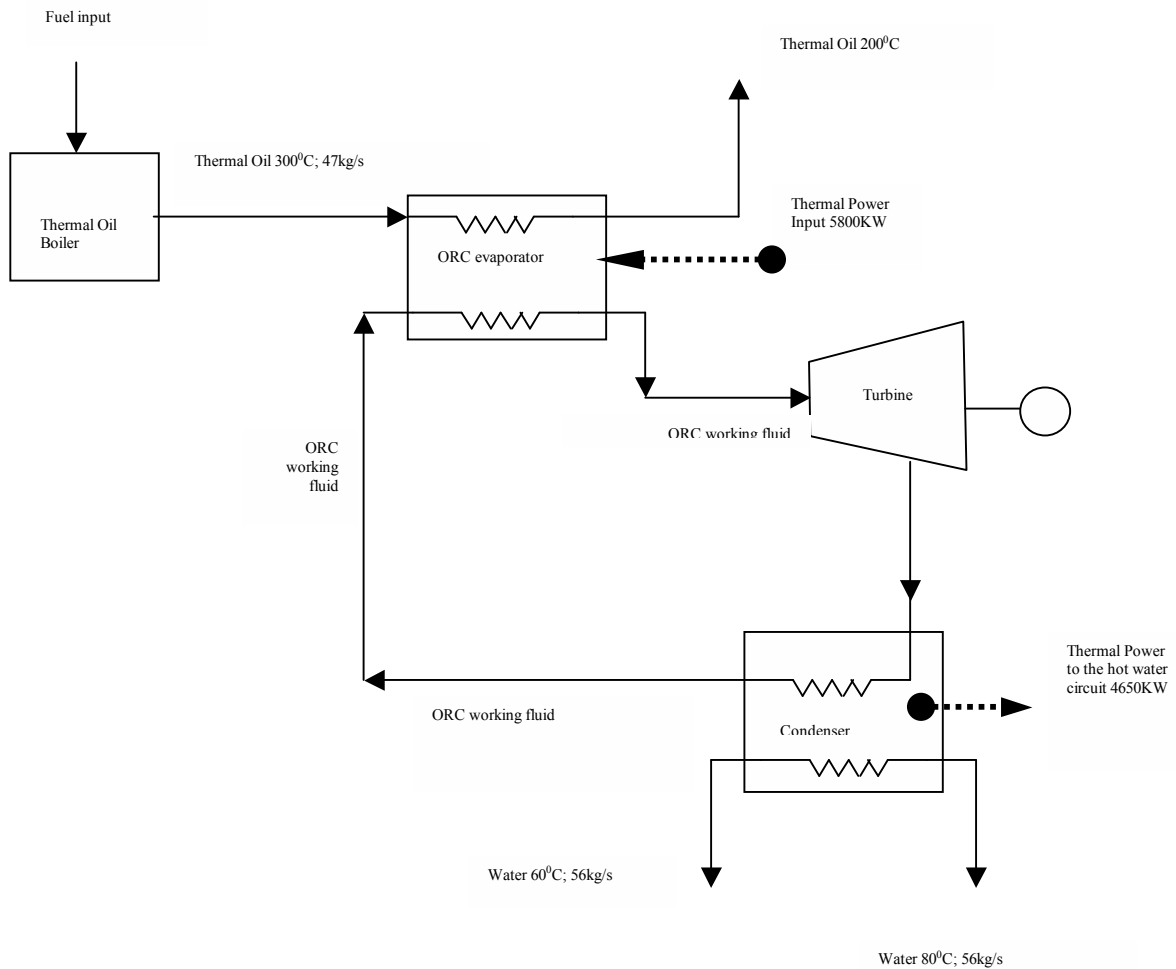
The organic working fluid confined in a closed and leakage-free circuit is vaporised using the heat of the hot source in the evaporator, which can be a shell-and-tube heat exchanger. The organic fluid vapour expands in the turbine and is then condensed using cold water in the shell-and-tube heat exchanger. Alternatively, ambient air can be used for cooling. The condensate is pumped back to the evaporator thus closing the thermodynamic cycle. Hot and cold sources are not directly in contact with the working fluid or with the turbine. For high temperature applications, a regenerator downstream of the turbine is also added, to further improve the cycle performance. The high molecular mass working fluid allows exploiting efficiently, low temperature heat sources to produce electricity in a wide range of power outputs.

The ORC has the following advantages:

1. High cycle efficiency
2. Very high turbine efficiency (up to 85%)
3. Low mechanical stress of the turbine, due to low peripheral speed
4. Low RPM of the turbine allowing the direct drive of the electric generator without reduction gear

5. No erosion of blades, due to the absence of moisture in the vapour nozzles
6. Long life

Figure 3.1 A Schematic Diagram of Organic Rankine Cycle



There are many other advantages, such as simple start-stop procedures, quiet operation, minimum maintenance requirements, good part load performance.

High Efficiency Rankine (HER) turbo generators have been commercially developed by many manufacturers to produce electricity in small power-per-unit turbines associated with biomass combustion systems.

As a part of my literature survey, the agent for ORC turbo generators in UK (TUBBODEN, Italy) was contacted. The technical data sheet of High Efficiency Rankine (HER) turbogenerators as obtained from TUBBODEN is given in Table 3.1. Since the electrical demand for my case study is 3MWe, it would be feasible to use three 1 MWe modules to supply a total of 3MW_e.

Table 3.1 Technical Data Sheet of High Efficiency Rankine (HER) Turbogenerators

ORC unit	HER1000
Heat source	Thermal oil in a closed loop
Thermal oil nominal temperature (In/Out)	300 / 250 °C
Thermal oil flow (about)	47 kg/s
Thermal power input from thermal oil	5800 kW
Hot water flow	56 kg/s
Hot water temperature (In/Out)	60 / 80 °C
Thermal power to the hot water circuit (about)	4650 kW
Net active electric power output	1000 kW
Efficiency (electricity vs. heat)	0.170
Overall dimensions (LxWxH)	13 x 2,5 x 6,5+ 6,5 x 2,5 x 4,6 m
Electric generator	asynch., 3 phase, L.V., 1250 kW

The process involves the following steps:

- a. Biomass is burned in a boiler to heat thermal oil at 250/300°C (in/out of boiler).
- b. The thermal oil is fed to a Rankine turbo generator, acting according to the Organic Rankine Cycle (ORC) concept. The turbo generator receives the thermal power from the hot oil, produces electricity and heats a flow of hot water at some higher temperature (in/out of ORC unit).
- c. The hot water is utilised for heating purposes, e.g. for space or process heating (in this case for wood drying), or alternatively it is cooled in an air cooler, in case no heat is needed.

The rationale for this process is:

Biomass is burned in a combustor made according to the well-established techniques in use also for hot water boilers. These combustors with their set of accessories (filters, controls, automatic ash disposal and biomass feed mechanism etc.) are nowadays safe, reliable, clean and efficient.

Hot thermal oil is utilised as heat transfer medium, giving a number of advantages, namely low pressure in boiler, large inertia and insensitivity to load change, simple and safe control and operation. Moreover, the adopted temperature (about 300°C) for the hot side ensures a very long life of the oil.

With the use of a properly formulated working fluid and to the optimisation of the machine design, both high efficiency, and high reliability are obtained. The turbine has a large rotor (about one meter of diameter), has low peripheral speed, and it is directly coupled, without any gear, to the electric generator. All the elements that constitute the machine are pre-assembled in factory on a single skid, so that the installation on site is extremely simplified.

Unlike steam, the adopted organic fluid is non-corroding and non-eroding for the valve seats, the tubing, the turbine blading, thus a very long operational life for the machine is ensured.

In the design of the turbo generator conservative criteria were adopted. The turbo generator can be started in a few minutes; it can be started even with a signal from a remote station, and it operates fully unattended. A complete data acquisition allows the operator, when present, to verify the performance of the machine. The data, including the record of the data gathered in the previous period (days or even months), can also be transferred by modem to a remote computer.

When the heat production is not required in a CHP, the condenser of the turbo generator can be cooled either by water (in a closed loop to be coupled with cooling towers) or directly through air coolers.

The boiler used with the Organic Rankine Cycle is a thermal oil boiler, which is much the same as a normal water boiler, except that oil is heated rather than water and to a much higher temperature. The thermal boiler sits on top of a biomass furnace - typically a large moving grate combustor. These state-of-the-art wood boiler plants are manufactured by French company Comptel for modern wood combustion system. These boilers can be used for both steam and thermal oil and for both wet and dry wood having outputs from 320 kW to 5,000 kW. In addition to boiler plant, a comprehensive range of fuel handling and de-ashing options are available.

Some salient features of these boilers include:

- Open bottom, wet walled boiler with ceramic lined combustion chamber.
- Auger fed moving grate.
- Integral ID fan and multi cyclone flue gas clean up.
- Fully modulating combustion control from 30 -100% MCR on wet (45% MC) wood. Below 30% MCR the boiler operates in on/off mode.
- Furnace temperature control.
- Lambda control of primary and secondary air supply for optimum excess air levels.
- Boiler efficiency is 81-82% at MCR and >80% at max modulating turndown.
- Wet-wood boiler ratings are at fuel MC of 45%

Boilers can be set up for lower fuel moisture values and can cope with $\pm 10\%$ of set figure without manual intervention.

Some additional features available with these types of boilers are:

- Automatic de-ashing (bottom and fly ash)
- Ram-stoker fuel feed for coarse fuels
- Inclined grate for 4.5 MW rating, can be used with wet wood
- High chrome grate for exceptional durability

Wet wood chip will be burnt because it will cost more to dry it than to get back the energy - modern wood fuel combustion technology is able to cope with 50 to 60% MC.

From the experience of experts in wood fuel combustion, chipped wood in large heaps will slowly dry especially if they are open. If wood fuel is made of fresh chip bark /chip which will be coming off the line, the MC can be anywhere from 40% to 65%. Therefore it is assumed that the MC of wood fuel is at 50% and if it can be dried, all the better. Also wood fuel in a big heap starts to compost with resulting dry mater loss, volatiles loss with reduction in Calorific Value and is a potential health risk for workers from fungal spore development. However this process does generate heat quite quickly even in small stacks, which will help some drying. But the chips will not be stacked more than 3 or 4 m deep or sufficient heat may build up to set the heap on fire.

A fairly big area for storage of the wood fuel and a good size fuel reception hall will be required. The wood fuel may be conveyed directly to the fuel hall from the storage area by conveyor and the fuel hall would use robotic grabs to drop fuel into a stoking hopper. The amount of wood fuel required for the process will depend on the overall thermal efficiency of the ORC and the calorific value of wood fuel.

3.1.1 Calculation of amount of wood fuel required for ORC

For 1 MW_e power generation at the generator, thermal input from the wood boiler is 5.8MW (ORC data sheet).

Other assumptions:

1. Boiler efficiency 80%.
2. Total hours of plant operation in a year 8000,
3. Electrical conversion efficiency at generators 17%
4. Calorific value of fuel 8.5 MJ/Kg at 50% MC

Amount of wood fuel required: 24564.7 tonnes.

For 3 such units the wood requirement: 73694.11 tonnes.

Some additional harvesting of wood fuel from nearby forest area will be required to meet the energy demand.

3.1.2 Calculation of the size of fuel hopper required

For 72 hours of continuous operation without manual intervention the amount of wood required is calculated to be 253 tonnes

275 cubic meters with density of wood fuel assumed as 0.92Gt/m^3 [6]

3.1.3 Heat Recovery and Use

Heat energy is removed from the condenser to supply on-site heating needs. The heat demand for the process is hot water at 105°C .

The heat extracted from the ORC working fluid at the condenser is 4.6 MW_t for each 1MWe unit. As per the data sheet from Turboden, the condenser cooling water needs to be in a closed loop, $60/80^\circ\text{C}$ inlet and outlet at flow rate of 56kg/s at the condenser. The total heat requirement for drying of logs in the sawmill is 3 MW_t , and water needs to be heated from ambient (say 8°C) to 105°C .

It is assumed that process water will be preheated to 70°C by heat exchange with the condenser cooling water. To get the process water temperature to 105°C it will be required to take additional heat from the biomass boilers and/or from a regenerator on the flue gases. The systems could be plumbed together using heat exchangers and flow mixing, and by getting additional heat from the back end of the boilers to boost the flow to a temperature of 105°C . This is possible but it may reduce the electrical efficiency of the system. Therefore at the feasibility stage an additional capital cost of $\pounds 150,000$ for flue gas heat recovery and/or additional boiler capacity is assumed.

3.2 Biomass Gasification

From literature review, the following methodology [8] was proposed for gasification of wood fuel to produce a low calorific value fuel gas suitable for use in power gas turbines.

The gas turbine can then be used to produce both electricity and heat as part of a cogeneration scheme.

TPS Termiska Processor AB ^[9] of Sweden who supplied the gasifier for Europe's first commercial B-IGCC scheme, the ARBRE project in Yorkshire, UK, and the World Bank's Global Environment Facility (GEF) demonstration project in northern Brazil, was contacted for gasifier specifications. They did not have specific information on bio mass gasification technology for a CHP. However they provided the following information:

- The calorific value of the syngas would depend on the type of wood, the moisture content and any treatment of the flue gas
- Wood should be dried to about 10 to 15% and would normally have a heating value of approximately 5.5 MJ/Nm³
- The calorific value can be increased if you pass the gas through a condensing scrubber.
- No information on cost estimates for this scale of CHP was readily available from them.

ALSTOM Power Ltd ^[10], UK, a world leader in the application of industrial gas turbines for biomass fuel, having supplied a Typhoon unit for the world's first Biomass-Integrated Gasification Combined Cycle (B-IGCC) scheme, a demonstration plant in Varnamo, Sweden and another Typhoon for, the ARBRE project in Yorkshire, UK, were contacted; requesting for specific information about gas turbine suitable for this case study, but no response was received.

Also General Electric, the supplier of aero-derivative gas turbine system (GE LM-2500) used in the World Bank's Global Environment Facility (GEF) demonstration project in northern Brazil, was contacted for gas turbine specifications, but no response was obtained.

Another gasifier manufacturer PRM Energy Systems Inc. ^[12], having a successful track record for gasification technology for past 19 years using various types of bio mass fuels, was contacted during the literature survey. Some information on gasification technology and cost estimates for this scale of provided by them has been used in this report.

Owing to dearth of detailed information about the gasifier and gas turbine system, it was not possible to perform a detailed gasifier or gas turbine design. Instead, the design and cost information obtained from PRM Energy and that given in the NREL report was scaled to fit my system. The proposed design/operating conditions are described below.

The wood gasification is proposed to be carried out using a gasifier provided by PRM Energy Systems Inc. The PRME bio mass gasification system includes a fuel metering bin, the reactor/gasifier, the combustion tube and chamber, the gasifier cooling water system, water cooled ash discharge conveyors, multi-zoned combustion air supply, rotary feeders and instrumentation required to provide automatic control over the process. The entire gasification/combustion process, from in-feed to ash discharge, can be controlled manually or by computer.

The gasifier is a vertical cylindrical steel shell, reduced in diameter in the upper portion and lined with a refractory capable of withstanding temperatures as high as 1560⁰C in a reducing atmosphere. The cross sectional area of the upper portion of the gasifier is reduced to provide the turbulence required to insure proper mixing of the product gas and the combustion air introduced into the combustion tubes in this area of the gasifier. The lower portion of the gasifier contains an appropriately sized grate and develops a design heat rate of approximately 350,000 Btu/ft² (3.9 GJ/m²) of grate area.

Fuel is metered to the gasifier from the fuel-metering bin. This bin is equipped with an in-feed levelling conveyor and a variable speed out-feed conveyor that delivers fuel to the gasifier. The speed of the out feed conveyor is automatically adjusted by the automatic control system to maintain a preset temperature in the first stage gasification zone. Discharge from the out feed conveyor is directed through an impact weigh metering device that provides precise indication and control of the fuel feed rate. The chips will be screened for oversize particles and any metallic objects. The storage area will have

capacity to hold four days of fuel. Before use the wood chips will be dried to around 15% moisture content, using waste heat from the process. Fuel is introduced to the gasifier by a water-cooled screw conveyor that discharges into the drying and heating zone of the gasifier. The gasification process is controlled by the proportioned application of gasification and combustion air in a manner that supports efficient gasification. Residence time in the gasifier is varied by a residence control system that is adjusted to achieve a target carbon content of the ash residue.

In the gasification zone of the gasifier, approximately 10 to 12% of the stoichiometric air requirement is admitted into the gasification air distribution area. The application of gasification air is multi-zoned and is controlled to maintain the proper temperature required to volatilise the biomass and allow partial combustion of the fixed carbon. Temperatures in this zone are controlled between 600 °C and 1300°C, depending on the particular biomass fuel and the required ash quality. A low gasification air flow rate (<0.1m/s) through the gasification zone, coupled with a low feed stock entry point and continuous ash discharge minimizes the amount of particulate matter entrained in the gasifier exhaust.

Combustion of the gases starts in the combustion tube assembly where the temperature of the gases is increased to promote thermal cracking of tars and hydrocarbons that were liberated during gasification. Partial combustion of gases in the combustion tube assembly, the use of mechanical bed agitation and precise control of the zoning of gasification air produces a clean, low calorific value gas. Figure 3.2 shows a schematic diagram of the Gasification and the gas turbine cycle.

Unfortunately, little concrete data is publicly available on the operating conditions, reactant ratios, and fuel gas produced by the gasifier. However the following assumptions are made for the design parameters and operating conditions ^{[8] [12]}

Figure 3.2 Schematic Diagram of Gasification Process and the Gas Turbine Cycle

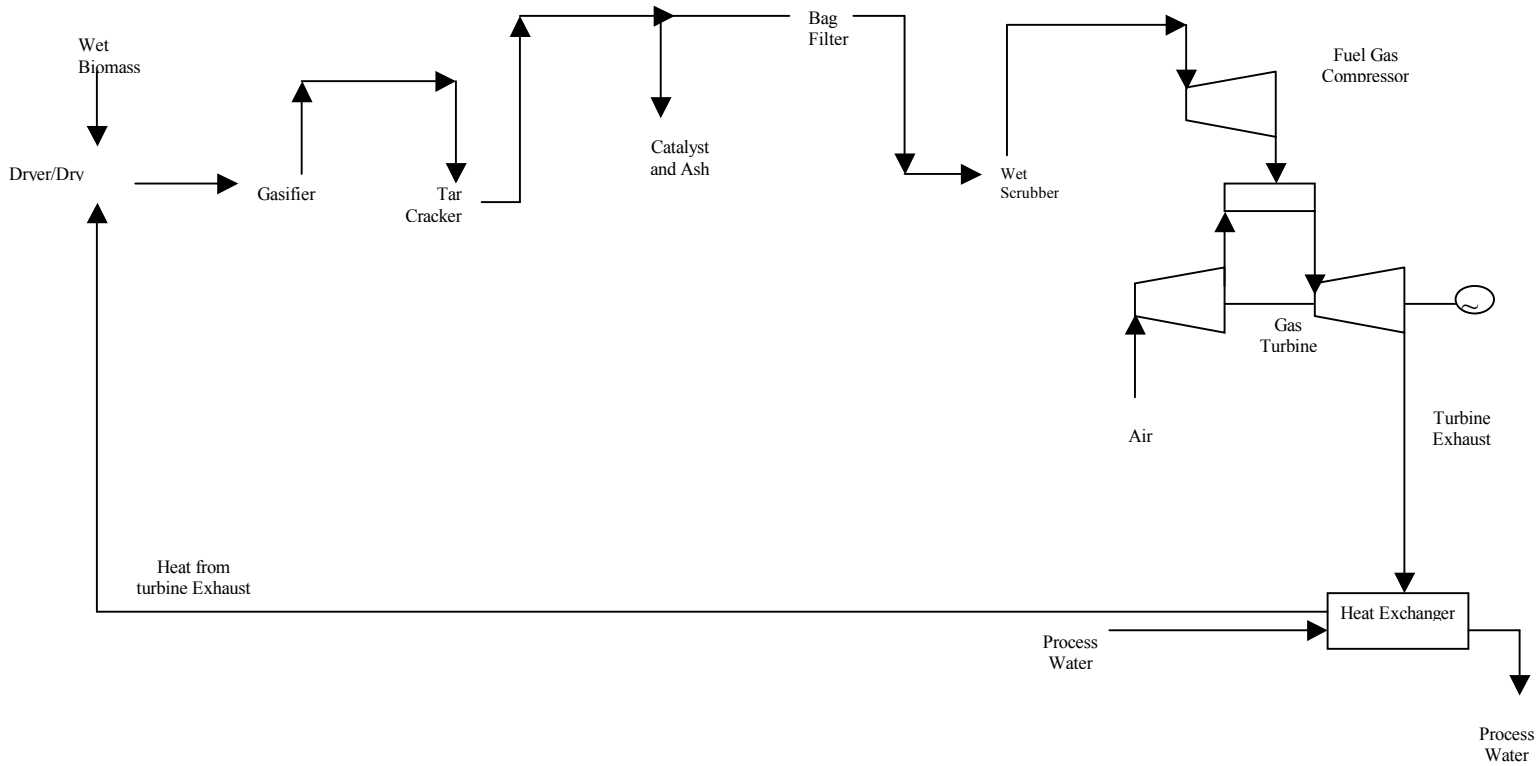


Table 3.2: Gasifier Design Parameters and Operating Conditions

Size of Wood chips	<12.7 mm
Gasifier temperature	870°C
Gasifier pressure	0.14 MPa
Fuel gas pressure	1.89 MPa
Dried wood feed to gasifier	3.5 Tonnes/hr
Dried wood moisture content	15 %
Air / wood ratio (wt/wt)	2.1
Calorific value of the syngas produced	~5 MJ/m ³

3.2.1 Gas Clean-up

Fuel gas exiting the gasifier enters a tar-cracking unit. This unit reduces the quantity of higher hydrocarbon species in the fuel gas that could otherwise foul the fuel gas cooler, plug the fabric filters, and increase wastewater treatment loads from the gas scrubber. Dolomite is used as the bed material in the tar cracker. The higher temperature of the tar cracker ensures conversion of any ungasified solids that escape the gasifier.

After exiting the second stage tar cracker cyclone, the fuel gas enters the syngas cooler. This unit may be used to preheat gasification air. In actual practice, the potential safety risk of this scheme would have to be carefully evaluated such an approach is feasible. In the syngas cooler, the temperature of the fuel gas is reduced to around 250°C.

Any particulate remaining in the fuel gas are removed in a bag filter unit. As the fuel gas is cooled, volatile alkali species present in the gas stream condense on the remaining particulate matter and are removed from the system by the filter bags. The particulate-free fuel gas is cooled further in a direct contact water scrubber that removes any trace higher hydrocarbons and most of the water in the fuel gas stream. This operation also removes a significant amount of the ammonia from the fuel gas. Following this step, the gas is further washed with a dilute sulphuric acid stream. These combined steps remove over 95% of the ammonia from the fuel gas. This ammonia would otherwise be likely to

produce NO_x in the gas turbine combustor. Purge streams are sent to wastewater treatment. The fuel gas then enters the fuel gas compressors.

After fuel gas cleaning, the fuel gas is compressed before its introduction into the gas turbine combustor. Although the turbine pressure ratio is 14.9, the fuel gas is compressed to a higher pressure to allow for pressure drop across the fuel control valve. This compression is accomplished in a multi-stage, inter-cooled centrifugal compressor.

Hot clean fuel gas is introduced into the gas turbine combustor along with air from the high-pressure turbine compressor. The turbine exhaust will be used to recover heat for heating the process water to a temperature of 105 °C. A summary of process conditions and results are given in Table 3.3

Table 3.3 A Summary of Process Conditions

Wood flowrate, kg/s	0.97
Air flow rate, kg/s	1.94
Fuel gas heating value, LHV, wet basis, MJ/m ³	5
Turbine pressure	14.9
Turbine firing temperature, °C	1,288
Gas turbine output, MW _e	3
Turbine exhaust temperature, °C	641
Net plant efficiency, %, HHV basis	19 %

3.2.2 Calculations for Biomass Gasification, Gas Turbine Cycle

The empirical relation between calorific value (CV) and moisture content (MC) is given by:

$$CV = 19.5 - (0.2197 - MC) \quad [13]$$

At 15% MC, the CV = 16.2 MJ/kg

The required feed rate 0.97kg/s ^[12]

Total energy input into the system $16.29 \times 0.97 = 15.71\text{MJ/s}$

Thermal efficiency of Gas Turbine $= 3/15.71 = 19.09\%$

Assuming Ideal Joule Brayton cycle and

Working fluid is air, which is assumed as ideal gas

The combustion process is replaced by a heat transfer to the fluid (air in this case) ^[14]

All processes are reversible

Inlet temperature for air into the compressor assumed 300°K

Isentropic Efficiency 0.78

$\gamma = 1.4$

$C_p = 1.005\text{ KJ / kg K}$

For the compressor,

$p_2 / p_1 = 14.9$

$T_1 = 300^{\circ}\text{K}$

$(T_{2s} / T_1)^{\gamma/\gamma-1} = p_2 / p_1$

$T_{2s} = 649.1^{\circ}\text{K}$

Isentropic Efficiency $= 0.78 = (T_{2s} - T_1) / (T_2 - T_1)$

$(649.1 - 300) / (T_2 - 300) = 0.78$

$T_2 = 747.5^{\circ}\text{K}$

For Turbine,

$$(T_3 / T_{4s})^{\gamma-1} = p_3 / p_4 = 14.9$$

$$T_3 = 1288^\circ\text{C} = 1561 \text{ }^\circ\text{K}$$

$$T_{4s} = 732.6 \text{ }^\circ\text{K}$$

$$\text{Isentropic Efficiency} = 0.78 = (T_3 - T_4) / (T_3 - T_{4s})$$

$$T_4 = 914.9 \text{ }^\circ\text{K} = 641 \text{ }^\circ\text{C}$$

Net power output is 3MW. So,

$$m \times C_p \times (T_3 - T_4) - m \times C_p \times (T_2 - T_1)$$

$$= m \times 1.005 \times 198.5 = 3 \times 10^3$$

$$m = 15.03 \text{ kg/s}$$

This is the ideal mass flow of the working fluid (air) in the turbine.

$$\text{Ratio of Heat to power} = (T_3 - T_2) / (T_3 - T_4 - T_2 + T_1) = 4.09 \cong 4$$

Ideally, available heat from the turbine exhaust is 12MW_t, but in actual case some of it will be lost in the process. This heat can be utilised for process heating.

Chapter 4 The Economics of CHP

In this chapter, the economic viability of the project is assessed. For the project to be feasible, apart from the social and environmental benefits, it should save money in the long run. In this section, how much money will be saved and how long will it take to get a return on the initial investment have been answered.

The types of cost associated with energy usage and the value of the cost/energy savings will depend on:

- a) Initial investment (i.e. the capital cost of the project)
- b) Fuel cost
- c) Other operating costs (i.e. maintenance, materials, labour, service, utilities, storage, handling etc.)

In this project, use of the wood chips produced from the sawmill, as a fuel, in a CHP scheme, will provide an alternative to selling them to the fibreboard manufacturers and the paper industry.

Cost comparisons have been done for two alternative ways of utilising the power and heat generated by the CHP scheme:

1. Using the heat and electrical energy generated to replace the existing system of energy consumption of the sawmill
2. Selling the renewable energy under the NFFO obligation

Also cost comparisons have been done for both the Organic Rankine Cycle technology and the wood gasification technology as described in Chapter 3.

4.1 Cost Calculations

The present heat and electrical energy demand of the sawmill of 3 MW_e and 3 MW_t respectively, have been taken as the basis for all cost calculations. The cost of

production of wood chips, which are used as a fuel in the CHP, will be equal to its current opportunity cost plus any additional investment required to enable its use for energy production on-site. This cost has been obtained from the sawmill.

The sawmill presently uses electricity for its running, and operates for 8000 hours a year. It has to pay a certain amount of Climate Change Levy, which has been taken into account in the cost calculations.

Currently, the sawmill uses heat generated from a boiler that is fuelled by the bark and oversize /undersize wood chips (termed as kiln fuel) produced during saw milling operation. The internal cost of kiln fuel calculated by the sawmill has been obtained from them. The boiler operates at quite low efficiency, which is another reason the sawmill is looking for an alternative source of heating.

An empirical relation has been used to determine the calorific value of the wood fuel at various moisture content.

4.1.1 CHP to Replace the Existing System of Energy Consumption of the Sawmill

The assumptions are:

1. Cost of electricity presently used for running the plant (moderately large category) 3.09 p/kWh ^[15]
2. Plant operation 8000 hrs in a year
3. Average Climate Change Levy applicable 0.25 p/kWh_e ^[15]
4. Internal cost of kiln fuel (presently used in boiler) £4/Tonne, calorific value 4.5 GJ/Tonne
5. Boiler (presently used in sawmill for heating) maintenance cost 0.1 p/kWh and boiler efficiency 50%
6. For ORC scheme efficiency of thermal oil boiler is 80% and the turbine is 18% ^[7]
7. Cost of woodchips and bark used in CHP £4/ Tonne, 0.19 p/kWh,
8. Calorific value of wood fuel at 50% MC is 7.4 GJ /Tonne ^[13]
9. For gasification/ gas turbine scheme, the overall thermal efficiency of conversion is 20% ^[8]

Using ORC technology:

PRESENT SYSTEM

A. ELECTRICITY COST:

1. Cost of electricity:

No of units of electricity consumed = $(3 \times 10^3 \times 8000) = 24,000 \times 10^3$ kWh

Total cost = $24,000 \times 10^3 \times 3.09 = 74160 \times 10^3$ p = £ 7,41,600

2. Climate change levy:

$24000 \times 10^3 \times 0.25 = 6000 \times 10^3$ p

Total Electricity Cost £ 8,01,600

B. HEATING COST:

1. Boiler fuel cost (£):

$\frac{\text{Boiler output (MJ) x Fuel tariff (£/kg)}}{\text{Boiler efficiency x Calorific value of fuel (MJ/kg)}}$

$\frac{(3 \times 8000 \times 60 \times 60) \times 4 \times 10^{-3}}{0.5 \times 4.5}$

£ 1,53,600

2. Boiler maintenance cost:

Present Boiler maintenance cost 0.1 p/kWh

$$=(3 \times 10^3 \times 8000) \times 0.1 \text{ p}$$
$$=24,000\text{£}$$

Total heating cost £1,77,600

TOTAL COST OF PRESENT SCHEME

$$\text{£}1,77,600 + \text{£} 8,01,600 = \text{£}9,79,200$$

CHP SCHEME

1. Fuel Cost

El energy output (kWh)xfuel cost (£/kWh)^[13]

Thermal efficiency

$$\frac{3 \times 10^3 \times 8000 \times 0.19 \times 10^{-2}}$$

$$0.8 \times 0.18$$

$$\text{£}3,16,666$$

2.Operation and Maintenance cost of ORC ^[13]

$$\text{£}90,000$$

TOTAL COST OF CHP SCHEME

$$\text{£}4,06,666$$

CAPITAL COST FOR THE ORC SYSTEM ^[13]

$$\text{£}15,00,000 \times 3 = \text{£}45,00,000$$

PAYBACK PERIOD

Savings in 1 yr running cost $9,79,200 - 4,06,666 = 5,72,534$

Simple payback is $45,00,000 / 5,72,534$

=7.85 yrs

Using gasification technology:

The same calculation is repeated now for the gasification technology ^[8] except that the thermal efficiency, capital cost and operation and maintenance cost will be different from the ORC technology. These calculations are given below:

CHP SCHEME

1. Fuel Cost

El energy output (kWh)xfuel cost (£/kWh)

Thermal efficiency

$3 \times 10^3 \times 8000 \times 0.19 \times 10^{-2}$

0.2

£2,28,000

2. Operation and Maintenance cost ^[8]

£2,00,000

TOTAL COST OF CHP SCHEME

£4,28,000

CAPITAL COST FOR THE GASIFICATION/GAS TURBINE SYSTEM ^[8]

£40,00,000

PAYBACK PERIOD

Savings in 1 yr running cost $9,79,200 - 4,28,000 = 5,51,200$

Simple payback is $40,00,000 / 5,51,200$

=7.25 yrs

The calculations using both the ORC technology and the wood gasification, gas cycle technology are given in Annex 1

4.1.2 Selling the Renewable Energy under the NFFO Obligation

The cost calculation for the second option that is selling the renewable energy under the NFFO obligation is presented in the spreadsheets ^[13] in the Annex2

If the grid connection to the site is sufficient to allow the electricity generated to be sold to the grid, it will almost certainly be more profitable to sell the renewable electricity generated under the Renewable Obligation, for 5.5 p/kWh, and 50% of the heat at 0.8p/kwh ^[13] than it will be to use it to replace whole-sale electricity on-site, at 3.09 p/kWh.

In this case also the payback period for both technologies is similar, that is around 3 years.

Chapter 5 Conclusions and Recommendations

The sawmill has two options of utilising the power and heat generated by the CHP scheme, using the wood by-products:

1. Using the heat and electrical energy generated to replace the existing system of energy consumption of the sawmill
2. Selling the renewable energy under the NFFO obligation

In this report a cost comparison has been done for the above cases using Organic Rankine Cycle technology and the Wood Gasification technology. The results show that the pay back period for replacing the existing system of energy consumption of the sawmill with a CHP using wood fuel applying either of these technology is nearly the same, which is around 7 years. The same is the result of selling the renewable energy under the NFFO obligation using any of the above technologies, however the pay back is much less in this case, it is only 3 years.

If the grid connection to the site is sufficient to allow the electricity generated to be sold to the grid, it will almost certainly be more profitable to sell the renewable electricity generated under the Renewable Obligation, than it will be to use it to replace whole-sale electricity on-site.

5.1 Summary of Results

The cost calculations show that the payback period for selling the renewable electricity generated under the Renewable Obligation is much less than replacing the existing system of electricity, and therefore is the most profitable option for the sawmill. Since Organic Rankine Cycle Technology is a more proven technology than gasification technology at this scale of application, it would be better to use the ORC technology to generate the heat and power from the wood by-products.

5.2 Direction for Future Work

The Governments are initiating programmes related to Climate Change, to reduce carbon emissions, to improve energy efficiency and exploit less carbon intensive energy sources. Bio energy is at the centre of these changes as the only renewable carbon fuel with the potential to address the full range of energy markets including heat, electricity and transport. The renewable energy strategies expect the bio energy sector to be pre-eminent in the global market for secure, indigenous and renewable energy supplies in the next century and to play a vital role in underpinning the overall transition to sustainable energy.

The Department of Trade and Industry of the UK has initiated work to develop long-term R&D strategies for the renewable energy technologies. In consultation with the industry, trade associations, EPSRC and academia, the European Commission and the international Energy Agency, these strategies are to be used to determine the priorities for future calls for R&D proposals that are to be issued by the programme. On biomass, the plan is to focus on advanced conversion processes, pyrolysis and gasification, work to improve the yield, diversity and economics of feedstock, and work on co-firing biomass with fossil fuels.

A new programme on embedded generation is to be included within the Renewable Energy Programme, addressing technology solutions that could facilitate an increase in generation capacity (renewable and other sources such as CHP) embedded within the distribution network, necessary if the Government is to achieve its target for 10% Electricity from renewable energy sources by 2010. These priorities will help industry develop technology options that will reduce the delivered cost of energy from biofuels.

References

1. www.britishbiogen.co.uk
2. Department of Trade and Industry, Digest of United Kingdom Energy Statistics 2001, Chapter 6, Combined Heat and Power.
3. Biomass Energy: Unit 5. Gasification and Pyrolysis © CREST 2001
4. Energy After Rio: Prospects and Challenges, United Nations Development Programme in collaboration with International Energy Initiative and Energy 21 Stockholm Environment Institute and in consultation with Secretariat of the United Nations Commission on Sustainable Development
5. Biomass Gasification for Energy Production, Henrik Lundberg, Michael Morris, Erik Rensfelt, TPS Termiska Processer AB, Studsvik, Sweden
6. Supplying Wood Fuel Version 1.2 – 19 August 1998, A guide for woodfuel suppliers developed by the British BioGen Fuel Supply Working Group.
7. Organic Rankine Cycle Turbo generators for Combined Heat and Power Production from Biomass. Dr. Ing. Bini Roberto, Dr. Ing. Manciana Enrico, Turboden Srl-Viale Stazione, 23-25122 Brescia –1
8. Cost and Performance Analysis of Three Integrated Biomass Gasification Combined Cycle Power Systems Kevin R. Craig and Margaret K. Mann, National Renewable Energy Laboratory
9. www.tps.se
10. www.poweralstom.com
11. www.arbre.co.uk

12. www.prmenergy.com
13. Turboden Ready Reconner from Econergy Ltd.
14. Energy Efficiency for Engineers and Technologists by TD Eastop and D R Croft
15. http://www.dti.gov.uk/energy/inform/energy_prices/2002
16. Co Generation: Combined Heat and Power, by J H Horlock