DESIGN OF A 2.5MW(e)
BIOMASS GASIFICATION POWER
GENERATION MODULE

ETSU B/T1/00569/REP

Contractor
Wellman Process Engineering Limited

Prepared by
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EXECUTIVE SUMMARY

In the increasingly industrialised world biomass has to be considered as a major sustainable energy resource for electricity production. Already large quantities of unused biomass material exists in the form of forestry waste and agricultural by-products and the cultivation of arable energy crops is usually possible. Efficient, reliable and cost effective technologies for the conversion of these biomass feed stocks to electrical power are currently under development.

At the scale of electrical production suited to biomass, conversion processes involving gasification have the potential of producing higher fuel to electrical power efficiencies over those employing direct combustion and steam cycle technology. Based on experience in the design and operation of Up-draught, Down-draught and Fluidised bed gasifiers Wellman firmly believes that Up-draught fixed bed gasification offers the most robust and commercially viable technology for continuous power generation in the 2.5MW(e) to 15.0MW(e) range. Based on over seventy years of commercial gasification and gas clean up experience Wellman Process Engineering set about the development of a gasification system to efficiently process wood chip to produce a clean fuel gas. This work was part funded by the Dti and reported through ETSU agreements B/TI/00398/00/00 and B/TI/00524/00/00. The conclusions from the development work was that a combination of thermal oxidative and catalytic cracking could be utilised to convert a raw gas generated by the up-draught gasification of wood to a clean gas acceptable for fuelling a gas engine generator set.

The purpose of this contract was to produce a detailed process and mechanical design of a gasification and gas clean up system for a 2.5MW(e) power generation module based on the generation of electrical power from a wood chip feed stock. The design is to enable the detailed economic evaluation of the process and to verify the technical performance data provided by the pilot plant programme. Detailed process and equipment design also assists in the speed at which the technology can be implemented into a demonstration project.
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INTRODUCTION

Wellman Process Engineering Limited.

Wellman Process Engineering Limited is one of five companies belonging to the Wellman Group, a private limited company of 500 employees with headquarters in Oldbury, West Midlands, UK. All the companies within the group have specialist design and manufacturing facilities supplying equipment to industrial codes and standards in a competitive international market.

Wellman Process Engineering has three product ranges one of which is gasification and the associated gas processing technologies. Gasifiers and gas processing equipment have been designed and manufactured by Wellman since the 1920’s with over 1,800 updraught single stage coke and anthracite gasifiers supplying fuel gas to UK industries in the 1940’s. Later the two stage gasifier was developed to gasify bituminous coal and commercial plants based on this technology have been supplied to America, South Africa and more recently China and Khzakhstan.

Updraught Fixed Bed Gasification.

In an updraught fixed bed gasifier the fuel is fed into the top of the gasifier and a mixture of air and steam blown into the base, it is this upward passage of the air and steam that gives the gasifier its name. Within the gasifier the fuel undergoes five distinct processes each merging gradually with the next. Initially is the Drying Zone where the water is removed from the fuel by contact with the hot upward flowing gases. Dry wood passes into the Pyrolysis Zone where further contact with gases at 600ºC slowly vaporises the volatile components of the fuel into the upward flowing gas. The pyrolysis zone produces a charcoal which in contact with carbon dioxide at 1100ºC reacts endothermically producing carbon monoxide and reducing the temperature of the upward flowing gas. The reaction rate reduces as the temperature falls and once below 600ºC the reaction becomes insignificant. This zone is known as the Reduction Zone. Carbon which is not consumed in the reduction zone gravitates into the Oxidation Zone where it reacts exothermically with the oxygen present in the air blast producing carbon dioxide and the heat needed in the upper zones of the gasifier. A pure air blast would generate very high temperatures in the oxidation zone causing ash fusion and operating difficulties. To control the temperature, steam is introduced into the air blast and this reacts endothermically with the carbon to produce hydrogen and carbon monoxide, both useful fuel gas components. Ash containing a small quantity of unreacted carbon leaves the oxidation zone and collects in the Ash Zone on the gasifier grate. The ash both protects the gasifier grate from the high oxidation zone temperatures and assists in the even distribution of the air blast. The raw fuel gas exits at the top of the gasifier.
Updraught gasification has the advantage of offering the most cost effective and established gasification technology in the 10MW(th) to 50MW(th) range. The disadvantage, is that the resultant gas contains condensable organics which require removing prior to its use as a fuel for an internal combustion engine.

**The Single Stage Gasifier**

The wood fuel moisture content is a critical factor in determining the most effective type of fixed bed gasifier. For wood with moisture contents up to 35wt.% (wet basis) a two stage gasifier is required, for moisture contents between 35wt.% and 40wt.% (wet basis) a single stage gasifier is most suitable. Although wood with moisture contents above 40wt.% can be gasified the resultant reduction in gas calorific value renders the process unattractive.

Wellman has selected single stage gasification as the optimum route for power generation for the following reasons:-

- Single stage gasifiers have a lower capital cost than a two stage unit with equivalent thermal output.

- Single stage gasifiers are not as tall as the equivalent two stage units, this helps to reduce the height profile of power generation schemes allowing sympathetic integration into the landscape, often a critical issue in project planning applications.

- A commercial power plant is most likely to receive wet or green wood fuel. To minimise the capital equipment cost and energy required in fuel processing only the minimum of wood drying is necessary.

- The gasification of high moisture content fuels results in low raw gas temperatures. This minimises the formation of high molecular weight organic compounds and their breakdown to carbon both of which can cause difficulties in downstream gas processing.

The raw fuel gas exiting at the top of the gasifier is a mixture of hydrogen, carbon monoxide, nitrogen, carbon dioxide, water vapour, low molecular weight hydrocarbon gases, organic vapours and aerosols containing complex organic compounds.
The typical composition of a raw gas produced from woodchip with a 37wt.% moisture content is:-

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume %</th>
</tr>
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<tbody>
<tr>
<td>Hydrogen</td>
<td>7.9</td>
</tr>
<tr>
<td>Methane</td>
<td>1.2</td>
</tr>
<tr>
<td>Water Vapour</td>
<td>38.8</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>18.3</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>29.4</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>4.4</td>
</tr>
<tr>
<td>Condensable Organic Compounds</td>
<td>57g/Nm³</td>
</tr>
<tr>
<td>Temperature</td>
<td>80ºC</td>
</tr>
</tbody>
</table>

**Raw Gas Processing**

In order to utilise the raw gas generated by the gasifier as a fuel for sustained operation of an internal combustion engine it is necessary to remove the condensable organic compounds and reduce the moisture content. Conventional gas processing separates these two undesirable components from the raw gas to leave a useful fuel gas. The disadvantage of this approach is that a significant proportion of the energy in the raw gas is lost as an undesirable and hazardous effluent difficult to dispose of.

The gas processing method recommended in this system design and based on pilot plant operation is to subject the raw gas from the gasifier to a combination of thermal oxidative and catalytic cracking. This process breaks down the high molecular weight aerosols and vapours into useful low molecular fuel gas components with the advantages of keeping the energy in the gas phase and minimising plant effluent.

**Modular Design**

The gasification and gas processing module has been designed to optimise the use of the commercially available 3.05m diameter Wellman single stage updraft gasifier.

In order to generate electrical power the following additional equipment will be required:-

- A wood storage and handling system capable of providing an uninterrupted supply of wood chip to the gasifier wood hoppers. Recommendations regarding the specification of this system is given in Section 2. The required specification for the wood chip fuel supplied to the gasifier is given in Section 4.
• Gas engine generator sets and gas supply pipework together with associated controls and cooling water system. Recommendations regarding the specification of the gas engine generator sets are discussed in Section 2 and a clean fuel gas composition is provided.

• A system to condense the steam produced in the gasification facility and return the condensate to the process. On a power generation scheme employing a single gasification module the only economic use for the steam is likely to be the provision of either process or district heating. On larger schemes however, the process generated steam supplemented with steam produced from waste heat from the gas engines could be used to generate additional electrical power in a steam driven turbine generator set. Steam conditions are given in Section 4.

• A water treatment system to treat scrubbing water prior to discharge from the facility.

The arrangement of the equipment within the gasification and gas clean up module has been designed to enable additional modules to be added in a linear fashion in order to increase the plant output in multiples of 2.5MW(e). The anticipated overall plant layout would enable a wood preparation and handling facility to be located to one side of the gasification and gas clean up building. It is envisaged that the gas engine generators will be situated either as self contained modules or in a separate building running parallel to the gasification and gas clean up modules again being capable of expansion in a linear fashion.
SECTION 2

PROCESS DESCRIPTION

Wood Handling and Supply

Raw wood chip will usually be delivered to the power generation facility in standard bulk tipping lorries. This wood has to be unloaded, screened, dried and stored to ensure a constant supply to the correct specification is available at the gasifier.

Various configurations for the wood handling system can be employed and the exact specification will depend upon the nature of the site and the client’s preferences concerning the raw fuel supply and delivery strategy.

Decisions over the quantity of fuel held on site will require consideration to the following factors:-

- Restrictions on movement of lorries to and from the facility. (Night and weekend deliveries may not be permitted.)
- Necessity of a strategic supply to allow for unexpected interruptions in delivery.
- Practicality of stock piling fuel at, or local to the facility.

Wellman recommend that as a minimum, the wood handling system is sized based on the following:-

- Raw wood storage; sufficient for 24 hours plant operation at full load.
- Dry wood storage; sufficient for 12 hours plant operation at full load.
- Strategic storage; sufficient for 3 days plant operation at full load.

Ideally the wood quality delivered to the facility would meet the specification required at the gasifier inlet as given in Section 4. However, in practice, the wood moisture content is likely to be higher than the maximum 40wt.% specified and there is the possibility of the fuel containing oversize material, excessive fine material and the occasional piece of tramp metal. It is important to remove oversize material and tramp metal as these can lead to problems in the downstream equipment, particularly the gasifier fuel feeders. Excessive fine material is less of a problem but the quantity should be limited to 10wt.% of the fuel in order to maintain reliable and stable operation of the gasifier. Fuel supply contracts should be negotiated which penalise the supplier of out of specification fuel.

The recommended maximum permitted quantity of oversize material in the fuel delivered to the site is 1wt.% and the maximum fines 12wt.%, this would result in at worst, handling 3wt.% of unusable fuel which should be returned to the fuel supplier for credit.
The moisture content of the fuel delivered to the facility should be between 35wt.% and 55wt.% with material outside of this wide and easily achieved tolerance not being accepted.

The fuel handling system suggested has been designed based on these criteria.

The type of wood dryer selected will depend on the quality of the heating media available. If high grade heat is available then a rotary type dryer is the most practical in terms of size and cost. Rotary dryers have been used for a wide variety of applications and various commercial designs are available. A facility of this nature is however more likely to contain low to medium grade heat and therefore a low temperature dryer would be required. Although this results in a physically large dryer, the overall plant efficiency is maximised and this is the option which we have specified for the facility. The low temperature dryer is likely to be either a floor ventilated unit, commonly used to dry grain, or a mesh belt dryer. Again, various commercial designs are available for both types.

A typical wood handling flow scheme is given in Appendix A, Drawing number Y5406 00 004

The Gasifier

Wood chip fuel of the correct size and moisture content delivered by the wood handling system is received in a small reception hopper mounted above the gasifier. The gasifier is always maintained in a full condition by the controlled addition of wood fuel via duplex lock hoppers feeding a variable speed screw conveyor. The lock hoppers allow fuel to be fed while maintaining a gas seal to atmosphere. Each gasifier is served by two fuel feeders which enables full output to be maintained in the event of a blockage occurring or routine maintenance being carried out on one of the units.

Gasification of the wood takes place in the main body of the gasifier which has a refractory lined upper section to reduce heat losses and a water jacketed lower section to prevent the build up of ash on the walls. A variable speed hydraulically operated grate discharges ash into a conical lower section from where a lock hopper enables its removal from the unit. For a single gasifier installation the ash would be discharged into skips for disposal, for larger installations a conveyor running beneath the units could be used to discharge the ash to a common collection point.

The water jacketed section of the gasifier forms part of a naturally circulated pressurised hot water circuit which has a steam drum mounted above the level of the water jacket. Pressure control of this circuit results in steam being flashed from the hot water and collecting in the drum. Sufficient steam is generated in this circuit to maintain the required saturation temperature of the gasifier air blast.

Steam shrouded ports in the top plate of the gasifier enable rods to be inserted into the gasifier without the escape of gas. This facility enables the condition of the
gasifier reaction zones to be monitored as well as providing a method of breaking up ash clinkers which can form if out of specification fuel is gasified.

The quantity of air supplied to the gasifier controls the gasification rate and consequently the quantity of gas generated. The air supply to the gasifier is provided by a centrifugal fan and is automatically controlled to maintain the operating pressure at the gasifier outlet.

A hydraulic power pack provides the hydraulic supply and controls necessary to rotate the gasifier grate.

**Gas Processing**

The gasifier is close coupled to the thermal and catalytic gas cracker by a specially designed gas burner which mixes the raw gas with a controlled quantity of preheated air. The air gas mixture entering the hot thermal cracker partially combusts. The temperature in the thermal cracker is carefully controlled by the introduction of secondary air which intimately mixes with the hot gases and results in further partial oxidation of the raw producer gas. This controlled oxidation and rise in temperature results in the high molecular weight organic aerosols breaking down into low molecular weight fuel gases and stable aromatic compounds. The hot gas mixture formed in the thermal section of the cracker is swept down through a catalyst bed which converts the aromatic compounds to low molecular weight fuel gases and the resultant hot gas mixture exits the base of the cracker. Burners designed for operation on either gas or oil are mounted on the cracker to heat the unit up to operating temperature prior to the introduction of the raw producer gas.

The gas exits the cracker at a temperature of approximately 650ºC, part is passed through the air preheater which supplies the cracker with both primary and secondary air. The gas streams are combined again in the inlet box of a waste heat boiler designed to recover heat from the process. The boiler can be designed to produce hot water or steam up to a pressure of 10bar as required for best optimisation and integration of waste heat recovery with waste heat utilisation.

The pressure of the gas leaving the waste heat boiler is increased using a centrifugal hot gas fan and then further cooled to between 60ºC and 75ºC and scrubbed by direct contact with water. The saturated gas is passed through a tubular cooler where indirect contact with cooling water reduces the dew point to around 30ºC. The condensate is collected and returned to the circulating water circuit employed by the direct contact cooler. Additional cooling of the circulating scrubbing water is provided by indirect contact with cooling water in a plate type heat exchanger. A mist eliminator after the tubular cooler removes mists and fogs from the gas prior to increasing the pressure in a second centrifugal type fan which delivers the clean gas to the engines. The water originally present with the wood fuel is condensed during the final gas cooling and hence a continual bleed of water is required to maintain the system at equilibrium. This water contains small quantities of dissolved organics and may require treatment prior to discharge into
the local foul water system. A typical composition for this water discharge is given in section 4.

A process flow diagram for the gasifier and gas processing system is given in Appendix A, Drawing number Y5406 00 05

The typical composition of the clean gas leaving the gas processing system is :-

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>17.3</td>
</tr>
<tr>
<td>Methane</td>
<td>2.4</td>
</tr>
<tr>
<td>Water Vapour</td>
<td>4.1</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>13.4</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>48.4</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>14.4</td>
</tr>
<tr>
<td>Condensable Organic Compounds</td>
<td>0.1 to 0.3g/Nm³</td>
</tr>
<tr>
<td>Temperature</td>
<td>35ºC</td>
</tr>
</tbody>
</table>

**Power Generation and Heat Recovery**

The clean gas can be used to fuel gas engine driven generator sets for the production of electricity. The majority of the waste heat generated by the engines can also be recovered and used to supply any low grade heat requirement associated with the project.

In order to provide a constant gas pressure to the engines and also to deal with fluctuating gas demand during start up and shut down of the engines a facility has to be available to either flare excess gas or utilise it in a waste heat boiler. For systems utilising the process waste heat, the boiler option is likely to be the preferable option and as with the gas processing waste heat boiler, it can be designed to produce hot water or steam up to a pressure of 10bar as required for best optimisation and integration of waste heat recovery with waste heat utilisation.

There is at present only a limited market for gas engines operating on producer gas and consequently the majority of engine manufacturers have been unwilling to invest in the optimisation of engines specifically for operation on this fuel. In general, engine manufacturers interested in the utilisation of producer gas have adapted natural gas fuelled engines for the low gas calorific value but have been unwilling to address the question of the condensible organics present. Suggested values for the acceptable level of condensible organics and particulates are 100mg/Nm³ and 50mg/Nm³ respectively, however these are arbitrary values and there is debate over the definition and method of measurement of “condensible organics”.

The companies currently prepared to supply engines for operation on producer gas include Caterpillar, Jenbacher, Wartsila and Waukesha. More recently Dale have also expressed interest in the provision of gas engines for producer gas. Ford Iveco have also supplied dual fuel diesel engines for testing to several companies in the UK.

Of these companies, Jenbacher AG of Austria are able to provide comprehensive data for gas engine operation and can offer packaged containerised 320 GS S.L engines for this duty complete with instrumentation, heat recovery and warranty. The 320 engine generates up to 0.59MW(e) operating on a producer gas fuel. Other engine ranges are also available, the largest producing 2.5MW(e) on a single unit. At 2.36MW(e) power generation four containerised 320 engines are both lower in installed cost and offer more flexibility in operation than the single larger unit.

Waste heat generated by the gas engine can be recovered from the first stage intercooler, oil cooler, water jacket and engine exhaust. Normally, heat recovered from the exhaust is limited to a final exhaust temperature of 120ºC. For maximum process energy efficiency however, it is possible to recover additional heat by exhaust gas condensation but the added cost of the heat exchanger coupled with the cost of treating the condensate generated rarely makes it economic to do so. Non-recoverable heat from the engine are radiation losses, second stage intercooling and final exhaust losses.

Using a combination of gas engines and the gas fired boiler the power generation facility can be operated in various ways to maximise the overall efficiency while meeting the demands of electrical and thermal requirements. The optimum will depend on the specific project requirement but as example, the following four scenarios are summarised in Table 1.

Scenario 1  Gasification module operating at 100% full load.  
95.0% of product gas to 5 engines operating 97.5% of full load.  
5.0% of product gas to waste heat boiler.

Scenario 2  Gasification module operating at 100% full load.  
77.8% of product gas to 4 engines operating at full load.  
17.2% of product gas to 1 engine operating at 87.1% of full load.  
5.0% of product gas to waste heat boiler.

Scenario 3  Gasification module operating at 100% full load.  
77.8% of product gas to 4 engines operating at full load.  
22.2% of product gas to waste heat boiler.

Scenario 4  Gasification module operating at 81.8% full load.  
95.0% of product gas to 4 engines operating at full load.  
5.0% of product gas to waste heat boiler.
Table 1  Comparison of possible electrical and thermal generation scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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</thead>
<tbody>
<tr>
<td>Engine recoverable heat (MWth)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exhaust gas to 221°C *</td>
<td>1.25</td>
<td>1.26</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Exhaust gas 221°C to 120°C</td>
<td>0.48</td>
<td>0.49</td>
<td>0.38</td>
<td>0.38</td>
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<tr>
<td>Oil cooler</td>
<td>0.44</td>
<td>0.44</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Jacket water cooler</td>
<td>1.78</td>
<td>1.78</td>
<td>1.44</td>
<td>1.44</td>
</tr>
<tr>
<td>1st stage intercooler</td>
<td>0.11</td>
<td>0.11</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Process gas WHB boiler (MWth)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process gas to 221°C *</td>
<td>1.53</td>
<td>1.53</td>
<td>1.53</td>
<td>1.25</td>
</tr>
<tr>
<td>Process gas 221°C to 120°C</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.22</td>
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<tr>
<td>Excess gas WHB boiler (MWth)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exhaust gas to 221°C *</td>
<td>0.32</td>
<td>0.32</td>
<td>1.43</td>
<td>0.26</td>
</tr>
<tr>
<td>Exhaust gas 221°C to 120°C</td>
<td>0.03</td>
<td>0.03</td>
<td>0.12</td>
<td>0.02</td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Recoverable Heat (MWth)</td>
<td>6.21</td>
<td>6.23</td>
<td>6.61</td>
<td>5.01</td>
</tr>
<tr>
<td>Electricity (MWe)</td>
<td>2.88</td>
<td>2.87</td>
<td>2.36</td>
<td>2.36</td>
</tr>
</tbody>
</table>

* steam produced at 10 bar, 184°C
SECTION 3

EQUIPMENT DESCRIPTION

Wood Handling and Supply

Included in this section is the equipment which receives raw wood chip from standard bulk tipping lorries and ensures that sufficient screened dry wood is made available to the wood feeding system.

Major items of equipment are :-

<table>
<thead>
<tr>
<th>Equipment No.</th>
<th>Equipment Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>T101</td>
<td>Wood reception hopper</td>
<td>To provide a suitable area for accepting wood chip from standard 20 tonne lorries.</td>
</tr>
<tr>
<td>S101</td>
<td>Magnetic separator</td>
<td></td>
</tr>
<tr>
<td>C101</td>
<td>Raw wood conveyor</td>
<td></td>
</tr>
<tr>
<td>C102</td>
<td>Wood screening feed conveyor</td>
<td></td>
</tr>
<tr>
<td>S102</td>
<td>Wood screening unit</td>
<td></td>
</tr>
<tr>
<td>T102, T103</td>
<td>Fines bin, Oversize bin</td>
<td></td>
</tr>
<tr>
<td>C103</td>
<td>Screened wood conveyor</td>
<td></td>
</tr>
<tr>
<td>T104, T105</td>
<td>Raw and Dry wood silos</td>
<td></td>
</tr>
<tr>
<td>C104, C107</td>
<td>Wood discharge units</td>
<td></td>
</tr>
<tr>
<td>C105</td>
<td>Dryer feed conveyor</td>
<td></td>
</tr>
<tr>
<td>D101</td>
<td>Wood chip dryer</td>
<td></td>
</tr>
<tr>
<td>F101</td>
<td>Wood dryer air fan</td>
<td></td>
</tr>
<tr>
<td>H101</td>
<td>Wood dryer air heater</td>
<td></td>
</tr>
<tr>
<td>C106</td>
<td>Dried wood conveyor</td>
<td></td>
</tr>
<tr>
<td>C108, C109, C110</td>
<td>Fuel feed conveyors</td>
<td></td>
</tr>
</tbody>
</table>

Wood Reception Hopper

- **Equipment No.**: T101
- **Function**: To provide a suitable area for accepting wood chip from standard 20 tonne lorries.
- **Description**: An unloading bay for standard 20tonne bulk tipping vehicles. Wood chip will be tipped into a bunker which is suitably sized to store the complete contents of a lorry. A screw or drag link type conveyor will draw wood chip out from the base of the bunker for downstream processing.

Raw Wood Conveyor

- **Equipment No.**: C101
- **Function**: To convey wood chip at a maximum rate of 170m³/h from the wood reception hopper to the wood screening feed conveyor.
Description A belt conveyor with integrated Magnetic separator S101.

Magnetic Separator

Equipment No. S101

Function To remove pieces of ferrous material accidentally delivered with the raw wood chip To convey wood chip from the wood reception hopper to the wood screening

Description A commercially available magnetic separator to separate ferrous materials which may occasionally enter with raw wood chips. It is envisaged that an over-band magnet will be located above a belt conveyor C101. feed conveyor.

Wood Screening Feed Conveyor

Equipment No. C102

Function To elevate raw wood chip at a maximum rate of 175m³/h from the raw wood conveyor to the wood screening unit.

Description A drag link or bucket type conveyor.

Wood Screening Unit

Equipment No. S102

Function To receive raw wood chip at a maximum rate of 125m³/h and recover suitably sized chips for use in the gasifier.

Description A commercially available wood chip classifier with upper and lower screen to separate raw wood chip into 3 size ranges. Oversize pieces of wood greater than 30mm in length must be removed from the feed to the gasifier to reduce the chances of bridging in the fuel feed system. Fine material less than 6mm cubed should also be removed from the wood chip fed to the gasifier.

Fines Bin

Equipment No. T102

Function To provide 36 hours temporary storage for fine material produced during the wood screening operation

Description A 15m³ storage pen located below the wood screening unit S102 in which fine material collects. The pen will be
mounted on a concrete base open at one side for access by front end loader.

Oversize Bin

Equipment No.  T103

Function  To provide 72 hours temporary storage for oversize material produced during the wood screening operation

Description  A 15m³ storage pen located below the wood screening unit S102 in which oversize material collects. The pen will be mounted on a concrete base open at one side for access by front end loader.

Screened Wood Conveyor

Equipment No.  C103

Function  To deliver raw screened wood at a maximum rate of 175m³/h to either:
(i) The Raw wood silo T104 which stores wood for drying.
(ii) The Dry wood silo T105 which stores fuel for the gasifier.

Description  A drag link type conveyor feeding from the Wood screening unit S102 and discharging into the Raw wood silo T104 while the dryer is operating or discharging directly into the Dry wood silo T105 in the event of a dryer system failure.

Dried Wood Conveyor

Equipment No.  C106

Function  To convey dried wood at a maximum rate of 18m³/h from the dryer to the Dry wood silo T105

Description  A drag link conveyor which feeds from the outlet of the dryer and discharges into the top of the dry wood silo T105.

Raw Wood Silo

Equipment No.  T104
Function
To provide a constant supply of wood chip to the wood dryer by providing buffer storage of wood chips received from the wood screening unit.

Description
A vertically mounted cylindrical carbon steel vessel of 420m³ capacity. The upper section designed to accept wood chip from the Screened wood conveyor C103. The raw wood discharge unit is fitted into the base of the silo.

Raw Wood Discharge Unit

Equipment No. C104

Function
To discharge wood chip from the Raw wood silo at a maximum rate of 18.2m³/h

Description
A rotary discharge unit for the controlled discharge of wood chip from the base of a 7m diameter flat bottomed silo.

Dryer Feed Conveyor

Equipment No. C105

Function
To continuously feed raw wood chip at a maximum rate of 17.5m³/h to the dryer.

Description
A drag link conveyor to convey wood chip from the base of the Raw wood silo T104 to the Wood chip dryer D101.

Dry Wood Silo

Equipment No. T105

Function
To ensure a constant supply of wood chip to the gasifier by providing 12 hours of buffer storage of dry wood chips.

Description
A vertically mounted cylindrical carbon steel vessel of 210m³ capacity. The upper section designed to accept wood chips from both the Dried wood conveyor C106 and the screened wood conveyor C103. The Dry wood discharge unit C107 is fitted into the base of the silo.

Dry Wood Discharge Unit

Equipment No. C107
Function To discharge chip from the Dry wood silo at a maximum rate of 18.2 m³/h

Description A rotary discharge unit for the controlled discharge of wood chip from the base of a 5m diameter flat bottomed silo.

Wood Dryer

Equipment No. D101

Function To utilise low grade process heat to dry up to 6,300kg/h of screened wood chip with a moisture content of 55wt.% (wet basis) to 35wt.% (wet basis). The dryer must also be capable of drying woodchip with a lower moisture content to a final product with 35wt.% moisture (wet basis)

Description A floor ventilated or mesh belt dryer. The type of dryer will depend on site specific details such as available space, temperature of heat source and access to front end loader.

Fuel Feed Conveyor No.1

Equipment No. C108

Function To continuously feed dry wood chip at a maximum rate of 15.2m³/h from the Dry wood silo discharge unit C107 to the Wood feeding transfer conveyor C110 mounted above the gasifier.

Description A drag link conveyor.

Fuel Feed Conveyor No.2

Equipment No. C109

Function To feed wood chip at a maximum rate of 15.2m³/h from either the Raw wood silo T104, if the raw wood is suitable for feeding to the gasifier, or from the Dry wood silo T105 if for any reason Fuel feed conveyor No.1 fails. In either case wood is delivered to the Wood feeding transfer conveyor C110.

Description A drag link conveyor with two inlets and one outlet port.

Wood Feed Transfer Conveyor

Equipment No. C110
Function  To enable the supply of wood chip to be maintained to both wood hoppers T201 and T202 in the event that either of the Fuel feeding conveyors C108 or C109 fail.

Description  A screw conveyor with duplex inlets and outlets fitted with a reversible drive so that wood chip can be transferred in either direction and hence supply either gasifier wood hopper.

Gasifier Wood Feed System

Included in this section is the equipment which receives wood chip from the wood hopper feed conveyor and provides a controlled delivery of wood chip to the fuel feeder discharge isolation valves on the gasifier.

Major items of equipment are :-

<table>
<thead>
<tr>
<th>Wood hoppers</th>
<th>T201, T202</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hopper discharge units</td>
<td>C201, C202</td>
</tr>
<tr>
<td>Wood feed lock hoppers</td>
<td>T203, T204, T205, T206</td>
</tr>
<tr>
<td>Lock hopper discharge units</td>
<td>C203, C204, C205, C206</td>
</tr>
<tr>
<td>Wood feed conveyors</td>
<td>C207, C208</td>
</tr>
</tbody>
</table>

Wood Hopper

Equipment No.  T201, T202

Function  To ensure a constant supply of wood chip to the gasifier wood feeders by providing buffer storage for wood chips received from the wood handling system. The level of wood chip in the hopper is controlled by a pair of level switches. A switch near mid height activates the wood feed conveyor while a switch mounted in the hopper top plate stops the wood conveyor. A level switch mounted near the base of the hopper warns of a low level condition.

Description  A vertically mounted cylindrical carbon steel vessel with tapering sections at both inlet and outlet and having an active volume of 14.5m³. The upper tapered section is closed by a top plate containing the connection to the Wood feeding transfer conveyor. The lower section has an open outlet which connects directly to the hopper discharge unit.

Hopper Discharge Unit

Equipment No.  C201, C202
Function  To intermittently discharge batches of wood chip at a maximum rate of 42m³/h from the base of a storage silo into an empty lock hopper. The lock hopper is maintained at a slightly positive pressure of 0.5kPa gauge. (Bottom cone of storage hopper has an angle to the vertical of 18°)

Description  Pneumatically operated variable throughput silo discharge unit.

Wood Feed Lock Hopper

Equipment No.  T203, T204, T205, T206

Function  To provide a lock hopper for feeding batches of wood chip from the wood hopper to the wood feed conveyor inlet chamber. A level switch mounted in the top of the hopper detects a full condition and is used to stop the flow of wood to the wood hopper. A low pressure air supply maintains the pressure in the hopper at 0.5kPa above atmospheric to prevent the ingress of gas from the gasifier to the lock hopper.

Description  A vertically mounted cylindrical carbon steel vessel with tapering sections at both inlet and outlet having an active volume of 0.35m³. The upper tapered section connects to the inlet feed valve and lower section has an open outlet which connects directly to the hopper discharge unit.

Lock Hopper Discharge Unit

Equipment No.  C203, C204, C205, C206

Function  To intermittently discharge wood chip from the base of a lock hopper into an empty screw conveyor feed hopper. The lock hopper is completely emptied during the discharge cycle. Both hoppers are at equal pressure.

Description  Vibratory bin discharge unit capable of a maximum discharge rate of 42m³/h.

Wood Feed Conveyor

Equipment No.  C207, C208

Function  To feed wood chip at a variable and continuous rate from the conveyor feed hoppers to the gasifier. Development of a plug of wood in the conveyor tube reduces the flow of
air into, and gas out of, the gasifier.

Description
A variable speed screw conveyor to continuously feed wood chip to the gasifier up to a maximum rate of 15 m³/h. The screw conveyor is flood fed with wood chip from two small feed hoppers which are integral to the casing of the conveyor and through which the screw passes. At least one of these hoppers always contains wood chip. The final section of screw is provided with half pitch flights to encourage the formation of a plug of wood chip. The design of the system allows for dismantling and maintenance.

The Gasifier

Included in this section is the gasifier and its associated ancillary equipment. The gasifier comprises equipment from the receipt of wood chip from the fuel feeder discharge isolation valves to the point at which the raw gas exits the gas off-take. The ancillary equipment includes the steam drum, air blast supply, hydraulic power pack and ash discharge.

Items of equipment are :-

- Gasifier
- Gasifier steam drum
- Air fan
- Ash lock hopper
- Ash conveyor
- Hydraulic power pack

Gasifier No. R201

Function
The efficient and controlled production of a raw gas stream by the updraught gasification of wood chip utilising an air / steam mixture.

Description
3.05m Single Stage Updraught Wellman Gasifier

A vertically mounted cylindrical vessel with a rotary grate mounted at its base. The upper section comprises a refractory lined carbon steel shell and the lower section an annular boiler.

The upper section of the gasifier comprises a flanged cylindrical section and a flanged top plate. The lower flange of the cylindrical section connects with the gasifier
reaction section. The section is fabricated from mild steel and incorporates the fuel feeder tubes, poke holes, raw gas off-take and an access manhole. The inner surface is lined with a facing layer of abrasion resistant refractory backed up by a lightweight insulation. The fuel feeder tubes extend into the chamber leaving a disengagement space for the gas. Around the top plate are four poke holes which enable the insertion of poke rods to determine the bed condition and position.

The reaction section of the gasifier consists of a mild steel fabricated annular boiler which contains the reaction zone. Hot water circulation pipes connect the water jacket to a steam drum where steam is flashed off. The water jacket and steam drum operate to produce steam at a pressure of 172 kPa (g) and are constructed to pressure vessel codes.

The grate assembly attaches to the bottom of the water jacket. The grate assembly acts to support the fuel being gasified while distributing the air and steam evenly into the bed. The grate also allows the ash to be removed from the base of the reaction zone in a controlled manner.

The grate consists of a number of horizontal, circular steel plates of reducing diameter mounted one above the other with a space between each. Replaceable wear resistant casting fitted to the periphery of the grate plates protect them from the abrasive nature of the ash.

The grate rotates on a large diameter slewing ring, the plates being offset to the axis of rotation. Movement of the grate thus produces a crushing action on the ash and any clinker, forcing it inwards through the gaps between the plates and into the conical ash hopper mounted below. The slewing ring is protected from falling ash on its inner face by a mild steel cover. A scraper blade fitted to the underside of the grate base plate pushes any ash that gets into the area away from the bearing and into a small well which can be periodically emptied.

The air/steam mixture enters the side of the ash bin and then passes up through the grate and out through the gaps between the plates.

A pair of hydraulic cylinders rotate the grate assembly mounted on the slewing ring.

The bottom plate of the grate has teeth profile cut into its periphery and a vertical pin attached to each cylinder rod engages with the teeth pulling the grate around when the cylinder rods are retracted. The cylinders are mounted on vertical pivots and when the cylinder rods extend, the pins push out of engagement. Springs maintain a side load on
the cylinders ensuring the pins re-engage correctly with the rack.

The hydraulic power pack contains an electrically driven pump, an oil reservoir, relief valves and a direction solenoid valve. With the direction solenoid valve de-energised, the relief valve lifts and the oil flows back to the tank. With it energised the pistons in the hydraulic cylinders retract and rotate the grate.

The speed of rotation of the grate is controlled by the frequency of operation of the hydraulic cylinders. An adjustable timer is set which initiates a complete extend/retract cycle of the cylinder rods at the required time interval.

**Gasifier Steam Drum**

*Equipment No.* T207

*Function*  
To feed wood chip at a variable and continuous rate from the conveyor feed hoppers to the gasifier. Development of a plug of wood in the conveyor tube reduces the flow of air into, and gas out of, the gasifier.

*Description*  
A horizontally mounted cylindrical carbon steel pressure vessel of 2.6m³ capacity with internal baffle plate.

**Air Fan**

*Equipment No.* F201

*Function*  
To supply air to the gasifier and cracker.

*Description*  
Electric motor driven, single stage, centrifugal air fan delivering 5,000Nm³/h at 5kPa(g) fitted with inlet guard and silencer.

**Ash Lock Hopper**

*Equipment No.* T208

*Function*  
To provide a lock hopper for collecting ash from the base of the gasifier and discharging it to the ash conveyor.

*Description*  
A vertically mounted cylindrical carbon steel vessel with a flat top and tapering outlet having an active volume of 0.28m³. The top plate has a flanged inlet connecting
directly to the inlet feed valve. The tapered outlet section connects directly to the discharge valve.

Ash Conveyor

**Equipment No.** C209

**Function** To receive and collect ash discharged from the gasifier lock hopper for transport to the ash storage bunker.

**Description** A self tipping skip for movement by fork lift truck supplied with a 4-way fork entry base frame and an automatic self locking return mechanism. The unit has a safety catch on the tip mechanism and a safety chain to prevent movement on the forks.

Grate Drive Hydraulic Power Pack

**Equipment No.** Fully piped and assembled unit incorporating:-
- T210 Hydraulic fluid tank
- P205 Hydraulic fluid pump
- S204 Hydraulic pump suction strainer
- S205 Hydraulic pump discharge filter

**Function** To provide the motive force to intermittently extend and retract the pair of grate drive hydraulic cylinders.

**Description** Hydraulic power pack comprising a hydraulic fluid tank, hydraulic fluid pump, direction solenoid valve, fluid strainers and filters and all necessary interconnecting pipework and instrumentation. The unit is rated to deliver 20l/min at 122kgf/cm².

The Cracker and Hot Gas Processing

Included in this section are the cracker, waste heat boiler and the associated ancillary equipment.

**Items of equipment are :-**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracker</td>
<td>R202</td>
</tr>
<tr>
<td>Spent Catalyst Conveyor</td>
<td>C210</td>
</tr>
<tr>
<td>Air Preheater</td>
<td>HE201</td>
</tr>
<tr>
<td>Process Gas Waste Heat Boiler</td>
<td>HE202</td>
</tr>
</tbody>
</table>

Cracker
Equipment No. R202

Function To break down the high molecular weight components of the raw gas to clean low molecular weight gases suitable for fuelling a gas engine.

Description A vertically mounted cylindrical vessel with carbon steel shell and refractory lining. Raw wood gas, directly from the gasifier, enters the top of the vessel through a specially designed burner where a controlled quantity of primary air is introduced resulting in the partial combustion of the gas and a rise in temperature. Four start up burners are mounted tangentially around the cracker just below the main gas burner and these are used both for heating up the cracker to operating temperature at start up and also to introduce secondary combustion air during normal operation. The quantity of secondary combustion air admitted is controlled to increase the cracker temperature to that necessary for thermal cracking of the long chain organic components. The dimensions of the vessel provide sufficient residence time for thermal cracking to occur and the resulting gas mixture which contains stable organics passes into the catalytic section of the cracker. The catalyst fills the lower part of the vessel supported by an alloy insert. The hot clean gas passes into the annulus between the insert and refractory wall and out of the bottom section of the cracker. The secondary air supplied through the start up burners prevents the burners from overheating during normal operation of the cracker. A pilot burner near the main gas burner ensures ignition of the raw gas at start up.

Air Preheater

Equipment No. HE201

Function To utilise part of the heat contained in the hot gas exiting the cracker to preheat the combustion air used by the cracker from ambient temperature to 300°C.

Description A stainless steel tube and shell heat exchanger.

Spent Catalyst Conveyor

Equipment No. C210

Function To periodically discharge spent catalyst from the bottom outlet of the cracker.
Description  A heavy duty inclined fixed speed screw conveyor mounted under the Cracker and designed to discharge spent catalyst at the rate of 5.5m³/h. In operation the screw conveyor is flood fed with catalyst and has close pitch flights under the inlet so that the conveyor operates in a 30% loaded condition. The design of the conveyor allow for dismantling and maintenance.

Process Gas Waste Heat Boiler

Equipment No.  HE202

Function  To utilise the heat contained in a hot process gas to generate saturated dry steam.

Description  Two pass waste heat boiler incorporating separator in the steam offtake to remove liquid water carry over.

Gas Scrubbing, Final Cooling and Pressure Boosting

Included in this section is the process equipment required to scrub, cool and boost the pressure of the gas for delivery to the gas engine generators.

Process gas from the waste heat boiler undergoes quench cooling and scrubbing which reduces the gas temperature to around 65°C. Further water scrubbing in a venturi scrubber ensures the removal of any particulates entrained from the gasifier or catalytic cracker. The scrubbing and cooling water is supplied from a circulating closed circuit system from which a continual bleed limits the build up of contaminants removed from the process gas. Saturated gas exiting the Venturi scrubber separator is cooled to 30°C by indirect contact with cooling water in a tube and shell heat exchanger. Mists and aerosols present in the cooled gas are coalesced in a demister element and removed prior to boosting the gas in a centrifugal gas booster for delivery to the gas engine generator sets. It is intended that the cooling water for the gas cooler is supplied from a cooling tower system.

Items of equipment are :-

- Hot gas booster F202
- Quench cooler HE205
- Venturi scrubber S201
- Venturi scrubber separator S202
- Scrubbing water tank T209
- Scrubbing water pumps P201 / P202
- Scrubbing water cooler HE203
- Gas cooler HE204
- Mist eliminator S203
- Clean gas booster F205
- Cooling water pump P203, P204
Cooling tower HE206

Hot Gas Booster

Equipment No. F202
Function To boost the pressure of the hot clean gas exiting the waste heat boiler in order to pass it through the gas scrubbing and cooling equipment.
Description An electric motor driven, single stage, centrifugal hot gas fan with gas tight casing and shaft seal to boost 18,000 m³/h of gas at 225°C through 7.5 kPa.

Quench Cooler

Equipment No. HE205
Function To quench cool and remove particulates from the hot gas by contact with a water spray.
Description A vertically mounted cylindrical vessel with conical base section and a tapering top section. The hot process gas enters at the side near the base of the vessel and flows upwards where it is cooled and scrubbed by a counter current water spay before exiting at the tapered top gas outlet. The water spray is provided by three sprays mounted in the side of the vessel. The excess water leaves from the bottom of the vessel.

Venturi Scrubber

Equipment No. S201
Function To cool the gas and remove particulates by contact with water.
Description A cylindrical upper section where the gas is sprayed with water prior to the water / gas mixture passing through a flooded venturi throat section. The water / gas mixture exiting the venturi throat passes into the close coupled Venturi Scrubber Separator.

Venturi Scrubber Separator

Equipment No. S202
Function To separate entrained liquid from the cooled gas exiting the venturi scrubber.
Description A vertically mounted cylindrical vessel with vane type demister, lower tangential gas inlet duct, central top gas outlet and conical base section with liquid outlet.

Scrubbing Water Tank

Equipment No. T207

Function i) To provide a reservoir of scrubbing water circulating around the gas processing system.  
ii) The tank incorporates a seal section with process dip pipes which form a liquid seal preventing the escape of gas to atmosphere.  
iii) To provide a continuous supply of scrubbing water to the scrubbing water pumps.

Description A closed top, rectangular steel tank of 4m³ capacity with internal baffle. Liquid inlets from the gas processing equipment are via removable dip pipes which prevent the escape of gas into the tank. The tank is fitted with inspection and clean out ports.

Scrubbing Water Pump

Equipment No. P201, P202

Function To pump water from the Scrubbing Water Tank (T209) to the Quench Cooler (HE205) and the Venturi Scrubber (S201) via the Scrubbing Water Cooler (HE203). Two scrubbing water pumps are provided, one operating and one an installed standby.

Description A centrifugal type pump delivering 38m³/h of water at a pressure of 4.3Bar(g)

Scrubbing Water Cooler

Equipment No. HE203

Function To cool recycled scrubbing water by indirect contact with cooling water.

Description A plate type heat exchanger.

Gas Cooler

Equipment No. HE204

Function To cool the saturated gas leaving the venturi scrubber from 75°C to 30°C and partially condense the water vapour
present by indirect contact with cooling water.

**Mist Eliminator**

**Equipment No.** S203

**Function** To remove water, entrained as droplets and aerosols from the cooled process gas prior to boosting.

**Description** A vertically mounted cylindrical vessel fitted with removable wire mesh type demister element. The gas enters at the side of the vessel near its base and travels upwards through the demister leaving at the conical exit. Water separated by the demister element coalesces and flows to the base of the unit where it leaves from the lower conical section of the vessel.

**Clean Gas Booster**

**Equipment No.** F203

**Function** To boost the pressure of the cold clean gas exiting the mist eliminator for delivery to the gas engines.

**Description** An electric motor driven, single stage, centrifugal gas fan with gas tight casing and shaft seal to boost 8,000m³/h of gas at 30°C through 10kPa.

**Cooling Water Pump**

**Equipment No.** P203, P204

**Function** To pump cooling water from the Cooling Tower (HE206) to the Gas Cooler (HE204) and the Scrubbing Water Cooler (HE203). Two cooling water pumps are provided, one operating and one an installed standby.

**Description** A centrifugal type pump delivering 120m³/h of cooling water at a pressure of 3Bar(g).

**Cooling Water Tower**

**Equipment No.** HE206

**Function** To cool 120m³/h of cooling water from 35°C to 20°C by evaporative cooling.
Description  Evaporative cooling tower fitted with automatic water
dosing system to maintain biocide and corrosion inhibitors
at the required concentration for safe operation.

Gas Engines

The clean gas is delivered to the gas engine generator modules through a common
gas main. Each engine generator is a self contained package unit which can be
operated independently. The exact number and mode of operation of the engines
will depend on the output requirements for the facility matched with the
capabilities of the selected engines.

The composition and calorific value of the cold clean gas will vary slightly depending on the composition of the wood fuel, ambient temperature and efficiency at which the gasification and gas processing plant is operated. The gas engines should thus be capable of operating over the following range of gas compositions:-

<table>
<thead>
<tr>
<th>COMPONENT (Vol.%)</th>
<th>NORMAL</th>
<th>BEST CASE</th>
<th>WORST CASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>17.3</td>
<td>21.5</td>
<td>11.3</td>
</tr>
<tr>
<td>Methane</td>
<td>2.4</td>
<td>2.5</td>
<td>1.9</td>
</tr>
<tr>
<td>Water Vapour</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>13.4</td>
<td>13.8</td>
<td>15.2</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>48.4</td>
<td>46.1</td>
<td>52.4</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>14.4</td>
<td>12.0</td>
<td>15.1</td>
</tr>
</tbody>
</table>

Gas Calorific Value

- MJ/Nm³ (Gross): 4.86, 5.50, 4.13
- MJ/Nm³ (Net): 4.35, 4.88, 3.77

Condensable organics (Measured as the non aqueous condensate collected
when the gas is cooled to -40°C)

- Normal: 0.1g/Nm³
- Maximum: 0.3g/Nm

Pressure 8kPa(g) at inlet to engine gas supply train.

Temperature 35°C

Dew Point 30°C

The gas engine generator modules will be supplied fully assembled and tested and
comprise: -
• Spark ignited, turbocharged and aftercooled, vee configuration gas engine operating at 1500rpm.

• Direct coupled generator delivering 415V, 3 phase, 4 wire, 50Hz supply together with synchronisation and safety controls suitable for connection to grid.

• Baseframe mounting for engine and generator.

• Fuel supply train with inlet filter, duplex shut off solenoid valves, self governing pressure regulating valves, gas/air mixing valve, exhaust driven gas/air turbocharger, two stage gas/air aftercooler and gas flow control valve.

• Air supply fitted with duplex inlet filters.

• Fully automated electronic fuel management system to optimise engine performance.

• Lubricating oil system with engine driven pump, oil cooler and duplex filters.

• Jacket cooling water system with water circulation pump, waste heat recovery heat exchanger, air blast cooler and three way control valve to direct the water to the air blast cooler when insufficient heat is being removed by the waste heat recovery system.

• Exhaust gas system with waste heat recovery heat exchanger and silencer.

• Electronic control system for engine monitoring and safe and efficient operation.
SECTION 4

SYSTEM SPECIFICATION

Output

Electrical

Operating at full capacity and taking no account for the parasitic load, the power generation facility produces:-

Gas engine generators 2.88MW(e)

Thermal

The quantity of thermal energy available from the power generation facility as “waste heat” will depend on the temperature at which this energy is delivered. Typically for the system operating at full capacity and taking no account of the heat required to dry the raw wood and based on a feed water temperature of 70°C the following represent the extremes of what is available:-

Saturated steam at 10Bar(g), 184°C 3.10MW(th)
Hot water @ 90°C 6.21MW(th)

Efficiencies

A wide variation on the energy conversion efficiency reported for a process can result from the basis and method used for its calculation. It is thus very important to fully understand the calculation method used and the base energy data before comparing efficiencies quoted for different technologies. Efficiencies for the Wellman power generation facility are quoted below based on both the higher and lower calorific value of the wood fuel and calculated as :-

Conversion Efficiency = Energy Output x 100
Energy in wood fuel

Wood fuel higher heating value 13.12MJ/kg @ 36.7wt.% moisture.
Wood fuel lower heating value 11.26MJ/kg @ 36.7wt.% moisture.

No allowance has been made for the heat requirement needed to dry the raw wood delivered to site to a wood with a moisture content of 36.7wt.%

No allowance has been made for the parasitic electrical demand of the gasification and gas processing system estimated as 117kW for 2.5MW(e) of power generation.
The conversion efficiencies are based on the facility operating at 100% full load and utilising 5 gas engine generator modules all operating at 97.5% of full load. (Option 1, Section 2)

Efficiency based on wood fuel lower heating value:-

Wood energy input = 11.26 MW

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical conversion efficiency</td>
<td>25.6%</td>
</tr>
<tr>
<td>Thermal conversion efficiency, high grade waste heat</td>
<td>27.5%</td>
</tr>
<tr>
<td>Thermal conversion efficiency, low grade waste heat</td>
<td>55.2%</td>
</tr>
<tr>
<td>Total conversion efficiency (electricity and low grade heat)</td>
<td>80.8%</td>
</tr>
</tbody>
</table>

Efficiency based on wood fuel higher heating value:-

Wood energy input = 13.12 MW

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical conversion efficiency</td>
<td>22.0%</td>
</tr>
<tr>
<td>Thermal conversion efficiency, high grade waste heat</td>
<td>23.6%</td>
</tr>
<tr>
<td>Thermal conversion efficiency, low grade waste heat</td>
<td>23.7%</td>
</tr>
<tr>
<td>Total conversion efficiency (electricity and low grade heat)</td>
<td>69.3%</td>
</tr>
</tbody>
</table>

**Fuel Supply**

**Description**
A wood chip feedstock produced from either a hard or soft wood, or a mixture of the two.

**Source**
Arable energy coppice, forest thinnings, forest residue or sawmill waste.

**Bark**
Maximum 10wt.%

**Mineral Matter**
Maximum 5wt.% in the form of dirt, stones etc.

**Moisture**
Minimum 35wt.% as supplied to the gasifier
Maximum 40wt.% as supplied to the gasifier
**Note**
Wood moisture contents of up to 55wt.% could be used but with a reduction in system capacity and efficiency.

**Size**
The feedstock should be chipped wood and commercial wood chips, typically 30mm x 20mm x 10mm are ideal. Care needs to be taken in the selection of material before delivery to the gasifier to avoid the presence of long pieces since these cause bridging in the fuel feed system.
The size of the chips should be:
  Minimum 10mm x 10mm x 10mm
  Maximum 30mm x 30mm x 30mm
The fines content (below 10mm cubed) should be a maximum of 10wt%.

Quantity
Average 3638.23kg/h (@ 36.7wt.% moisture)

Proximate Analysis
As Received Basis
Component          Weight %
  Fixed Carbon      11.7
  Volatile Matter   51.0
  Moisture          36.7
  Ash               0.6

Ultimate Analysis
Dry Basis
Component          Weight %
  Hydrogen          6.0
  Carbon            51.4
  Nitrogen          0.4
  Oxygen            41.3
  Ash               0.9

Calorific value
Gross Wood 36.7wt.% moisture 13.0MJ/kg
Dry Wood 20.5MJ/kg

Bulk Density 254kg/m³ @ 35wt.% moisture.

Utilities

Start Up Gas

Function A fuel gas for initial heating of the thermal and catalytic cracker prior to the introduction of the raw wood gas. A small quantity of gas is also required for the pilot burner which stabilises partial combustion of the raw wood gas at the main burner.
Once the cracker is at operating temperature the gas to the heat up burners will be switched off and it is envisaged that it will also be possible to shut down the pilot burner once flame stabilisation is achieved.

Source The fuel can be either Natural gas or LPG and the quantities for both these fuels is provided.

Natural gas Calorific value 34.8MJ/m³ net @15°C and 1bar (abs)
Density 0.723kg/m³ @15°C and 1bar (abs)

LPG (Propane) Calorific value 86.43MJ/m³ net @15°C and 1bar (abs)
Density 1.87kg/m³ @15°C and 1bar (abs)
Start up Burners

<table>
<thead>
<tr>
<th>Component</th>
<th>Natural gas</th>
<th>LPG (Propane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric flow</td>
<td>33.83 m³/h</td>
<td>13.62 m³/h</td>
</tr>
<tr>
<td>Mass flow</td>
<td>24.46 kg/h</td>
<td>25.46 kg/h</td>
</tr>
<tr>
<td>Duration</td>
<td>26 hours</td>
<td>26 hours</td>
</tr>
<tr>
<td>Total requirement</td>
<td>880 m³</td>
<td>355 m³</td>
</tr>
<tr>
<td></td>
<td>640 kg</td>
<td>665 kg</td>
</tr>
</tbody>
</table>

Pilot Burner

<table>
<thead>
<tr>
<th>Component</th>
<th>Natural gas</th>
<th>LPG (Propane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric flow</td>
<td>49.66 m³/h</td>
<td>0.83 m³/h</td>
</tr>
<tr>
<td>Mass flow</td>
<td>129.29 kg/h</td>
<td>1.56 kg/h</td>
</tr>
<tr>
<td>Duration</td>
<td>24 hours</td>
<td>24 hours</td>
</tr>
<tr>
<td>Total requirement</td>
<td>50 m³</td>
<td>20 m³</td>
</tr>
<tr>
<td></td>
<td>36 kg</td>
<td>38 kg</td>
</tr>
</tbody>
</table>

Pressure

- Minimum at terminal point: 2 kPa gauge
- Maximum at terminal point: 5 kPa gauge

Temperature

Ambient

Connection

50mm Flanged BS4504 PN10

Boiler Feed Water

Function

To provide the Gasifier steam drum / Annular boiler and the Process gas waste heat boiler with a constant supply of boiler quality water. This can be either boiler quality water produced by suitable treatment of process water, returned steam condensate or a mixture of the two.

Quality

The boiler feed water quality is to be determined for the process water quality at the specific operating site. The following figures are however a guide.

- Maximum hardness: 5 mg/l measured as CaCO₃
- Maximum suspended solids: 2 mg/l
- Maximum dissolved solids: 30 mg/l
- pH: 7.5 to 9.5
- Dissolved oxygen: Zero

Quantity

- Normal: 2700 kg/h
- Maximum: 3500 kg/h

Pressure

- Minimum at terminal point: 2 Bar gauge at ground level
- Maximum at terminal point: 5 Bar gauge at ground level
Temperature
Minimum  5°C
Maximum  80°C

Connection  40mm Flanged BS4504 PN10

Process Water

Function  The facility uses process water in the following areas:-
  Cooling tower make up
  Initial filling of the scrubbing water tank
  Cooling of boiler water samples.

Quality  Mains water

Quantity
Normal  2,820 kg/h
Maximum  4,000 kg/h

Pressure
Minimum at terminal point  2 Bar gauge at ground level
Maximum at terminal point  6 Bar gauge at ground level

Temperature
Minimum  1°C
Maximum  20°C

Connection  There are two connection points as follows:-
  Cooling tower  40mm Flanged BS4504 PN10
  Building  25mm Flanged BS4504 PN10

Electrical Supply

Supply  3 phase, 415 volt, 50 hertz

Load Requirement  Table 2 gives the estimated parasitic electrical load for the
  2.5MW(e) power generation facility operating at full output.
  
  Total connected load  216 kW
  Average load  117 kW

Connection  500 amps / phase recommended

---

Table 2  Electrical load for 2.5MW(e) power generation module.
<table>
<thead>
<tr>
<th>Item</th>
<th>Connected Load</th>
<th>Absorbed Power</th>
<th>Usage</th>
<th>Power Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Power Transformer</td>
<td>4.5 kW</td>
<td>4.5 kW</td>
<td>60%</td>
<td>2.7 kW</td>
</tr>
<tr>
<td>Instrument Air Compressor, BL201</td>
<td>5.5 kW</td>
<td>4.8 kW</td>
<td>60%</td>
<td>2.9 kW</td>
</tr>
<tr>
<td>Lock Hopper Discharge Unit, C203</td>
<td>0.37 kW</td>
<td>0.37 kW</td>
<td>10%</td>
<td>0.1 kW</td>
</tr>
<tr>
<td>Lock Hopper Discharge Unit, C204</td>
<td>0.37 kW</td>
<td>0.37 kW</td>
<td>10%</td>
<td>0.1 kW</td>
</tr>
<tr>
<td>Lock Hopper Discharge Unit, C205</td>
<td>0.37 kW</td>
<td>0.37 kW</td>
<td>10%</td>
<td>0.1 kW</td>
</tr>
<tr>
<td>Lock Hopper Discharge Unit, C206</td>
<td>0.37 kW</td>
<td>0.37 kW</td>
<td>10%</td>
<td>0.1 kW</td>
</tr>
<tr>
<td>Wood Feed Conveyor, C207</td>
<td>1.5 kW</td>
<td>0.6 kW</td>
<td>100%</td>
<td>0.6 kW</td>
</tr>
<tr>
<td>Wood Feed Conveyor, C208</td>
<td>1.5 kW</td>
<td>0.6 kW</td>
<td>100%</td>
<td>0.6 kW</td>
</tr>
<tr>
<td>Cooling Water Pump, P203</td>
<td>15.0 kW</td>
<td>11.0 kW</td>
<td>100%</td>
<td>11.0 kW</td>
</tr>
<tr>
<td>Cooling Water Pump, P204</td>
<td>15.0 kW</td>
<td>11.0 kW</td>
<td>Standby</td>
<td>0 kW</td>
</tr>
<tr>
<td>Cooling Tower Fan No.1.</td>
<td>11.0 kW</td>
<td>7.5 kW</td>
<td>35%</td>
<td>2.6 kW</td>
</tr>
<tr>
<td>Cooling Tower Fan No.2.</td>
<td>11.0 kW</td>
<td>7.5 kW</td>
<td>35%</td>
<td>2.6 kW</td>
</tr>
<tr>
<td>HP Boiler Feed Water Pump, P206</td>
<td>2.2 kW</td>
<td>2.2 kW</td>
<td>65%</td>
<td>1.4 kW</td>
</tr>
<tr>
<td>Grate Drive Hydraulic Pump, P205</td>
<td>3.0 kW</td>
<td>3.0 kW</td>
<td>5%</td>
<td>0.2 kW</td>
</tr>
<tr>
<td>Air Fan, 201</td>
<td>15.0 kW</td>
<td>12.8 kW</td>
<td>100%</td>
<td>12.8 kW</td>
</tr>
<tr>
<td>Spent Catalyst Conveyor, C210</td>
<td>2.2 kW</td>
<td>2.2 kW</td>
<td>Rare</td>
<td>0 kW</td>
</tr>
<tr>
<td>Hot Gas Booster, F202</td>
<td>75.0 kW</td>
<td>45.0 kW</td>
<td>100%</td>
<td>45.0 kW</td>
</tr>
<tr>
<td>Clean Gas Booster, F205</td>
<td>37.0 kW</td>
<td>29.0 kW</td>
<td>100%</td>
<td>29.0 kW</td>
</tr>
<tr>
<td>Scrubbing Water Pump, P201</td>
<td>7.5 kW</td>
<td>4.94 kW</td>
<td>100%</td>
<td>4.9 kW</td>
</tr>
<tr>
<td>Scrubbing Water Pump, P202</td>
<td>7.5 kW</td>
<td>4.94 kW</td>
<td>Standby</td>
<td>0 kW</td>
</tr>
</tbody>
</table>

**Discharges**

**Ash**

Ash is discharged from the base of the gasifier.

**Description**

A granular and generally friable solid comprising the inorganic components present in the wood together with a quantity of charcoal. The ash having passed through the high temperature zone of the gasifier (1150°C) is generally free of volatile organic components.

**Composition**

The composition of the ash depends on the wood fuel utilised but the following components are to be expected.

<table>
<thead>
<tr>
<th>Component</th>
<th>Range</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>5 to 80 wt.%</td>
<td>20 wt.%</td>
</tr>
<tr>
<td>Calcium oxides</td>
<td>30 to 80 wt.%</td>
<td>35 wt.%</td>
</tr>
<tr>
<td>Potassium oxides</td>
<td>1 to 40 wt.%</td>
<td>16 wt.%</td>
</tr>
<tr>
<td>Sodium oxides</td>
<td>1 to 15 wt.%</td>
<td>2 wt.%</td>
</tr>
</tbody>
</table>
Silica 1 to 30 wt.% 16 wt.%
Alumina 1 to 20 wt.% 4 wt.%
Magnesia 1 to 15 wt.% 4 wt.%
Iron oxides 0.5 to 3 wt.% 2 wt.%
Trace metal oxides* 0 to 2 wt.% 1 wt.%

* Traces of oxides of Titanium, Manganese, Copper, Cobalt, Zinc and nickel are typical of the metals found in some trees.

Flow
Normal 90 kg/h
Maximum 200 kg/h

Pressure
Discharged from gasifier to hopper at atmospheric pressure

Temperature
Normal 50 °C
Maximum 80 °C

Size
Normal 2 mm to 50 mm granules / lumps
Maximum lump size 150 mm

Connection
300 mm nominal bore discharge pipe from ash lock hopper at base of gasifier.

Scrubbing Water

The moisture present in the wood fuel is vapourised in the gasifier and as the gas is cooled below its dew point in the gas processing system a portion of this moisture is condensed and collects with the scrubbing water. To maintain the scrubbing water at equilibrium it thus necessary to arrange a constant bleed from the system. This scrubbing water bleed has to be disposed of and depending on local regulations and water treatment systems it may be necessary to undertake primary treatment prior to discharge to the local foul water sewer.

Description
Aqueous condensate with small quantities of dissolved organic compounds and suspended solids.

Composition
Typical concentration of the following organic components present in an aqueous solution are as follows:-

<table>
<thead>
<tr>
<th>Component</th>
<th>mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>10</td>
</tr>
<tr>
<td>Acetone</td>
<td>112</td>
</tr>
<tr>
<td>Isopropyl alcohol</td>
<td>62</td>
</tr>
<tr>
<td>alcohol (no molecular ion)</td>
<td>33</td>
</tr>
</tbody>
</table>
Methyl furan  19  
Benzene       470  
Toluene       12  
Furancarboxaldehyde  25  
Styrene       38  
Propynyl benzene  42  
Methyl cresol   12  
Naphthalene    140 

Flow 
Normal 1,523 kg/h 
Maximum 2,000 kg/h 

Pressure 
Normal 250 kPa g 

Temperature 
Normal 60 °C 
Maximum 75 °C 

Connection  25mm Flanged BS4504 PN16 

**Labour Requirement**

We would suggest a 2.5MW(e) power generation facility would require the following personnel:-

1 operator per shift for normal operating and labouring duties. 
50% utilisation of 1 supervisor per shift to set operating criteria, monitor plant performance, check on wood chip supplies and quality, organise scheduled maintenance, etc. 
30% utilisation of secretarial services for week days only. 
10% utilisation of a manager for week days only to oversee the operation and long term development of the facility. 

This assumes that normal maintenance staff and facilities are made available when required.

Depending on the type of site and possibilities of job sharing, it is likely that the facility will have a full time operator and supervisor on each shift with sufficient shifts to cover holidays and absence.

**SECTION 5**

**GENERAL ARRANGEMENT**
The following drawings provided in Appendix A show the general arrangement of the gasifier and gas processing equipment:

- Y5406 00 115 Front view of 2.5MW(e) gasifier and gas processing module
- Y5406 00 116 End view of 2.5MW(e) gasifier and gas processing module.
- Y5406 00 117 Plan view of 2.5MW(e) gasifier and gas processing module.

A simple structure has been indicated housing the equipment but the detailed architectural design is outside the scope of this project and can be varied to suit both location and local planning requirements.

The arrangement of the equipment within the gasification and gas clean up module has been designed to enable additional modules to be added in a linear fashion in order to increase the plant output in multiples of 2.5MW(e). The anticipated overall plant layout would enable a wood preparation and handling facility to be located to one side of the gasification and gas clean up building. It is envisaged that the gas engine generators will be situated either as self contained modules or in a separate building running parallel to the gasification and gas clean up modules again being capable of expansion in a linear fashion. Drawing Y5406 00 118 Appendix A, gives a typical plan view of a possible overall arrangement of multiple power generation modules.
APPENDIX A

DRAWINGS – NOT ALL AVAILABLE IN ELECTRONIC VERSION

The following drawings have been included:

- Y5406 00 001 Wood handling system PFD
- Y5406 00 001 Gasifier and gas processing PFD
- Y5406 00 115 Front view of 2.5MW(e) gasifier and gas processing module
- Y5406 00 116 End view of 2.5MW(e) gasifier and gas processing module.
- Y5406 00 117 Plan view of 2.5MW(e) gasifier and gas processing module
- Y5406 00 118 Proposed arrangement for three 2.5MW(e) power generation modules.