PREFEASIBILITY STUDY FOR BIOMASS POWER PLANT, NAMIBIA

POWER PLANT TECHNICAL ASSESSMENT

2012/07/31 Revised: 11/09/2012

Confidentiality: Public

Quality Management

Issue/revision	Issue 1	Revision 1	Revision 2	Revision 3
Remarks	1st Draft	Final Draft		
Date	31/07/2012	11/09/2012		
Prepared by	Steven Wood, Michael Huisenga	Steven Wood, Michael Huisenga		
Signature				
Checked by	Kevin Whiting	Kevin Whiting		
Signature				
Authorised by	E.Theeboom	E.Theeboom		
Signature				
Project number	3190623559	3190623559		
Report number				
File reference				

PREFEASIBILITY STUDY FOR BIOMASS POWER PLANT, NAMIBIA

POWER PLANT TECHNICAL ASSESSMENT

2012/07/31

Client

NamPower

Consultant

Elan Theeboom
3rd Floor
35 Wale Street
Cape Town
8001
South Africa

Tel: +27 21 481 8646
Fax: +27 21 481 8799

www.wspenvironmental.co.za

Registered Address

WSP Environment & Energy South Africa
1995/008790/07
WSP House, Bryanston Place, 199 Bryanston Drive,
Bryanston, 2191, South Africa

WSP Contacts

Elan.theeboom@wspgroup.co.za
Kevin.Whiting@wspgroup.com

Table of Contents

Technical Assessment

1 Introduction

1.1 Overview

An assessment of several commercially available technologies has been performed to determine the most suitable scenario for generating electrical power from encroacher bush in Namibia. Broadly, a number of thermochemical technologies are available to NamPower including combustion, gasification and pyrolysis, but the commercial and technical maturity and the cost of producing electricity varies substantially.

Of these technologies combustion is by far the most commercialised to date and thus best suited to provide NamPower with low cost and reliable electricity, the key drivers of the technology assessment. It is also the lowest risk and hence most likely to attract financial support from risk-wary institutional investors. As discussed in the project inception report, WSP recommends the use of commercially proven combustion or staged gasification technologies for the conversion of biomass to heat energy for generating electricity.

There is also potential to use biomass as a replacement for coal at the existing Van Eck Power Station, particularly when biomass is pre-treated via a torrefaction process in order to transform it into a material with similar characteristics to coal. There may be good opportunities for using torrefied material at Van Eck but we do not consider an investment in a production system to be appropriate given the lack of commercial experience internationally. However, an arrangement to purchase torrefied material from a producer may offer potential.

1.2 Scenarios

Following the pre-feasibility study a number of potential technical scenarios and locations for biomass power facilities in Namibia have been identified. These are summarised in Table 1. Scenarios 1 and 2 relate to new, dedicated biomass power generation facilities. Scenario 3 relates to the conversion of an existing coal power plant to operate on a high proportion of biomass.

Table 1: Summary of Scenarios

Option	Site location	Co-operating institutions	Fuel	Fuel Pre-Treatment	Electrical Capacity (MWe)
1	Near Otjiwarongo (ca. 300 km North of Windhoek)	Cheetah Conservation Fund (CCF)	Wood chips	None	5
2a	Ohorongo Cement North Otavi (ca 400 km North of Windhoek)	Schwenk – EFF (Energy for Future) + Ohorongo Cement	Wood chips	None	2 X 10
2b					
2c	Otjikoto Substation	None	Wood chips	None	
2d					
3	Omaruru (ca. 200 km Northwest of Windhoek)	Green Coal or other torrefied pellet supplier	Torrefied pellets for use at Van Eck power station	Torrefaction	After refurbishing (3 X 22)

1.3 Scope

The aim of the study is to determine the most appropriate technical solution(s) for generating electricity from encroacher bush. The technical assessment covers all the areas addressed in the inception report. We have split the assessment into two parts; Part A covers new biomass plant (Scenarios 1 and 2) and Part B covers the use of existing facilities, specifically Van Eck power station (Scenario 3):

Part A – Dedicated biomass power plant:

- Technology options for generating between 5 and 20 MW of electricity from encroacher bush biomass chips
- Representative mass and energy balances;
- Representative plant layouts;
- Investment cost; and
- Operation and maintenance costs

Part B – Co-firing at Van Eck power station:

- Technology
- Market status
- Existing activity in Namibia
- Opportunity and way forward for NamPower

1.4 Technical Options for Power Generation

1.4.1 Part A - Dedicated Biomass to Power

There are three distinct technologies available for the generation of electricity from encroacher bush biomass; combustion, gasification and pyrolysis, described briefly below. Of these, direct combustion is the most proven and represents the lowest commercial and technical risk, and can be expected to provide electricity at lowest cost and with highest reliability.

Combustion

Biomass combustion for power generation is a commercially mature technology and there are many examples worldwide at a wide range of scales. Most plants employ either grate furnace or fluidised bed combustion technology, and the heat produced is virtually always used to raise steam for use in a conventional steam turbine. Some fluidised bed systems are examples of 'close-coupled gasification', where distinct gasification and combustion processes occur in different regions of the furnace. However since the gas produced is immediately combusted these systems can be considered a form of staged combustion.

We have considered three biomass combustion technologies in this study:

- Air-Cooled Vibrating Grate (Grate Boiler)
- Circulating Fluidized Bed (CFB)
- Bubbling Fluidized Bed (BFB)

The above technologies are well proven technically and commercially and would be suitable for using encroacher bush as a feedstock.

Gasification

Gasification is the thermal degradation of organic matter when heated in a reduced oxygen environment. The oxygen levels present in the reactor (gasifier) are insufficient for complete combustion of the biomass to occur, and instead the fuel breaks down into simpler molecules. The predominant fraction is gas consisting of varying fractions of carbon monoxide and hydrogen (known as syngas), but there are also liquid and solid (char) components. The gas can simply be combusted to raise steam for electricity generation in a conventional steam turbine, used in a gas engine or upgraded for use as vehicle fuel or as a feedstock for chemicals.

Gasification for generation of electricity via a traditional steam cycle is well proven, and we consider close coupled gasification systems to be essentially a combustion process as described above. This type of system does not differ radically from conventional combustion in performance terms, and there are numerous commercial examples.

Higher electrical efficiencies are possible when syngas is used in a gas engine, but this technology is not well proven commercially when using biomass as a feedstock. Significant gas cleaning is required (particularly to remove condensable tars) and achieving reliable operation is challenging.

Hence we do not consider 'advanced' gasification (i.e. any gasification system other than where the gas is combusted in the furnace) to be an appropriate technology for NamPower due to the technical and commercial risks associated with such plants.

Pyrolysis

Pyrolysis is similar process to gasification except the feedstock is heated in the complete absence of oxygen. Biomass breaks down into gas, liquid and solid phases, with the proportion of each phase dependent on the temperature, exposure time and heating rate of the reactor.

Most pyrolysis systems aim to maximise the liquid fraction (bio-oil), which can be used to generate power in an internal combustion engine or can be upgraded for use as a vehicle fuel or feedstock for chemicals. The gas produced via pyrolysis differs from that produced by gasification and can have a higher heating value, but contains a high level of tars and is challenging to use for electricity generation.

Few commercial scale pyrolysis power generation systems exist, and we do not consider pyrolysis to be an appropriate technology for NamPower due to the considerable technical and commercial risks associated with such plants.

1.4.2 Part B - Biomass Co-Firing at Van Eck

Coal-fired power stations are generally able to accept a proportion of biomass feedstock. There is potential therefore to use encroacher bush to generate electricity at the Van Eck power station. The proportion of biomass material that can be fired alongside coal can be increased considerably by pre-treating the biomass via torrefaction, which uses heat to convert the material to a substance resembling coal.

Co-firing of encroacher bush 'as received'

In theory, biomass co-firing with coal can be accomplished at ratios of 10% with bubbling fluidized bed boilers and up to 20% with stoker boilers. Depending on a number of factors related to the configuration of the existing boilers at Van Eck, a number of biomass co-firing options exist.

- **Straight Co-fire –** blending wood chips with coal feed into a bubbling fluid bed, circulating fluid bed or traveling grate boiler at a defined ratio.
- **Retrofit** – involves modifying an existing unit by adding a stoker or bubbling fluidized bed bottom and converting it to a dedicated biomass boiler.
- **Suspension co-fire –** dedicated biomass burners can be added to existing pulverized coal combustors to fire finely ground biomass.
- **Partial-suspension firing –** injection of wood chips into a pulverized coal (PC) combustor though ports in the top of the boiler. Combustion is achieved partly during suspension and partly on the furnace bottom.

A study carried out by VTT concluded that Van Eck's current boiler systems are not suitable to handle and co-fire biomass as a blended fuel, and that a major retrofit to install a dedicated biomass boiler (or boiler bottom) would be required. VTT recommends that one of the boilers (equivalent to 27 MWe) be overhauled with the installation of biomass storage and handling capability and a new traveling grate boiler. VTT estimates that this would result in de-rating the steam generation capacity and equivalent electric output to 20 MW.

Co-firing of torrefied encroacher bush

Torrefaction is a thermochemical process whereby biomass is exposed to temperatures of 200 to 400°C under atmospheric pressure and in the absence of oxygen (Figure 9). It can be described as a mild form of pyrolysis. Torrefaction is typically used as a technique to produce a higher energy fuel from biomass.

During the torrefaction process, water and a proportion of the volatiles (organic chemicals) contained within the biomass are re-moved, and cellulose, hemicellulose and lignin also partly decompose.

Torrefaction process produces a solid, dry material which displays similar characteristics to coal. It can be compacted, usually into briquettes or pellets using conventional densification equipment, to improve its hydrophobic properties. This means that the final product will not absorb water and can be stored in moist air or rain as opposed to the original biomass.

Though not fully commercialised, tests using torrefied material produced by Green Coal on one line of the Van Eck plant demonstrated satisfactory operation at up to 80% biomass, though modifications to the plant are likely to be required.

2 Part A – Dedicated Biomass to Power Facilities

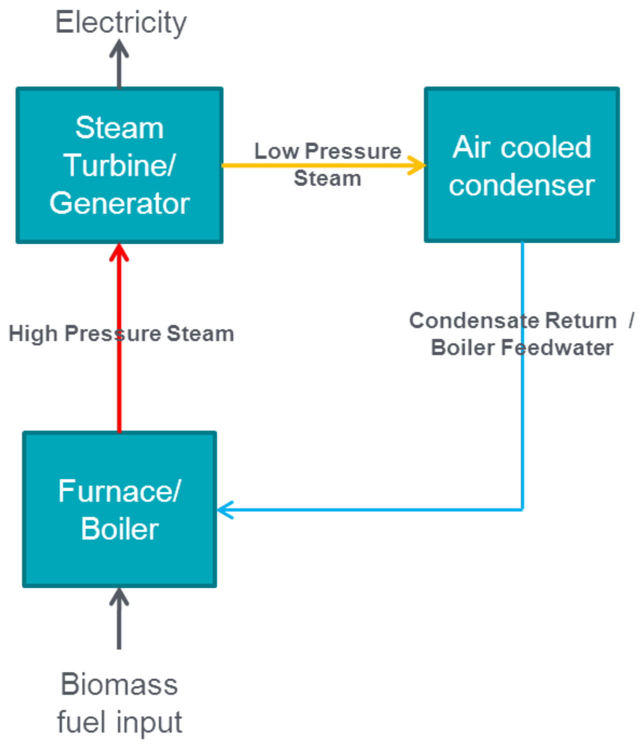
2.1 Overview

In this chapter we consider the most appropriate technology and plant configuration for a new biomass to power plant fuelled by encroacher bush. Our assessment focusses on the following three types of biomass furnace designs, all of which are well proven and offered by various vendors:

- Air-Cooled Vibrating Grate Biomass Furnace and Boiler (Grate Boiler)
- Circulating Fluidized Bed Biomass Furnace and Boiler (CFB)
- Bubbling Fluidized Bed Biomass Furnace and Boiler (BFB)

Although the furnace and boiler technology may differ substantially, virtually all biomass power plants of this scale will operate using the same thermal cycle: combustion of biomass will raise steam which will be passed through a turbine-generator to generate electricity. Figure 1 presents a simplified, schematic overview of any biomass combustion power plant which shows the elements common to any facility. Each element shown in this figure has been modelled in detail, with technical data and cost estimates sourced from vendors.

Figure 1: Simplified schematic of biomass combustion process and steam cycle



In addition to the thermal plant a number of auxiliary plant elements will be required:

- Fuel reception
- Fuel handling system
- Ash handling system

- Buildings and other civil works
- Grid connection (considered in separate report)

The technical solution and associated cost of these elements will vary depending on the technology and/or location of the facility. For example, Ohorongo Cement is currently processing encroacher bush to produce fuel for use in their furnace, and so the existing operations mean that less infrastructure would be required than at a clear site such as the Otjikoto substation.

2.2 Selection of Plant Size

During the course of the study, the team considered a wide variety of plant sizes (listed as 2 – 30 MWe in the Inception Report, although even larger plant sizes were considered prior to the Inception Report). The team eventually settled on a 20 MWe plant as the upper limit and a 5 MWe plant for the smaller concept. The progressive downscaling on plant sizes relates primarily to the growing appreciation (within the team) for supply chain related risks, and hence the need to reduce this risk by downscaling to a more pragmatic plant size (in terms of reducing fuel demand and hence reducing the strain on the supply chain). A 20 MWe unit also linked well with the preferred size as expressed by potential partner organisations such as Schwenk, as it matches the local demand at the Ohorongo Cement plant. Furthermore the volume of fuel supply is comparable to the proven (existing) supply chain set up at Ohorongo Cement (i.e. by EFF). Finally, the 20 MWe plant size allows for useful comparability to the boiler size at Van Eck.

The smaller size could have been selected as 2 MWe, however the 5 MWe unit was considered to offer more flexibility for modular upscaling suitable for the Otjiwarongo location, and in addition at the 2 MWe scale the steam cycle efficiency drops significantly. As the 20 MWe unit is made up of 2 x 10 MWe units, this provides a flexible analysis for the 5, 10 and 20 MWe plant sizes.

The successful establishment of a 5 - 20 MWe plant will be necessary to prove the commercial feasibility for either even larger power plants or for a geographically distributed network of power plants in this range.

2.3 Methodology

In order to inform the pre-feasibility study WSP contacted various technology suppliers and requested technical data, drawings and budget cost quotes for appropriate biomass power plants. The equipment vendors that were contacted are shown in Table 2. The focus for contacting equipment vendors was on established markets for biomass combustion, particularly Europe, North America and local suppliers in South Africa. WSP also identified potential suppliers in China and India; however relatively few suppliers were identified as potentially able to offer a solution to NamPower. At this stage equipment vendors based in these countries were not contacted, but a list of potential organisations is included in Table 3

Table 2: Biomass equipment vendors contacted

Company	Country
KIV Engineering d.o.o	■ Slovenia
■ Outotec (Energy Products of Idaho)	■ USA
■ Babcock International	■ South Africa
■ Babcock & Wilcox Volund	■ Denmark
■ Oschatz	■ Germany/UK
■ Group Five	■ South Africa

MW Power (Metso - Wartsilla JV)	Finland
Aker Solutions	UK
Weiss A/S	Denmark
Imperative Energy Ltd	UK
RES Enterprises Limited	UK
Vapor Finland Oy	Finland
Envirotherm GmbH	Germany
Foster Wheeler	Finland
Bertsch	Germany
Standard Kessel	Germany
Urbas	Austria
ITI Energy	UK
PRM Energy	USA
Repotec	Austria
HOST	Holland
Nexterra Energy	Canada
Vyncke	Germany

Table 3: Suppliers of biomass combustion plant in India and China (not contacted)

Country	**Company**
India	Urja Thermal Solutions
	NS Thermal Energy PVT Ltd
	Sitson India PVT. Ltd.
China	Harbin Intelligence Thermal Electricity Engineering Group
	Shandong Runh Power Plant Engineering Technology
	Taishan Group Co., Ltd.
	Qingdao Shuangzi Precision Machinery Co.,Ltd

Detailed discussions with equipment vendors have allowed WSP to recommend representative equipment configurations, sizing, and operational parameters for each boiler type to NamPower. It should be noted that numerous vendors contacted either did not respond at all or declined to provide information. The reasons varied but common responses were being too busy, considering the project to be in too early a phase to allow a specific response and a lack of interest in working in Namibia. However six organisations responded positively and much of this appraisal is based on the technical and financial data we received from them.

A listing of each biomass boiler type and the and the advantages and typical applications are presented in

Table 4.

Table 4: Biomass Boiler Technology Summary

Boiler Type	Typical Uses	Advantages	Data Received from Equipment Vendors?
Grate Boiler	Wood chips, municipal solid wastes, and coal combustion	Simple proven design and low maintenance requirements	Yes
CFB	Low moisture biomass & coal combustion	High combustion efficiency and low NOx emissions due to long residence time and low operating temperature, high fuel flexibility	Yes
BFB	High moisture content biomass & municipal solid wastes	Ability to burn high moisture content fuels, fuel flexibility	Yes

To complement the data received from technology suppliers, thermodynamic modelling software package Thermoflex[1] has been used to produce detailed technical data for a 'typical' generic biomass combustion plant for each scenario. The combination of actual data and Thermoflex has allowed us to build up a complete picture of the technical performance of each plant type. Similarly, we have been able to produce comprehensive estimates of capital and operational costs based on the responses received from vendors, supplemented by robust assumptions where actual data could not be solicited.

Through review of detailed technical information provided by equipment vendors including process flow diagrams, mass & energy balances and plan layout diagrams, WSP has been able to determine representative plant configuration corresponding to each boiler type and scenario considered. For each boiler type, a simple Rankine steam cycle is proposed as this is by far the most commercially proven and reliable means of generating power at this scale.

In addition to contacting equipment vendors WSP engaged with a local integrated construction services, materials and infrastructure investment group based in South Africa, who provided data around civil works costs in Namibia which has informed our appraisal.

2.4 Selection of Suitable Technology – Furnace and Boiler Plant

In this section we have described the technical parameters and performance of the combustion systems we consider appropriate for the generation of electricity from encroacher bush. In each case we have based our analysis on an actual, modern plant offered by vendors, though we have been careful to make sure the modelling represents a 'typical' plant (i.e. is not made overly specific to a single plant type given that a variety of vendors who have not provided data to the study may be able to provide a system).

2.4.1 Grate Furnace and Boiler

10MW Grate Combustion System

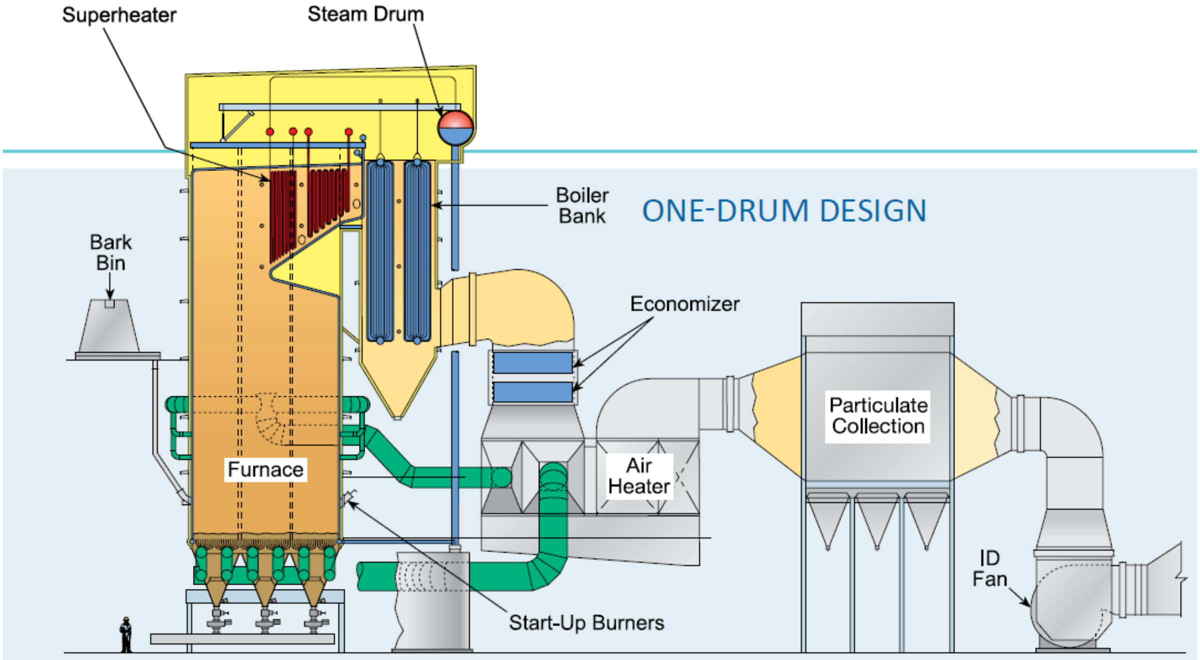
The 10 MW grate boiler scenario is based on the use of an air cooled vibrating grate boiler. This type of boiler has a proven track record with biomass fuels and relatively low maintenance costs.

[1] Thermoflow Inc. (http://www.thermoflow.com/ConvSteamCycle_TFX.htm)

The boiler uses an air cooled vibrating grate combustion furnace supplied with under-grate (primary) air and over-fire (secondary) air. Biomass fuel is fed to the grate via screw conveyers, with large particles falling on to the grate and small particles igniting in suspension above the grate.

In common with most grate combustion systems, heat generated is recovered via the boiler section located directly above the furnace. The boiler is equipped with a superheater section, economizer, and water wall evaporative section.

Figure 2: Vibrating grate boiler, courtesy of Babcock & Wilcox Power Generation Group

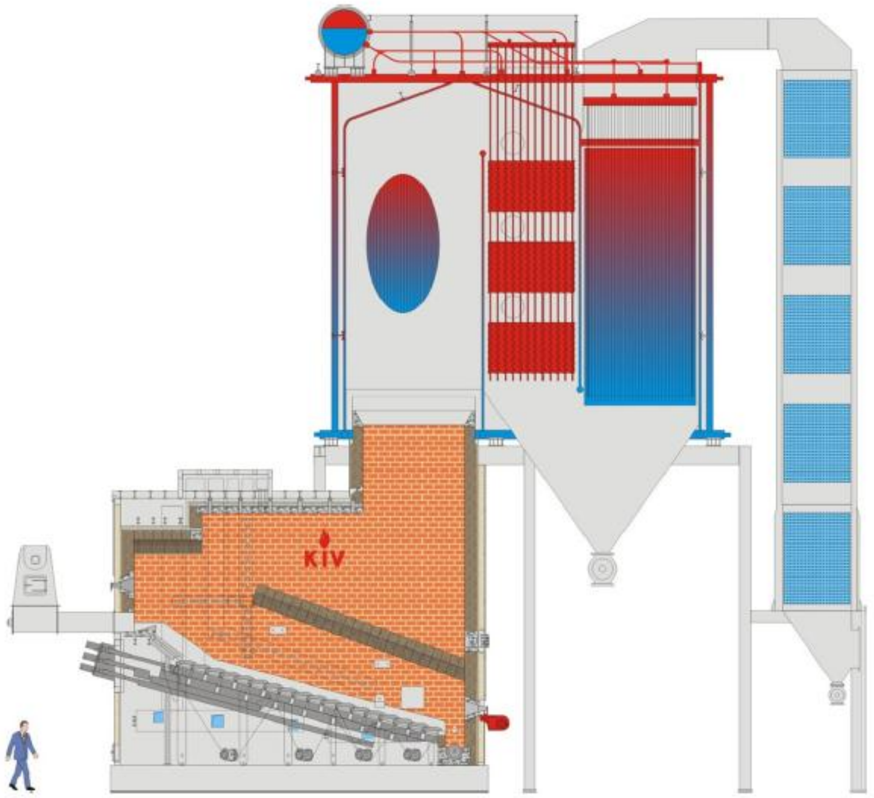


5 MW Grate Combustion System

The 5 MW grate boiler scenario is based on an air cooled vibrating grate boiler. These systems can be supplied in sizes up to 7 MW so is well suited to small scale applications.

The technology uses an air cooled vibrating grate combustion furnace supplied with under grate and over fire air. The boiler is equipped with a superheater section, economizer, and water wall evaporative section.

Figure 3: Air cooled vibrating grate boiler example, courtesy of KIV

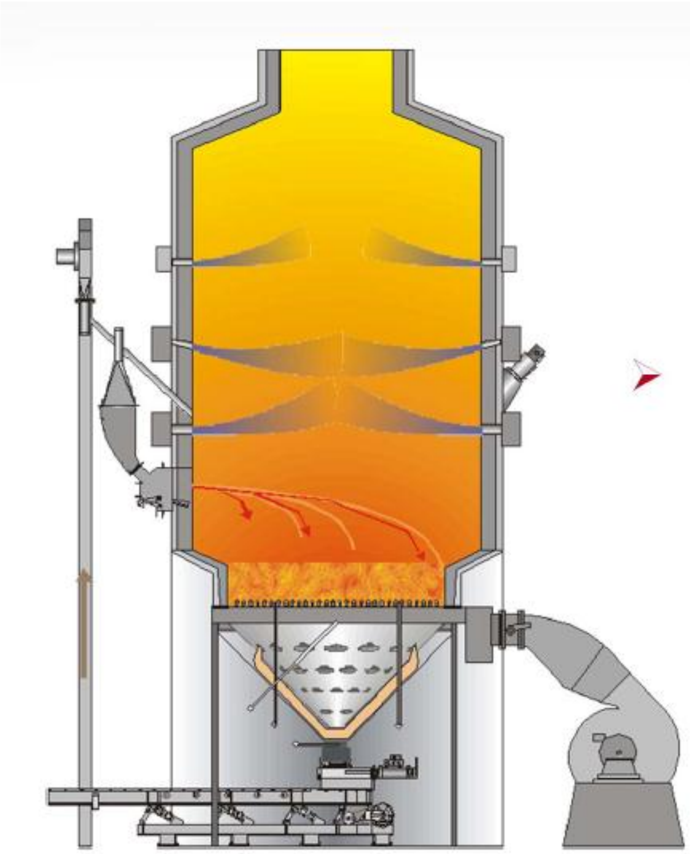


2.4.2 Bubbling Fluidized Bed (BFB) Furnace and Boiler

The BFB boiler scenario is based on a staged gasifier. This type of boiler has a high fuel flexibility and relatively low cost, and discussions with suppliers indicated that the staged gasification system is able to achieve a lower capital cost per unit of heat delivered when compared to a single stage combustion process. First, the fluidized bed section of the furnace is smaller (lower bed diameter) than a standard fluidized bed combustor because gasification requires less air per unit fuel than complete combustion (refer to Figure 4). Decreasing the size of the bed means less bed media that needs to be fluidized by forced draft air fans and less material used during construction. This also results in lower operating costs because the required fan power is lower than a typical BFB. Gasification of the fuel is accomplished in the fluid bed section and volatile gases are fully oxidized in the upper furnace by delivery of secondary air. Char particles remaining in the fluid bed will be completely combusted just as they would in a BFB combustion furnace. The upper portion of the furnace has a larger diameter than a conventional BFB gasifier to accommodate higher flows of secondary air needed for complete oxidization.

WSP's assessment of this technology is that this is a not a true gasifier as the gasification and combustion reactions are so closely coupled that the synthesis gas produced is immediately combusted as an intrinsic part of the process. Hence it is a combustor that accomplishes combustion in two stages and therefore the system should not be perceived to carry some of the technology risk associated with more advanced gasification units (i.e. those that use the syngas for uses other than direct combustion to raise steam).

Figure 4: Bubbling Fluidized Bed Staged Gasifier example, courtesy of Outotec

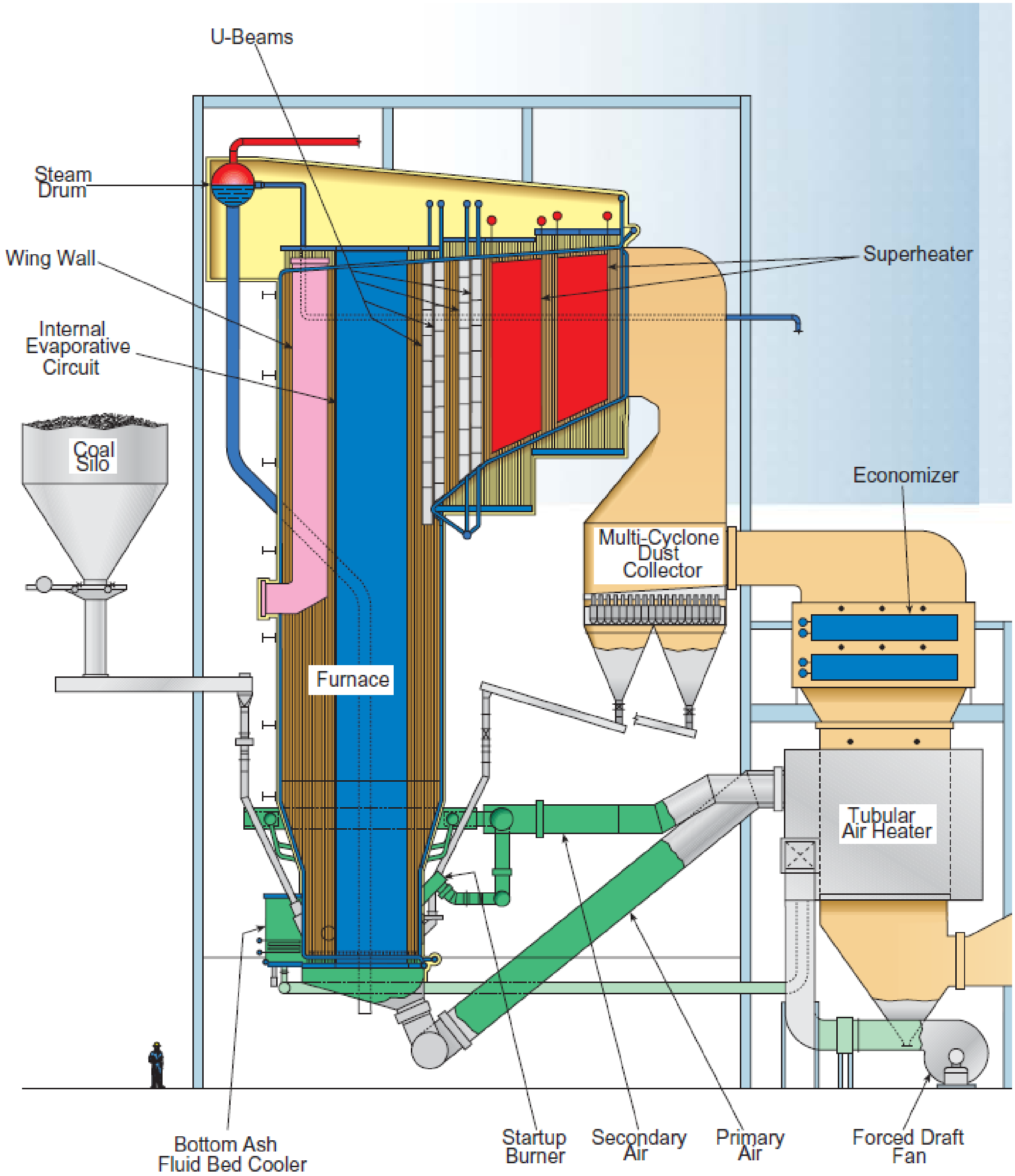


2.4.3 Circulating Fluidized Bed (CFB) Furnace and Boiler

The CFB boiler scenario has been based on an internally recirculating circulating fluidized bed (IR-CFB) system. Discussions with suppliers indicated that this system is best suited for the application which involves a low moisture content fuel. This boiler is shown in Figure 5.

The IR-CFB is a circulating fluidized bed boiler in which a portion of the bed media (sand) is recirculated in the main furnace chamber. Primary fluidizing air is supplied below the bed with sufficient velocity to force the bed media and fuel particles upward through the furnace. Due to an expansion in cross-sectional area at the top of the furnace, the velocity of the existing flue gas is decreased causing sand and particles to drop out of the flow and fall back down the furnace. Some media and particles will continue onward toward the heat exchanger tubes and are collected using a series of U-beams designed to separate particulate and sand from the flow. These materials fall back down into the main furnace as well. These two components make up the primary recirculation loop. Bed media, fuel particles and ash escaping this primary collection mechanism will be collected using cyclone separators following the superheaters and delivered back the bed. This is the secondary recirculation loop. The boiler will be supplied with superheaters, economizers, refractory lined water wall and steam drum. Primary and secondary combustion air will be preheated by exiting flue gas following the economizer.

Figure 5: Internally Recirculating Circulating Fluidized Bed boiler example, courtesy of Babcock & Wilcox Power Generation Group, Inc.



Thermoflex has the ability to create a thermodynamic model of a CFB system and this model will provide a reasonably accurate estimate of the heat and mass balance for a CFB. Detailed technical operating and performance data was not provided by suppliers at the time of the study, so a number of assumptions were made and Thermoflex was used to model the optimized performance of the system and determine some of these parameters.

2.5 Selection of Suitable Technology – Electrical Generation Plant

2.5.1 Steam Turbine Generator

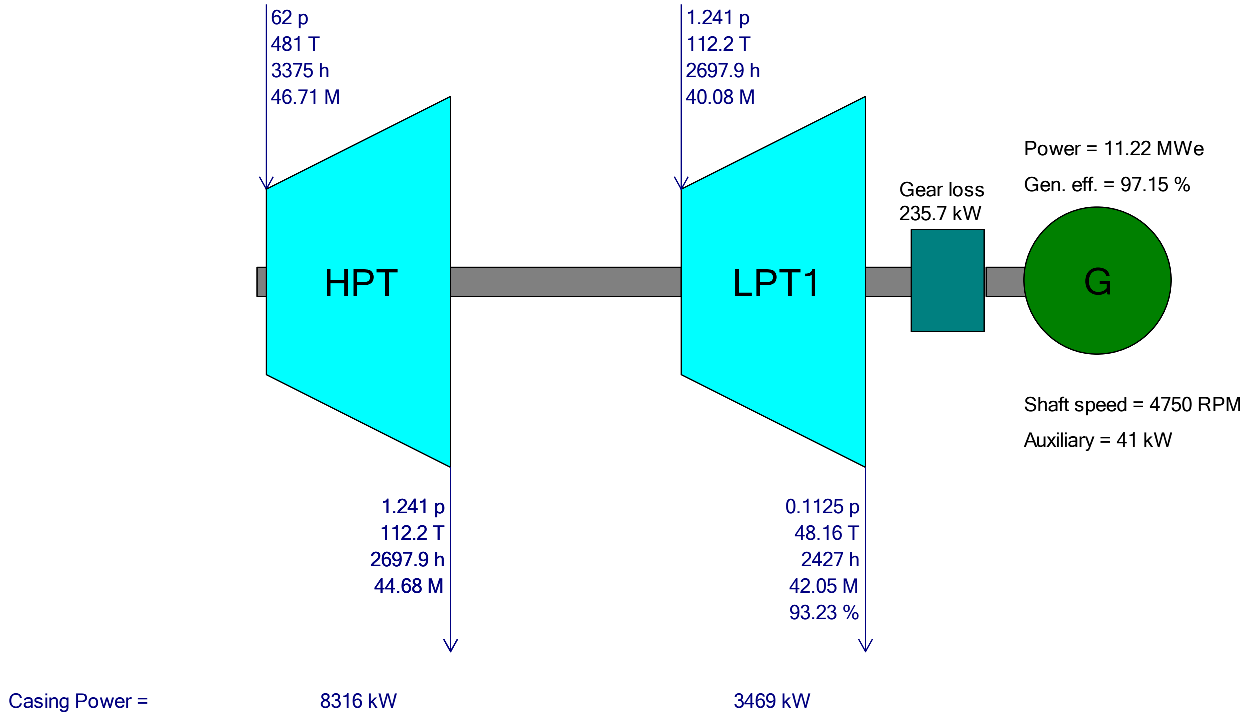
The vast majority of biomass power plants make use of a traditional steam (Rankine) cycle for generating electricity. This is well proven, well understood technology and the only practical, economic option for the generation of electricity from a combustion process at this scale. Gasification systems can theoretically achieve greater efficiencies (particularly at small scale) by using the syngas in gas engines or turbines, but this is not fully commercialized and we do not consider this to be a suitable option for NamPower. Hence we have modelled a steam turbine generator for the generation of electricity for each scenario.

The steam turbine generator assembly is modelled using data supplied by a major steam turbine manufacturer who have suggested a turbine that will provide low cost reliable electricity production for the plant. Key parameters for a unit sized to provide a net electrical output of 10MW are summarised in Table 5 and the schematic design of the high and low pressure sections is presented in Figure 6.

Table 5: Representative turbine generator parameters

Parameter	**Value / Unit**
Machine Type	Condensing extraction, non-reheat type machine with auto extraction at 1.241 bar(a)
Gross electrical output / Nameplate Capacity	11.78 MW (13.09 MVA at power factor of 0.9)
Generator efficiency	97.2%
Turbine inlet pressure	62 bar-absolute
Turbine inlet temperature	482°C
Exhaust Pressure	112.5 mbara at average and 200 mbara at design conditions
Speed	Turbine speed of 4750 RPM geared to 3000 rpm (50 Hz) at generator
Unit weight	59 tonnes
Unit dimensions	14 m (l) x 2.4 m (w) x 2.3 m (h)
Foundation dimensions	15.2 m (l) x 2.9m (w)

Figure 6: Schematic of the steam turbine generator from the 10 MW CFB modelled scenario, units are p[bar], T[°C], h[kJ/kg], M[t/h]



2.5.2 Air-Cooled Condensers

The air cooled condenser unit has been modelled using design parameters suggested by a major supplier of cooling systems, who have provided budgetary cost quote and preliminary engineering design information for their recommended system; a condenser unit constructed of aluminium coated carbon steel tubes which will be fabricated in China and shipped to and erected in Namibia. This condenser uses fans to force air across heat exchanger tubes supplied with saturated steam from the turbine exit. As the steam condenses, the latent heat is transferred to the ambient air.

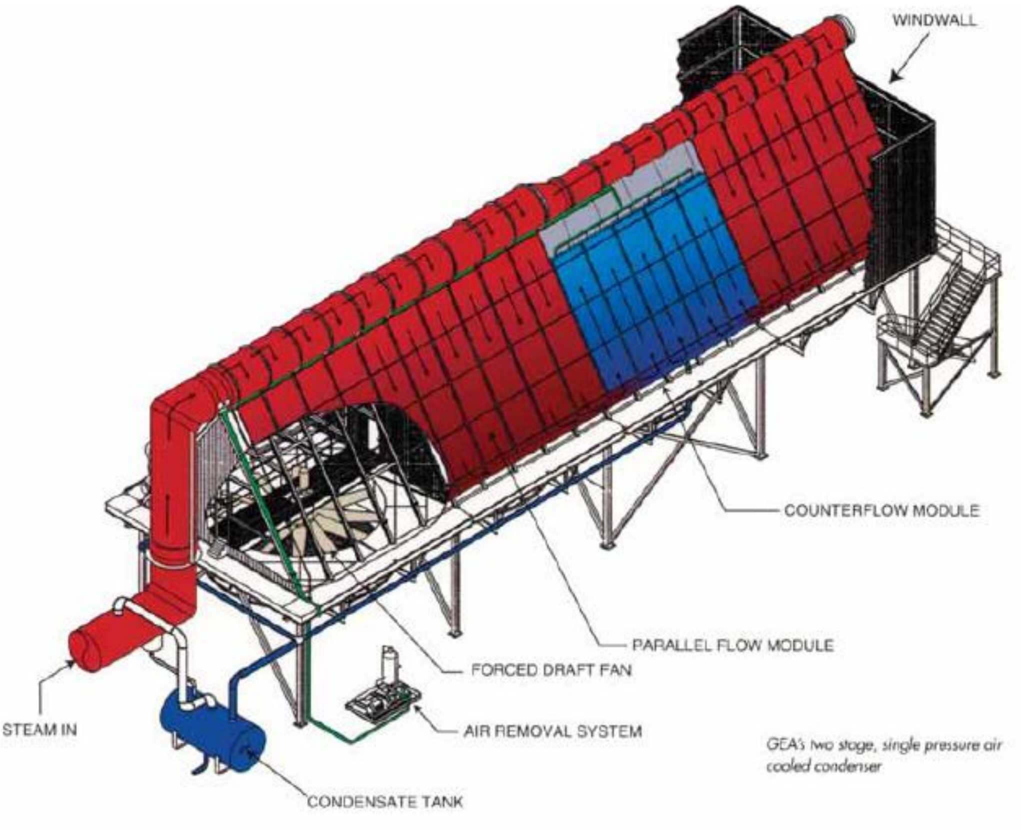
The condenser for the 10 MWe plant will need to reject approximately 26 MW of thermal energy to the ambient air. This can be accomplished with a single unit containing two air fans. The total fan power required is 220 kW (2% of net power) and the fans will have a diameter of approximately 10m each. This results in a condenser unit having dimensions of 13.3m wide, 17.5m in height, and 26.6m in length. Total weight of supply is 130 tonnes, though will be substantially heavier in operation due to the additional water load.

Relevant design considerations for the ACC units include:

- Design condensing pressure of 200 millibar at max annual ambient temperature, 112.5 millibar at average annual temperature
- Entering steam quality of 95%, temperature of 48.16°C
- Heat rejection capacity of 26.4 MWth
- Air temperature rise of 19°C
- Constructed of aluminium coated carbon steel tubes with aluminium fins

- Calculated heat exchanger effectiveness of 0.69

Figure 7: Air cooled condenser unit, courtesy of GEA USA



3 Detailed Plant Modelling

3.1 Overview of Scenarios Modelled

In order to cover all the scenarios outlines in Section 1, five individual plant configurations have been designed and modelled which account for the use of three different boiler types, two net power outputs (5 MWe and 10 MWe) and the potential use of hot air as a source of boiler combustion air at the Ohorongo Cement plant.

- 5 MWe Grate boiler plant
- 10 MWe Grate boiler plant utilising waste heat from cement plant at Ohorongo
- 10 MWe Grate boiler plant at Otjikoto substation
- 10 MWe Fluidised bed boiler plant utilising waste heat from cement plant at Ohorongo
- 10 MWe Fluidised bed boiler plant at Otjikoto substation

Table 6 summarises this by scenario. The assessment of the fluidised bed boilers has been based on the BFB design since this is the base case for the commercial modelling, and both types perform similarly from a technical point of view. However, we have also modelled the technical performance of a CFB system at both Ohorongo and Otjikoto.

Table 6: Technology by scenario

<table>
<tr><th>Scenario</th><th>Site location</th><th>Proposed Technology</th><th>Additional Energy Inputs</th><th>Electrical Output</th></tr>
<tr><td>1</td><td>Cheetah Conservation Fund (CCF), near Otjiwarongo</td><td>Grate combustion with steam turbine</td><td>None</td><td>Single 5 MW unit</td></tr>
<tr><td>2a</td><td rowspan="2">Ohorongo Cement North Otavi</td><td>Grate combustion with steam turbine</td><td rowspan="2">64,500 m³/hr of hot air at 300°C</td><td rowspan="4">2 X 10 MW units (at same site)</td></tr>
<tr><td>2b</td><td>Fluidised bed combustion (BFB) with steam turbine</td></tr>
<tr><td>2c</td><td rowspan="2">Otjikoto Substation</td><td>Grate combustion with steam turbine</td><td rowspan="2">None</td></tr>
<tr><td>2d</td><td>Fluidised Bed Combustion (BFB) with steam turbine</td></tr>
</table>

Based on discussions with Ohorongo Cement we understand that Scenarios 2a and 2b will have the opportunity to use approximately 40 tonnes per hour (64,500 m^3 per hour) of hot air at 300°C. This is equivalent to 3.22 MW of free thermal energy input to the process, equal to nearly 10% of the required fuel (LHV) heat input. This additional energy input will effectively increase the efficiency of the combined process and reduce the quantity of biomass required to provide a given output.

3.2 Thermoflex Heat Balance Software

A review of several software tools was performed during the study in order to select a simulation software package that could be used to generate heat and mass balances and determine rough order of magnitude equipment sizing. The commercially available software tools capable of developing heat and mass balance range considerably in their capabilities. Ultimately, Thermoflex, which is a software package in the Thermoflow suite of thermal power plant software simulation tools was selected. This tool was selected because it is a superior product in terms of capability and flexibility to model a very wide range of thermal power plants and usability. WSP purchased a three month license for the software tool to undertake the modelling.

Thermoflex has been used to develop the data and information shown below for each of the scenarios discussed above. Separate from this report and its appendices, WSP is providing a plant design report which contains these sets of data for each scenario. These data have been extracted from Thermoflex and assembled as a PDF report as supplementary information.

- **Process flow diagrams (PFD)**. Users construct plant models using a series of icons for various equipment types, so model construction and data validation is performed through a visual user interface and this allows users to simultaneously generate simplified process flow diagrams for each model. Included in each PFD are the main processes which include the combustion process, heat exchangers, heat rejection, power generation, and emission control systems. Ancillary systems such as chemical water treatment are not included in the scope of the program. Stream parameters have been shown in each PFD so that the temperature, pressure, mass flow rate and stream enthalpy can be known at each stage of the process.
- **System & plant summary**. These simply detail the plant high level performance metric such as net electrical efficiency, and heat rates etc.
- **Heat and mass balances**. Thermoflex provides high heat and mass balance summary data at the plant level and at the component level. The models must balance or the software will require the user to make changes to the process in order to achieve a valid result.
- **Boiler schematic and heat balance**. A more detailed summary of the boiler in each scenario is presented which displays flows of air, fuel and steam to and from the biomass furnace. A detailed heat balance for the furnace is presented. NOTE: this does not include the boiler's economizer and superheater sections, this are not part of the "furnace" component in Thermoflex but are included in the model for each scenario as separate components.
- **Emission & stack summary**. Presents the rates of generation of emissions of particulate, SO_2 and NOx at various stages throughout the process. The stack summary presents emission rates in mg per normal cubic meter at 6% excess oxygen from the stack.
- **Fuel summary**. This report simply summarizes the user defined fuel. Thermoflex allows the user to specify a specific fuel's composition, calorific value, ash composition and melting temperature.
- **Water summary**. This report indicates the consumption of water by the plant including boiler blowdown and cooling as needed.
- **Turbine specification & overall balance**. These two reports provide a detailed description and energy balance for the steam turbine generator. This report could be used to request bids from suppliers and also provides an estimated size and installed cost for the machinery.
- **Turbine schematic**. Shows the steam flows to and from each stage of the turbine.
- **Turbine plan and elevation**. Representative drawings indicating the layout and size of equipment needed.

As Thermoflex is a highly configurable and flexible modelling tool it requires a large amount of specific input data to fully and accurately model a given process. Many of the required inputs can be obtained as default assumptions from the software tool, as an example, Thermoflex will by default assume electrical efficiencies for generators, pumps and fans. Thermoflex will also calculate certain efficiencies. The steam turbine generator assembly is given a set of input assumptions that allows Thermoflex to estimate performance of the unit using a combined thermodynamic and engineering level of detail, so that isentropic efficiencies are computed by the software rather than assumed by the user. The same is true of the furnace, Thermoflex will compute its performance with few required inputs from the user excepting that the user needs to specify air and fuel parameters. In addition, a number of input parameters have been obtained from equipment suppliers contacted during the study. This obviously is the best source of data but supplier specific data is often incomplete or in many cases suppliers are not willing to disclose of detailed performance data for their equipment at this early stage. As a result, the input parameters used the in the models have a mix of sources but each parameter has been selected for equipment and site specific reasons. A summary of the types and sources of input data needed are presented below.

- **Ambient conditions**. Average annual air temperature, pressure and relative humidity are all specified to the program so that combustion and cooling air are accurately modelled. Since the site locations considered in the study are close in proximity, only one data set was used and is specific to the Otjiwarongo location. Long term historical hourly data sets were obtained from The National Ocean and Atmospheric Administration (NOAA) and annual averages were determined.
- **Biomass furnace and boiler**. With the exception of defining the boiler's superheated steam temperature and pressure, much of the required furnace parameters are defined by Thermoflex and these include the furnace fuel gas temperature, the required primary and secondary air flow rates and pressures. A 20% excess air factor is assumed for all furnace types. The biomass boiler equipment suppliers WSP has received equipment supply quotes from have not supplied sufficiently detailed technical operating data to justify overriding Thermoflex default assumptions regarding such parameters as radiant heat loss, blow down steam consumption etc. Thermoflex has been allowed to compute the optimal operating parameters.
- **Steam turbine performance**. Thermoflex contains an additional module to allow detailed efficiency determinations for steam turbine assemblies. This module allows first allows users to define a turbine configuration, e.g. condensing extraction machine with a high and low pressure stage in a single casing design. Users can then define parameters such as location and amounts of steam leakages, exhaust area and design, and turbine group efficiency determination method. Since Thermoflex computes overall steam turbine efficiency, i.e. kWe per kg of steam consumed, a correction factor is used to modify this calculation to align with net efficiencies of the actual machinery for which WSP has received cost quotes.
- **Steam cycle parameters**. The steam cycle configuration which uses a single feedwater heater and both high and low pressure turbine stages was determined after reviewing the offerings of biomass power plant suppliers and reviewing the designs of existing thermal plants of this scale. Thermoflex determines the optimal steam extraction pressure and quantity for feedwater heating. In general, each scenario uses a single feedwater heater that is fed by low pressure extraction steam and condensate. The boiler uses an evaporative section, an economizer and a superheater. Thermoflex furnace components for the grate boiler also allow the use of a second radiant superheater built into the furnace. The circulating fluid bed furnaces allow in bed heat exchangers which have not been used in the modelling as they are assumed to introduce additional technical challenges for operation and maintenance. Both low pressure condensate and high pressure boiler feedwater pumps are needed and their respective pressure rise is optimized by Thermoflex.
- **Condenser performance**. Discussions with equipment suppliers have provided appropriate input assumptions for the site location and technology types. For example, one supplier recommended the operative condenser steam pressure and air temperature rise. This ultimately dictates the enthalpy which can be extracted by the steam turbine during extraction, so these parameters are key both to equipment sizing and performance of the entire plant.
- **Fuel composition**. Detailed fuel composition and CV data are supplied to Thermoflex as discussed below.

The result of incorporating as much known information from the various equipment vendors contacted, from modelling site specific conditions and from using the best simulation software available on the market is a highly accurate and configurable process model that NamPower can use with confidence to inform the feasibility of constructing a biomass fired power plant. In addition, the models can be refined as more information becomes available or if scenarios need to be modified.

3.3 Biomass Composition

Biomass composition data for Namibian Encroacher bush is quite limited in the public domain. A review of previous studies conducted has produced very little reliable composition and calorific value data. WSP commissioned Inspectorate, a Bureau Veritas Group Company, in South Africa to conduct composition analysis on six Encroacher bush biomass samples including 2 torrefied bush samples. The first four samples in the tables below arise from the Inspectorate analysis report. In addition, an analysis report became available from Laborelec, a GDF Suez company, to the study team during the feasibility study which provided an additional data point. The fifth sample shown below arises from the Laborelec analysis report. Each analysis report contains a proximate analysis, ultimate analysis and ash composition analysis. The Laborelec study also determined ash deformation temperature. Together these two studies can be used to develop a representative biomass composition analysis based on the five untreated biomass samples. This is useful since encroacher bush would be sourced from several presently unknown locations and may vary seasonally as different regions are harvested.

The proximate analysis results are presented in Table 7. The gross calorific value (GCV) reported in the analysis report has been converted to net calorific value (NCV). The average results are also converted to weight per cent on an as-received basis for a moisture content of 15%. This is the assumed moisture content on an as-fired basis by the biomass furnace and which is used in the heat and mass balance calculations. In practice, the moisture content may actually be lower if NamPower employ a windrow drying technique similar to that used by Schwenk, so 15% is likely a conservative assumption. **NOTE**: at the time when the technical modelling was performed, only the fifth sample (chopped Encroacher Bush from 07/02/2011) was available and this dataset was used in the mass & energy balance calculations presented in this study.

Table 7: Proximate analysis of raw Namibian Encroacher bush, reported on an Air-dried Basis

Sample Name	H_2O	Ash	Volatile	Fixed Carbon[2]	GCV (kJ/kg-AR)	NCV (kJ/kg-AR)[3]
(G1) Gershon hammermill <5 cm wood chips	4.3	11.4	68.8	15.5	16,150	15,143
(EFF1) EFF hammermill <5 cm wood chips	10.2	4.6	68	17.2	16,380	15,288
(EFF2) EFF 5-20 cm wood chips	5.9	6.6	70.5	17	16,900	15,828
(CCF1) CCF 5-20 cm wood chips	7.5	1.7	72.1	18.7	17,360	16,228
Chopped Encroacher Bush Samples 07/02/2011 (as received)	9.20	5.30	71.20	14.30	15,553	14,219
Average of all Samples	7.42	5.92	70.12	16.54	16,469	15,260
Average of all Samples at 15% M.C.	15.00	5.44	64.38	15.19	15,120	13,909

The ultimate analysis results are presented in Table 8. A further Chlorine analysis is also currently being undertaken at a separate laboratory (Inspectorate had reported difficulties in undertaking reliable Chlorine analysis on biomass combustion samples).

[2] Fixed carbon is determined by difference

[3] Net calorific value is not reported but is computed using GCV, hydrogen and moisture contents

Table 8: Ultimate analysis of raw Namibian encroacher bush

Sample Name	C	H	N	O	S	Cl[4]	F	Ash	H_2O
(G1) Green Coal hammermill <5 cm wood chips	42.60	4.32	0.51	36.68	0.06			11.40	4.30
(EFF1) EFF hammermill <5 cm wood chips	45.30	4.30	0.51	34.91	0.05			4.60	10.20
(EFF2) EFF 5-20 cm wood chips	46.20	4.52	0.65	35.94	0.06			6.60	5.90
(CCF1) CCF 5-20 cm wood chips	47.90	4.70	0.56	37.46	0.05			1.70	7.50
Chopped Encroacher Bush Samples 07/02/2011 (as received)	41.95	5.08	0.55	37.86	0.06	0.124	<0.001	5.36	9.20
Average of all Samples	44.79	4.58	0.56	36.54	0.06	0.124	<0.001	5.93	7.42
Average of all Samples at 15% M.C.	41.12	4.21	0.51	38.54	0.05	0.11	0.00	5.45	10.00

Table 9: Ash analysis of raw Namibian Encroacher bush

Sample Name	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3
(G1) Green Coal hammermill <5 cm wood chips	56.95	28.5	2.19	1.33	0.5	3.09	0.39	2.49	1.54	2.56
(EFF1) EFF hammermill <5 cm wood chips	64.5	21.7	1.93	2.23	0.79	3.34	0.57	0.36	2.45	1.85
(EFF2) EFF 5-20 cm wood chips	48.5	29.13	10.17	1.14	1.89	4.96	0.58	0.81	1.2	1.07
(CCF1) CCF 5-20 cm wood chips	52.1	24.54	6.15	1.27	3.11	3.79	0.9	0.45	0.73	5.73
Chopped Encroacher Bush Samples 07/02/2011	6.7	1.8	0.4	0.1	3.4	68.2	4.3	0.6	11.2	3.2
Average of all Samples	45.75	21.13	4.17	1.21	1.94	16.68	1.35	0.94	3.42	2.88

3.4 Thermal Plant Design

For the purposes of this study, a simple steam cycle is proposed which is based on the design parameters supplied by equipment vendors. When modelling each scenario a number of common assumptions have been made regarding the steam conditions and the type of turbine and condensers employed. Basic steam cycle details are presented below:

- **Boiler Steam Conditions** - boiler superheated steam outlet conditions are 480°C and 62 bar(a) for the 10MWe line plants and 420°C and 45 bar(a) for the 5MWe plant. These conditions represent an approximate upper limit in steam pressure and temperature recommended by the boiler suppliers to ensure that superheater tubes do not experience excessive fouling. This is due to the relatively high chlorine content expected in the biomass fuel, and the presence of alkali metals in the ash which together can result in severe heat exchanger fouling at high temperatures and pressures. In addition, steam turbine generators can be purchased from vendors "off the shelf" at these steam conditions. Turbine generators typically require further project based engineering design at higher pressures, the cost of which is unlikely to be justified at the 5 - 20 MWe scale.
- **Steam Turbine Generator** – superheated steam will enter the turbine generator assembly at the conditions specified above. The condensing-extraction turbine will have a high pressure stage which operates

[4] Not available at time of writing

between the steam inlet pressure of 62 bar(a) and 1.24 bar(a) where a controlled extraction will remove a small portion of steam for feedwater heating (see below). The low pressure turbine stage will further expand the remaining steam from 1.24 bar(a) to the condenser pressure of 112.5 mbar(a). The turbine drive shaft will be coupled to a generator which will produce electricity to supply the plant and export to the grid.

- **Air Cooled Condensers** – saturated steam exiting the turbine generator will be condensed with air cooled condensers at a pressure of 112.5 mbar(a). Air cooled condensers require far less water than evaporative systems (cooling towers) and are considered the most appropriate type of condenser for this application. The assumed condenser pressure corresponds to an annual average ambient temperature of 21°C. However, the air cooled condensers have been sized at a maximum design ambient temperature of 35°C and a condenser pressure of 200 mbar(a). Air will be forced across the heat exchanger tubes with fans and will experience a maximum temperature rise of 19°C. Design turbine exit conditions are steam quality of 92.75%, a pressure of 112.5 mbar(a) and a temperature of 48°C.
- **Feedwater Heating** – A single feedwater heater and dearator is proposed to be supplied with steam extracted from the steam turbine at 1.24 bar(a). Approximately 3 to 4% of the steam produced by the boiler will be extracted to pre-heat the feedwater prior to entering the boiler's economizer section.

WSP's assessment for plants of this scale considered in this study (5 - 20 MW) is that cycle efficiency improvements such as steam re-heat and regeneration (use of multiple feedwater heaters) are unlikely to be economical as the additional electrical output would be more than offset by the additional capital and maintenance costs. However, a detailed equipment cost assessment and comparison of levelised cost of generation has not yet been performed. This activity would need to be carried out at a later stage of the project development cycle.

A number of other assumptions have been made which are common to all the scenarios:

- Operational hours – 8,100 per year which equates to a plant availability of 92.5%
- Biomass net calorific value (NCV) – 15.55 MJ/kg
- Biomass gross calorific value (GCV) – 16.89 MJ/kg

Details of the thermal performance of each biomass boiler are provided in Table 10.

Table 10: Thermal performance of the biomass boilers used in each scenario

Scenario		Furnace exit temperature (°C)	Blowdown (proportion of steam production)	Steam pressure (bara)	Steam temperature (°C)	Thermal efficiency (computed)
1	5MW grate	982	1%	45	450	92.4%
2a	2x10MW grate	982	1%	62	480	92.4%
2b	2x10MW BFB	816	0.25%	62	480	93.6%
2c	2x10MW grate	982	1%	62	480	92.4%
2d	2x10MW BFB	816	0.25%	62	480	93.6%

3.5 Energy Performance

The energy performance of each plant has been modelled using Thermoflex. A summary of the electrical output and efficiency of each plant is provided in Table 11.

The efficiency of the 5MW plant is notably lower than the 20MW plants as the thermodynamic efficiency of the steam cycle inherently falls at small scale (lower steam pressure and temperature), and because the parasitic load does not fall linearly with rated output, reducing the proportion of electricity available to export.

The parasitic load of the plant ranges from approximately 10% of total output for the 20MW scenarios to 15% for the 5MW plant.

The electrical efficiency of the Ohorongo Cement scenarios is somewhat higher than plant located at Otjikoto as a result of the additional hot air input.

The efficiency of the grate and fluidised bed systems are broadly similar, though the BFB gives a slightly higher efficiency.

Table 11: Electrical Generation Summary

Scenario		Gross Electrical Output (MW)	Parasitic Load (MW)	Net Electrical Output (MW)	Net Electrical Efficiency
1	5MW grate	5.9	0.9	5.0	20.7%
2a	2x10MW grate	22.8	2.8	20.0	26.5%
2b	2x10MW BFB	22.4	2.4	20.0	26.5%
2c	2x10MW grate	22.7	2.7	20.0	24.3%
2d	2x10MW BFB	22.3	2.3	20.0	24.8%

3.6 Process Flow Diagrams

Process flow diagrams (PFDs) for each scenario have been generated using Thermoflex and provide a visual representation of the thermodynamic simulations performed for each scenario. These PDFs are simplified in that they do not show an engineering level of detail. Each process flow diagram includes shows stream data including mass flow rates, temperature, pressure, and stream enthalpy in SI units at each section of the process. Steam and water flow lines are displayed in blue while air and flue gas streams show up in red. Fuel flows are displayed in orange.

These diagrams are provided in the report Appendix numbered as follows:

- Appendix A – Scenario 1 – 5 MW Grate Boiler Plant at Otjiwarongo
- Appendix B – Scenario 2a – 2 x 10 MW Grate Boiler Plant at Ohorongo
- Appendix C - Scenario 2b – 2 x 10 MW BGB Boiler Plant at Ohorongo
- Appendix D - Scenario 2c – 2 x 10 MW Grate Boiler Plant at Otjikoto
- Appendix E - Scenario 2d – 2 x 10 MW BFB Boiler Plant at Otjikoto

3.7 Plant Layout and Elevation

3.7.1 Layout Drawings

The proposal from one of the suppliers contacted has included a representative layout drawing for a 5 MW grate boiler plant and this is assumed to be accurate for Scenario 1. The drawing includes a general plant layout showing the 6.5 MW gross output turbine generator, the boiler, the sub-station, the air cooled condensers, water tanks and emission controls and stack. The drawing includes a sectional view of the boiler and indicates a total building height of 20 meters would be required.

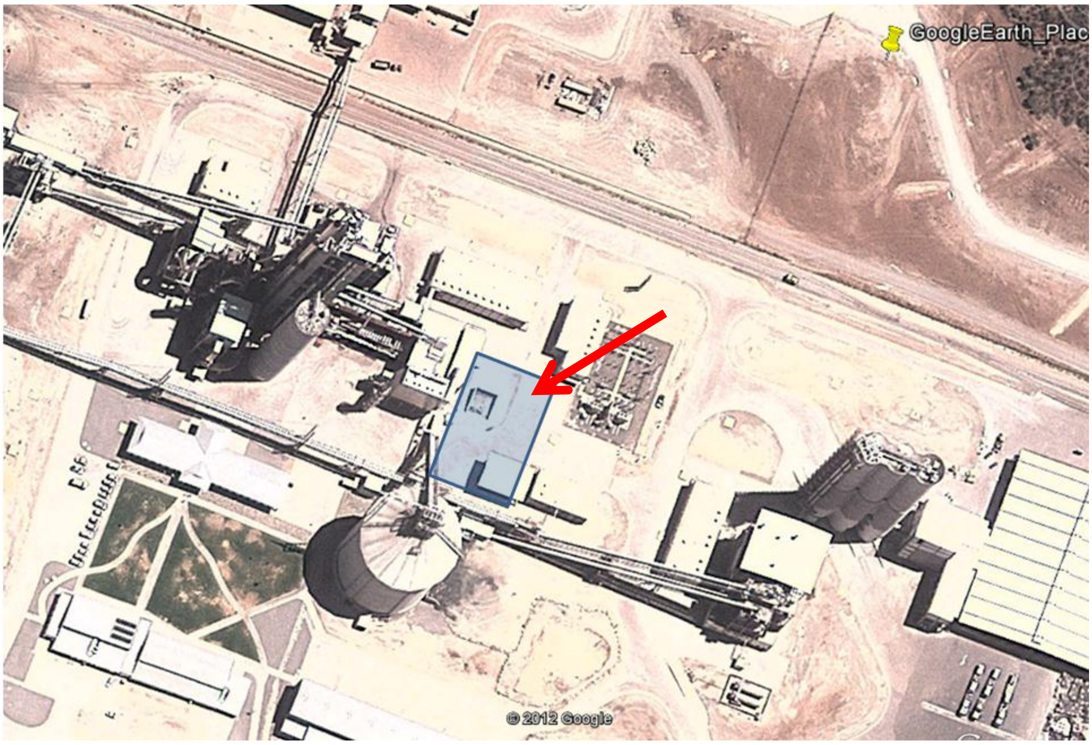
In addition, based on information provided by technology suppliers, WSP and Otto Simon have developed a representative plant layout drawing for a typical 20 MW biomass combustion plant (2 lines each of 10MW). The drawing is based on information received from supplier's grate boiler technology and air cooled condensers. This layout drawing would be generally representative for all of the 2 line 20 MW scenarios considered since the boilers will all have roughly the same footprint requirement. The drawing includes boilers, flue gas treatment and stacks, turbine generators and air cooled condensers. The plant layout footprint has been modified to fit into the preferred space as indicated by Schwenk (Ohorongo Cement) – see next section. The following drawings are provided in the appendices:

- Appendix F – Plant layout drawing for Scenario 1 – 5 MW Grate Boiler Plant
- Appendix G – Plant layout drawing for Scenario 2a-2d – Representative of 2 x 10 MW biomass combustion plants

3.7.2 Available Site Area

For the Ohorongo Cement scenarios a preliminary site for a biomass plant has been identified within the cement plant complex itself (Figure 8). The site dimensions are 100m x 44m, and the plant layout drawing suggests it would be feasible to locate a 20MW plant within this area, though further work would be necessary to confirm that there is sufficient space for vehicle movements and construction access etc., and that the elevation of the buildings or stack would not be an issue.

Figure 8: Potential site for biomass combustion plant at Ohorongo Cement (Scenarios 2a, 2b)



Neither the Otjikoto Substation site or CCF site are thought to have significant restrictions.

3.8 Process Requirements

The plant will require various inputs of materials and energy to allow it to perform reliably and efficiently:

- Biomass fuel
- Auxiliary fuel and electricity
- Water
- Chemicals for flue gas treatment
- Chemicals for boiler cleaning and water treatment

These aspects are considered in this section.

3.8.1 Fuel Requirements

It is assumed that biomass will arrive at the plant reception in the form of chips. The biomass fuel requirement for each plant is shown in Table 12.

Table 12: Biomass Fuel Requirements

Scenario		**Biomass Consumption**	
		Tonnes/hr, as received	**Tonnes/y, as received**
1	5MW grate	5.6	45,247
2a	2x10MW grate	18.2	147,226
2b	2x10MW BFB	17.4	141,167
2c	2x10MW grate	19.1	154,386
2d	2x10MW BFB	18.7	151,535

The fuel requirement is based on biomass 'as received' on delivery to the plant (i.e. raw, air dried encroacher bush biomass chips with the composition described in Section 3.2).

3.8.2 Water Requirements

Water use will primarily be limited to water needed by the boiler for heat exchanger surface cleaning, referred to as blowdown, and water required to replace that lost to leaks particularly at the turbine. Blowdown water consumption for each boiler is automatically computed in Thermoflex and is estimated at around 1% of the total steam production. Blowdown water use will need to be supplied to the plant and will need to be treated to remove impurities. Additional water is needed to make up for steam leakages in the turbine and steam power system. The requirement for each plant is shown in Table 13.

Small quantities of water will also be required for non-process use, but this will be small relative to process use and has not been quantified.

Table 13: Water Consumption

Scenario		Boiler Blowdown	Steam Turbine Leakages	Total Water consumption	
		Tonnes/hr	Tonnes/hr	Tonnes/hr	Tonnes/y (approx. equivalent to m^3/y)
1	5MW grate	0.26	0.06	0.32	2,606
2a	2x10MW grate	0.94	0.12	1.06	8,584
2b	2x10MW BFB	0.23	0.12	0.35	2,854
2c	2x10MW grate	0.94	0.12	1.06	8,584
2d	2x10MW BFB	0.23	0.12	0.35	2,854

It is noted that wet-cooling systems were also considered at the earlier stages of the study (up to 81 tonnes/hr for a 20 MWe system); however all the vendors approached indicated a preference for air-cooled technology for proposed power plants. Within the context of Namibia, this is also clearly the more environmentally sustainable option.

The supply of water will need to be considered further i.e. as to whether it is possible to get the needed supply form municipal supply or whether it will need to be sourced from groundwater (and possibly treated). The following is noted with regards to water supply for each scenario:

- Scenario 1 (CCF): Water supply may be either from the municipality or from groundwater. A geohydrological investigation will be required if water is to be sourced form groundwater. Based on the information available, boreholes in the Otjiwarongo area are capable of supplying 3 – 15 tonnes/hr of groundwater. However the availability of good yielding boreholes is variable and will need to be proven in the specific location considered.
- Scenario 2a & 2b (Ohorongo Cement): The site falls within compartment G of the Grootfontein-Tsumeb-Otavi water management area, for which the total abstraction permits are limited to 1.5Mm^3/year (GKW Consult, 2002). In discussions undertaken with Mr Piet Heyns, formerly a senior government official overseeing water management in Namibia and now a private consultant, it was indicated that obtaining a water permit for the amount of water being requested was unlikely to be an issue (this was referring to a permit for much greater water extraction values to support a wet cooling system for a 30 MWe plant i.e. circa 121.5 tonnes/hr). Hence, obtaining water for the air cooled systems in Table 12 is unlikely to be an issue.

  Furthermore, according to the specialist groundwater study for the Ohorongo Cement Facility, the cement facility abstracts already approximately 70,000m^3 per year, from four boreholes drilled to a depth of 31,52m below the ground surface, with a yield rate of 4m^3 per hour and a drawdown of 9,72m. It is probable therefore that water can be obtained from the existing infrastructure or an expansion thereof.
- Scenario 2c & 2d (Otjikoto): Groundwater is the main source of supply in this area. The possibility of receiving a supply from the nearby Tsumeb municipality cannot be ruled out, however on-site or near site boreholes may also be an option, subject to site specific geohydrological site investigation. The site is situated within the Karst Aquifer which forms part of the Tsumeb-Otavi-Grootfontein Subterranean Water Control Area, or Karst Water Control Area (KWCA). The Karst Aquifers host the most important groundwater resource in the region and the water is generally of good quality. The aquifer is defined as having moderate to high potential. Nevertheless, groundwater monitoring over the wider area of the Otavi Mountain Lands (OML) in the past indicates a steady decline in the water levels in the Otavi Mountain Lands. The aquifer is already extensively used, and has a sustainable yield of 36 Mm^3/a, currently allocated up to 32.8 Mm^3/a (KWMA). The MAWF has divided the Karst aquifers in the Grootfontein-Tsumeb-Otavi area into compartments for administrative purposes. The site falls on the border of compartment B1 and B2, for which the total abstraction permits are limited to 2.4 Mm^3/year and 5.2

Mm^3/year respectively (Mazambani et al). According to Christian & Associates, (2009) the area around Tsumeb has high groundwater potential (~15m^3/ hour >360m^3/day). For the volumes of water being considered for the air-cooled systems proposed in Table 12, and considering that electricity generation is a high priority economic sector, obtaining sufficient water is unlikely to be an issue, although this will still be subject to a site specific geohydrological study. Auxiliary Fuel and Electricity Requirements

In normal operation the plant will consume electricity for process and non-process usage, including for pumps, fans, controls and lighting. This will be supplied by the plant itself for the vast majority of the time. However during start-up and shut-down periods the plant will require auxiliary fuel to initiate combustion and electricity from the grid to power the plant while the turbine is off-line. Such requirements are small relative to the total annual load, but still represent an operational cost. An approximate estimate of the annual total fuel and power requirement is provided in Table 14. These estimates are subject to a high level of uncertainty as the consumption depends on a number of factors such as the reliability of the plant, emissions legislative requirements and technology type.

Table 14: Auxiliary Fuel and Electricity Requirements

Scenario		**Electricity (MWh/y)**	**Auxiliary Fuel (MWh/y)**
1	5MW grate	14	386
2a	2x10MW grate	45	1,255
2b	2x10MW BFB	38	1,208
2c	2x10MW grate	44	1,317
2d	2x10MW BFB	36	1,290

3.8.3 Other Consumables

Biomass power plants require a number of consumables to ensure proper and effective long term operation.

Emissions control

Fluidised bed boilers utilise limestone injection as a reagent to control sulphur emissions. Grate boilers can control sulphur emissions via injection of lime into the flue gas, however the equipment vendors advised this is unlikely to be necessary to comply with emissions limits given the composition of the biomass. Nitrogen oxides (NOx) emissions are controlled with selective non-catalytic reduction emission control devices. These require a supply of urea which is combined with an aqueous reagent (to produce a slurry) and injected into the flue gas. The urea will be completely consumed by the reactions and leave the facility as gaseous components via the stack (converting a proportion of NOx into benign N_2 and H_2O in the process). Limestone supplied to the fluidised bed boilers will be converted to calcium sulphate, which will be a solid residue present in the boiler ash.

Boiler cleaning

Boiler water cleaning will also be required in order to remove impurities and dissolved gases that can lead to corrosion (via a demineralisation plant or reverse osmosis unit), and also periodically to remove deposits of scale etc. that may accumulate. This will require various chemicals depending on the type of system used. At this stage it has not been possible to quantify the quantities required as it depends on the raw water composition and choice of technology, but it is expected the quantities required will be relatively small compared to other consumables. Costs have been estimated based on rule-of-thumb data available to WSP, expressed as a cost per unit of fuel input rather than a cost per tonne of chemicals.

The annual consumption of the consumables above is shown in Table 15.

Table 15: Consumables

Scenario		Emissions Control - SO_2 Reduction	Emissions Control - NOx Reduction		Boiler Cleaning Chemicals
		Limestone (tonnes/y)	Urea (tonnes/y)	Aqueous Reagent (tonnes/y)	
1	5MW grate	0	119	238	Actual quantities unknown – cost estimated based on fuel input
2a	2x10MW grate	0	407	813	
2b	2x10MW BFB	745	389	778	
2c	2x10MW grate	0	407	813	
2d	2x10MW BFB	745	389	778	

3.9 Process Emissions

3.9.1 Air Emissions

Emissions of pollutants have been quantified by Thermoflex for the various plant configurations modelled. Each plant design uses an electrostatic precipitator or fabric filter to control particulate emissions and all scenarios are assumed to use an SNCR device to control NOx emissions. Sulphur concentrations in the raw biomass are low enough that flue gas scrubbers are not required to control SO_2 emissions in the flue gas, though the fluidised bed models use limestone injection to prevent formation of SO_2 emissions simply because this is a low cost solution, particular for Scenario 2b where the plant is located at Ohorongo Cement, owing to the proximity to a limestone mine. Table 16 outlines the emission control devices which have been assumed for each scenario.

Table 16: Emission control devices used

Scenario	Particulate	Sulphur Dioxide (SO_2)	Nitrogen Oxides (NOx)
Grate Boilers	ESP with removal efficiency of 99.7%	Uncontrolled	SNCR with 50% NOx reduction effectiveness
Bubbling Fluidized Bed Boilers	Fabric Filter with removal efficiency of 99.9%	Bed limestone injection with 80% removal efficiency	SNCR with 50% NOx reduction effectiveness
Circulating Fluidized Bed Boilers	Fabric Filter with removal efficiency of 99.9%	Bed limestone injection with 90% removal efficiency	SNCR with 50% NOx reduction effectiveness

Thermoflex has been used to predict dust loading and SO_2 emissions based on boiler type, operating temperature and fuel parameters. User specified NOx production rates are inputted and from these baseline emission production rates along with the control efficiencies established above, NOx production in the furnace is assumed to be 211 g per GJ (HHV) for all boilers and all scenarios since boiler specific generation rates have not been provided by equipment vendors.[5]

[5] EPA AP 42 Emission Factor database

Table 17: WHO Guidelines for stack emissions from solid fuel boilers, emission rates in mg/Nm3 at 6% O_2 on dry gas

	Non-degraded areas		**Degraded areas**	
	Limit for boilers <50MWth fuel	Limit for (solid fuel) boilers >50 MW to <600MWth fuel	Limit for boilers <50MWth fuel[6]	Limit for (solid fuel) boilers >50 MWth to <600MWth fuel
Particulates	50	50	50	30
SO_2	2000	900 - 1500	2000	400
NOx	650	510	650	200

Table 18 presents the computed stack emission concentrations reported at 6% excess oxygen on dry gas as recommended in the World Health Organisation guidelines. Each power plant scenario presented can achieve the emission limits proposed by WHO for non-degraded areas. It would be possible to reduce the SO_2 emissions from the grate system to similar level as the fluidised bed system by installing acid gas scrubbers with lime injection to the flue gas, but with a penalty of increased capital and operational costs.

Table 18: Plant air emissions in mg/Nm^3 at 6% O_2, dry

Scenario		**Emission Concentration (mg/m^3 , 6% O_2 dry basis)**		
		Particulates	**Sulphur Dioxide (SO_2)**	**Nitrogen Oxides (NOx)**
	WHO guidelines limits <50 MWth[7]	***50***	***2,000***	***650***
1	5MW grate	25	225	299
	WHO guidelines limits 50 to 600 MWth[8]	***50***	***900 - 1500***	***510***
2a	2x10MW grate	25	225	299
2b	2x10MW BFB	9	46	311
2c	2x10MW grate	25	225	299
2d	2x10MW BFB	9	46	311

A more comprehensive assessment of total plant air emissions in tonnes per annum is presented in Table 19 for informational purposes. With the exception of ammonia, which is formed in the SNCR system as a result of incomplete oxidation following NOx reduction, the other species are all formed as combustion products. The emission totals presented here represent species total annual stack emission subsequent to the emission controls used.

---

[6] Higher performance levels than these in the table should be applicable to facilities located in urban / industrial areas with degraded airsheds or close to ecologically sensitive areas where more stringent emissions controls may be needed

[7] Applies to the 5 MW electrical output scenario

[8] Applies to all 20 MW electrical output scenarios

Table 19: Plant air emissions in tonnes per year

Scenario		All figures in tonnes/year						
		Nitrogen Oxides (NOx)	Sulphur Dioxide (SO_2)	Sulphur Trioxide (SO_3)	Hydrogen Chloride (HCL)	Ammonia (NH_3)	Carbon Dioxide (CO_2)	Particulate Matter
1	5MW grate	72	54	13	46	37	69,543	6
2a	2x10MW grate	247	185	44	158	127	237,252	21
2b	2x10MW BFB	249	36	0	155	128	230,076	7
2c	2x10MW grate	247	185	44	158	127	237,252	21
2d	2x10MW BFB	249	36	0	155	128	230,076	7

3.9.2 Ash Production and Disposal

Biomass fuel contains a proportion of non-combustible matter that will pass through the furnace and exit as ash. Some of the ash will drop out the bottom of the furnace while some will be entrained in the hot gases exiting the boiler and will be collected by electrostatic precipitators or fabric filters (fly ash).

The quantities of ash generated from plants modelled in each scenario are provided in Table 20.

Table 20: Total boiler bottom and fly ash production by scenario

Scenario		Bottom Ash	Fly Ash	Total Ash	
		Tonnes/hr	Tonnes/hr	Tonnes/hr	Tonnes/y
1	5MW grate	0.05	0.26	0.30	2,457
2a	2x10MW grate	0.15	0.84	0.99	7,994
2b	2x10MW BFB	0.33	0.78	1.11	9,022
2c	2x10MW grate	0.16	0.88	1.04	8,384
2d	2x10MW BFB	0.36	0.84	1.20	9,684

Encroacher bush composition analysis conducted by Laborelec of GDF Suez and Inspectorate was made available during the study.[9] The analysis included ash composition analysis. The Encroacher bush ash analysis is presented below showing all metal oxides present in the biomass as an average between the Laborelec and the Inspectorate Encroacher bush sample analyses. The collection of ash from the combustion process will take place at the boiler and cyclone separators. Both of these sources of ash will contain unburned carbon, and as such, presents the representative composition of ash collected from fluidized bed boilers and grate boilers adjusted for the content of unburned carbon. The fluid bed boiler ash stream will also contain calcium sulphate produced in the reaction of limestone used to control sulphur dioxide emissions. This has not been accounted for in the ash analysis below but would be present at up to 7% by weight in the BFB and CFB residues.

[9] Refer to Solid Biofuel Analysis Report Number 2011-BIO-026

Table 21: Representative Ash Analysis

Component	Weight % in as received biomass	Weight % in BFB and CFB combustion residue	Weight % in Grate Boiler Combustion Residue
SiO_2	45.8%	41.2%	45.2%
Al_2O_3	21.1%	19.0%	20.9%
Fe_2O_3	4.2%	3.8%	4.1%
CaO	1.2%	1.1%	1.2%
MgO	1.9%	1.7%	1.9%
Na_2O	16.7%	15.0%	16.5%
K_2O	1.3%	1.2%	1.3%
TiO_2	0.9%	0.8%	0.9%
P_2O_5	3.4%	3.1%	3.4%
SO_3	2.9%	2.6%	2.8%
Other Ash	0.5%	0.5%	0.5%
Unburned Carbon		9.90%	1.30%

Initial discussions with Schwenk, who are majority owners of the Ohorongo Cement plant, indicate the biomass combustion ash could be used as a feedstock in the cement production process. For facilities sited at or near Ohorongo Cement, this would be the best use of the combustion ash residues from both an economic and environmental perspective. Effectively the ash produced could be disposed of at zero cost.

For the scenarios where a plant is located at Otjikoto or Otjiwarongo it is unlikely to be viable to transport the ash to Ohorongo Cement in an economically viable manner. In these cases it will be necessary to find alternative outlets, or dispose of via landfill. Ash from encroacher bush is rarely classified as hazardous, and could potentially be used as a construction material or agricultural additive. However if suitable outlets cannot be found within an economic transportation distance the most appropriate solution may be to develop a non-hazardous landfill at or close to the combustion plant, in order to avoid haulage costs to existing landfills which may be significant given the geography of Namibia. This option would need further investigation if a site other than Ohorongo Cement is chosen, or if it is found that the cement plant cannot accept the ash for any reason.

3.9.3 Effluent Emissions

Much of the water required for process use will be contained in a closed system; however there will be an effluent discharge from boiler blowdown. The quantity of blowdown water arising from each scenario is provided in Table 22.

Table 22: Blowdown Emissions

Scenario	System	Blowdown effluent	
		Tonnes/hr	Tonnes/y
1	5MW grate	0.2597	2,104
2a	2x10MW grate	0.463	3,750
2b	2x10MW BFB	0.1167	945
2c	2x10MW grate	0.4698	3,805
2d	2x10MW BFB	0.1165	944

Blowdown water will contain dissolved minerals and impurities which mean effluent consents will be required if disposed of off-site. At this stage we envision the use of boiler blowdown water for ash cooling. A proportion will be lost to evaporation in this process, with the remaining water sent to a settlement/evaporation pond where the water will evaporate and remaining minerals contained on-site, avoiding the requirement to discharge off-site.

This is similar to the arrangement currently in place at the Van Eck coal-fired plant.

3.10 Heat and Mass Balances

High level mass and energy balance information has been presented in the previous sections of this chapter which convey the key process inputs and outputs such as feed rates of biomass, ash production, water consumption, etc. needed to deliver a 5 MW or 20 MW net electrical output. Thermoflex also provides a detailed heat and mass balance for the plant and for each component in the process scenario modelled. Generally these include fuel flows, air and flue gas flows, steam and water flows, mechanical compression and expansion power. These heat and mass balances have been copied from Thermoflex and are presented in the Tables below. The reader is however, encouraged to also refer to the supplementary design report provided for further details and reference for where each component is physically located in the process.

Table 23: Heat and Mass Balance for Scenario 1

HEAT BALANCE				
Zero enthalpy @ 77F (25C) & vapour H2O.				
Component		**[kW]**	**[kW]**	**%**
Air-cooled Condenser[28]	Heat input	-2.42		
Duct[24]	Heat removed/lost		0.00	
Duct[4]	Heat removed/lost		13.68	
Duct[21]	Heat removed/lost		6.33	
Economiser[11]	Heat input	40.98		
Economiser[11]	Heat removed/lost		49.58	
Fan[17]	Compression power	15.58		
Fan[20]	Compression power	221.90		
Fan[25]	Compression power	13.63		
Fuel Source[2]	Heat input	24125.00		
Furnace w/Grate[1]	Heat removed/lost		342.50	
Gas/Air Sink[29]	Heat removed/lost		12589.00	
Gas/Air Source[18]	Heat input	-22.61		
Gas/Air Source[26]	Heat input	-15.07		
Gas/Air Source[30]	Heat input	-3393.00		
General HX[3]	Heat removed/lost		6.15	
General Pump[7]	Pumping power	11.98		

General Pump[9]	Pumping power	2.32		
General Pump[34]	Pumping power	44.72		
Makeup/Blowdown[14]	Heat input	-222.00		
Parallel Tubular Air Heater[12]	Heat input	7.21		
Parallel Tubular Air Heater[12]	Heat removed/lost		10.53	
Pipe[16]	Heat removed/lost		16.66	
Selective Non-Catalytic Reduction[6]	Heat removed/lost		0.00	
Stack[23]	Heat removed/lost		1469.50	
Steam Turbine[8]	Expansion power		4171.00	
Steam Turbine[8]	ST leak outs		266.30	
Steam Turbine[10]	ST leak ins	225.00		
Steam Turbine[10]	Expansion power		2105.90	
Superheater[5]	Heat input	22.38		
Superheater[5]	Heat removed/lost		28.49	
Total Energy Input		**21075.00**		
Total Energy Output			**21076.00**	
Cycle Heat Balance Error			**1.03**	**0.0043**
MASS BALANCE				
Component		**[t/h]**	**[t/h]**	**%**
Air-cooled Condenser[28]	Mass flow in	0.00		
Fuel Source[2]	Mass flow in	5.59		
Furnace w/Grate[1]	Mass flow out		0.56	
Gas/Air Sink[29]	Mass flow out		3008.00	
Gas/Air Source[18]	Mass flow in	20.05		
Gas/Air Source[26]	Mass flow in	13.36		
Gas/Air Source[30]	Mass flow in	3008.00		
Makeup/Blowdown[14]	Mass flow in	0.32		
Makeup/Blowdown[14]	Mass flow out		0.00	
Stack[23]	Mass flow out		38.70	
Steam Turbine[8]	Mass flow out		1.24	
Steam Turbine[10]	Mass flow in	1.18		
Total Mass Flow In		**3049.00**		
Total Mass Flow Out			**3049.00**	
Cycle Mass Balance Error			**0.00**	

Table 24: Heat and Mass Balance for Scenario 2a

HEAT BALANCE				
Zero enthalpy @ 77F (25C) & vapour H2O.				
Component		**[kW]**	**[kW]**	**%**
Air-cooled Condenser[28]	Heat input	-4.35		
Deaerator[16]	Heat removed/lost		0.00	
Duct[24]	Heat removed/lost		0.00	
Duct[4]	Heat removed/lost		23.46	
Duct[31]	Heat removed/lost		4.79	
Economiser[11]	Heat input	59.65		
Economiser[11]	Heat removed/lost		74.27	
Fan[17]	Compression power	14.18		
Fan[20]	Compression power	393.90		
Fan[25]	Compression power	50.07		
Fuel Source[2]	Heat input	39250.00		
Furnace w/Grate[1]	Heat removed/lost		554.80	
Gas/Air Sink[29]	Heat removed/lost		21633.00	
Gas/Air Source[18]	Heat input	-17.10		

Gas/Air Source[26]	Heat input	3223.00		
Gas/Air Source[30]	Heat input	-5831.00		
General HX[3]	Heat removed/lost		4.97	
General HX[19]	Heat removed/lost		20.90	
General Pump[7]	Pumping power	25.81		
General Pump[9]	Pumping power	4.02		
General Pump[34]	Pumping power	113.90		
Makeup/Blowdown[14]	Heat input	-361.10		
Pipe[27]	Heat removed/lost		29.92	
Selective Non-Catalytic Reduction[21]	Heat removed/lost		0.00	
Stack[23]	Heat removed/lost		2415.70	
Steam Turbine[8]	Expansion power		8423.00	
Steam Turbine[8]	ST leak outs		462.60	
Steam Turbine[10]	ST leak ins	418.80		
Steam Turbine[10]	Expansion power		3678.00	
Superheater[5]	Heat input	44.36		
Superheater[5]	Heat removed/lost		57.43	
Total Energy Input		**37384.00**		
Total Energy Output			**37383.00**	
Cycle Heat Balance Error			**-0.86**	**-0.0022**
MASS BALANCE				
Component		**[t/h]**	**[t/h]**	**%**
Air-cooled Condenser[28]	Mass flow in	0.00		
Deaerator[16]	Mass flow out		0.00	
Fuel Source[2]	Mass flow in	9.09		
Furnace w/Grate[1]	Mass flow out		0.96	
Gas/Air Sink[29]	Mass flow out		5170.00	
Gas/Air Source[18]	Mass flow in	15.16		
Gas/Air Source[26]	Mass flow in	40.16		
Gas/Air Source[30]	Mass flow in	5170.00		
Makeup/Blowdown[14]	Mass flow in	0.52		
Makeup/Blowdown[14]	Mass flow out		0.00	
Stack[23]	Mass flow out		63.91	
Steam Turbine[8]	Mass flow out		2.03	
Steam Turbine[10]	Mass flow in	1.97		
Total Mass Flow In		**5237.00**		
Total Mass Flow Out			**5237.00**	
Cycle Mass Balance Error			**0.00**	

Table 25: Heat and Mass Balance for Scenario 2b

HEAT BALANCE				
Zero enthalpy @ 77F (25C) & vapour H2O.				
Component		**[kW]**	**[kW]**	**%**
Air-cooled Condenser[28]	Heat input	-3.88		
Deaerator[16]	Heat removed/lost		0.00	
Duct[24]	Heat removed/lost		0.00	
Duct[4]	Heat removed/lost		23.35	
Duct[31]	Heat removed/lost		10.79	
Economiser[11]	Heat input	62.19		
Economiser[11]	Heat removed/lost		75.35	
Fan[17]	Compression power	40.25		
Fan[20]	Compression power	387.00		
Fan[25]	Compression power	23.26		

Fuel Source[2]	Heat input	41159.00		
Furnace w/Grate[1]	Heat removed/lost		583.60	
Gas/Air Sink[29]	Heat removed/lost		20529.00	
Gas/Air Source[18]	Heat input	-38.58		
Gas/Air Source[26]	Heat input	-25.72		
Gas/Air Source[30]	Heat input	-5533.00		
General HX[3]	Heat removed/lost		10.46	
General HX[19]	Heat removed/lost		0.73	
General Pump[7]	Pumping power	20.39		
General Pump[9]	Pumping power	3.81		
General Pump[34]	Pumping power	115.50		
Makeup/Blowdown[14]	Heat input	-365.70		
Parallel Tubular Air Heater[13]	Heat input	11.85		
Parallel Tubular Air Heater[13]	Heat removed/lost		17.56	
Pipe[27]	Heat removed/lost		30.35	
Selective Non-Catalytic Reduction[21]	Heat removed/lost		0.00	
Stack[23]	Heat removed/lost		2467.50	
Steam Turbine[8]	Expansion power		8556.00	
Steam Turbine[8]	ST leak outs		465.60	
Steam Turbine[10]	ST leak ins	421.80		
Steam Turbine[10]	Expansion power		3498.00	
Superheater[5]	Heat input	46.23		
Superheater[5]	Heat removed/lost		58.27	
Total Energy Input		**36324.00**		
Total Energy Output			**36326.00**	
Cycle Heat Balance Error			**1.48**	**0.0036**
MASS BALANCE				
Component		**[t/h]**	**[t/h]**	**%**
Air-cooled Condenser[28]	Mass flow in	0.00		
Deaerator[16]	Mass flow out		0.00	
Fuel Source[2]	Mass flow in	9.53		
Furnace w/Grate[1]	Mass flow out		0.99	
Gas/Air Sink[29]	Mass flow out		4906.00	
Gas/Air Source[18]	Mass flow in	34.20		
Gas/Air Source[26]	Mass flow in	22.80		
Gas/Air Source[30]	Mass flow in	4906.00		
Makeup/Blowdown[14]	Mass flow in	0.53		
Makeup/Blowdown[14]	Mass flow out		0.00	
Stack[23]	Mass flow out		66.02	
Steam Turbine[8]	Mass flow out		2.04	
Steam Turbine[10]	Mass flow in	1.98		
Total Mass Flow In		**4975.00**		
Total Mass Flow Out			**4975.00**	
Cycle Mass Balance Error			**0.00**	

Table 26: Heat and Mass balance for Scenario 2c

HEAT BALANCE				
Zero enthalpy @ 77F (25C) & vapour H2O.				
Component		**[kW]**	**[kW]**	**%**
Air-cooled Condenser[28]	Heat input	-3.88		
Deaerator[16]	Heat removed/lost		0.00	
Duct[24]	Heat removed/lost		0.00	
Duct[4]	Heat removed/lost		23.35	

Duct[31]	Heat removed/lost		10.79	
Economiser[11]	Heat input	62.19		
Economiser[11]	Heat removed/lost		75.35	
Fan[17]	Compression power	40.25		
Fan[20]	Compression power	387.00		
Fan[25]	Compression power	23.26		
Fuel Source[2]	Heat input	41159.00		
Furnace w/Grate[1]	Heat removed/lost		583.60	
Gas/Air Sink[29]	Heat removed/lost		20529.00	
Gas/Air Source[18]	Heat input	-38.58		
Gas/Air Source[26]	Heat input	-25.72		
Gas/Air Source[30]	Heat input	-5533.00		
General HX[3]	Heat removed/lost		10.46	
General HX[19]	Heat removed/lost		0.73	
General Pump[7]	Pumping power	20.39		
General Pump[9]	Pumping power	3.81		
General Pump[34]	Pumping power	115.50		
Makeup/Blowdown[14]	Heat input	-365.70		
Parallel Tubular Air Heater[13]	Heat input	11.85		
Parallel Tubular Air Heater[13]	Heat removed/lost		17.56	
Pipe[27]	Heat removed/lost		30.35	
Selective Non-Catalytic Reduction[21]	Heat removed/lost		0.00	
Stack[23]	Heat removed/lost		2467.50	
Steam Turbine[8]	Expansion power		8556.00	
Steam Turbine[8]	ST leak outs		465.60	
Steam Turbine[10]	ST leak ins	421.80		
Steam Turbine[10]	Expansion power		3498.00	
Superheater[5]	Heat input	46.23		
Superheater[5]	Heat removed/lost		58.27	
Total Energy Input		**36324.00**		
Total Energy Output			**36326.00**	
Cycle Heat Balance Error			**1.48**	**0.0036**

MASS BALANCE

Component		**[t/h]**	**[t/h]**	**%**
Air-cooled Condenser[28]	Mass flow in	0.00		
Deaerator[16]	Mass flow out		0.00	
Fuel Source[2]	Mass flow in	9.53		
Furnace w/Grate[1]	Mass flow out		0.99	
Gas/Air Sink[29]	Mass flow out		4906.00	
Gas/Air Source[18]	Mass flow in	34.20		
Gas/Air Source[26]	Mass flow in	22.80		
Gas/Air Source[30]	Mass flow in	4906.00		
Makeup/Blowdown[14]	Mass flow in	0.53		
Makeup/Blowdown[14]	Mass flow out		0.00	
Stack[23]	Mass flow out		66.02	
Steam Turbine[8]	Mass flow out		2.04	
Steam Turbine[10]	Mass flow in	1.98		
Total Mass Flow In		**4975.00**		
Total Mass Flow Out			**4975.00**	
Cycle Mass Balance Error			**0.00**	

Table 27: Heat and Mass Balance for Scenario 2d

HEAT BALANCE

Zero enthalpy @ 77F (25C) & vapour H2O.				
Component		**[kW]**	**[kW]**	**%**
Air-cooled Condenser[28]	Heat input	-3.93		
Bubbling Fluidized Bed[1]	Heat removed/lost		1574.40	
Deaerator[16]	Heat removed/lost		0.00	
Duct[24]	Heat removed/lost		0.00	
Duct[4]	Heat removed/lost		21.23	
Duct[19]	Heat removed/lost		0.00	
Economiser[11]	Heat input	43.76		
Economiser[11]	Heat removed/lost		54.60	
Fan[17]	Compression power	11.78		
Fan[20]	Compression power	110.00		
Fan[25]	Compression power	172.30		
Fuel Source[2]	Heat input	40398.00		
Gas/Air Sink[29]	Heat removed/lost		20480.00	
Gas/Air Source[18]	Heat input	-24.92		
Gas/Air Source[26]	Heat input	-37.38		
Gas/Air Source[30]	Heat input	-5520.00		
General Pump[9]	Pumping power	3.67		
General Pump[34]	Pumping power	112.60		
Makeup/Blowdown[14]	Heat input	-121.60		
Pipe[15]	Heat removed/lost		30.10	
Selective Non-Catalytic Reduction[7]	Heat removed/lost		0.00	
Stack[6]	Heat removed/lost		1089.80	
Steam Turbine[8]	Expansion power		8378.00	
Steam Turbine[8]	ST leak outs		466.20	
Steam Turbine[10]	ST leak ins	422.10		
Steam Turbine[10]	Expansion power		3463.00	
Superheater[5]	Heat input	50.13		
Superheater[5]	Heat removed/lost		58.26	
Tubular Air Heater[13]	Heat input	3.10		
Tubular Air Heater[13]	Heat removed/lost		4.57	
Total Energy Input		**35620.00**		
Total Energy Output			**35620.00**	
Cycle Heat Balance Error			**-0.27**	**-0.0007**
MASS BALANCE				
Component		**[t/h]**	**[t/h]**	**%**
Air-cooled Condenser[28]	Mass flow in	0.00		
Bubbling Fluidized Bed[1]	Mass flow in	0.05		
Bubbling Fluidized Bed[1]	Mass flow out		0.71	
Deaerator[16]	Mass flow out		0.00	
Fuel Source[2]	Mass flow in	9.35		
Gas/Air Sink[29]	Mass flow out		4894.00	
Gas/Air Source[18]	Mass flow in	22.09		
Gas/Air Source[26]	Mass flow in	33.14		
Gas/Air Source[30]	Mass flow in	4894.00		
Makeup/Blowdown[14]	Mass flow in	0.18		
Makeup/Blowdown[14]	Mass flow out		0.00	
Stack[6]	Mass flow out		64.03	
Steam Turbine[8]	Mass flow out		2.03	
Steam Turbine[10]	Mass flow in	1.97		
Total Mass Flow In		**4961.00**		
Total Mass Flow Out			**4961.00**	
Cycle Mass Balance Error			**0.00**	

3.11 Biomass Combustion Technical Summary

The following conclusions can be drawn from the technical assessment of biomass combustion power plants:

- The use of biomass combustion plant to generate electricity from encroacher bush appears feasible at all potential locations. The use of proven combustion or staged gasification systems with a steam turbine generator for the generation of electricity is recommended.
- The use of gasification, pyrolysis or other novel systems is not recommended given the limited proven commercial experience.
- Both grate and fluidised bed combustion technologies are appropriate for use with encroacher bush chips, performing in a broadly similar manner and meeting WHO emissions guidelines.
- The chlorine content of the encroacher bush biomass is the most significant technical concern at present. Although detailed analysis is still awaited, other sources indicate a relatively high level of chlorine. This may limit the boiler steam pressure and temperature in order to prevent excessive fouling, potentially resulting in a reduction in efficiency and/or an increase in maintenance requirements. Although only modest steam temperatures and pressures have been included in the modelling undertaken (in accordance with advice from equipment vendors to mitigate chlorine presence), the suitability of the systems modelled should be reviewed when the results of the encroacher bush chlorine content are available.
- The efficiency of the 5MW plant is notably lower than the 20MW plants.
- Locating a plant at Ohorongo Cement offers potential technical advantages over the Otjikoto substation and Otjiwarongo sites due to the hot air supply from the cement plant, and the potential to recycle the ash at the same facility.

4 Financial Analysis

WSP have developed comprehensive capital and operational cost estimates for each biomass combustion plant scenario. This data has been used as inputs to the financial model developed by IER. Full details of the commercial assessment are available in an accompanying report.

4.1 Plant Capital Cost Estimates

Capital costs (CAPEX) estimates have been developed based on equipment vendor quotes. Since the quotes provided did not necessarily include all plant elements, the basic costs have been supplemented by our own internal data (predominantly from similar projects) and rule-of-thumb estimates where it has not been possible to source actual data. For the grate systems four cost estimates were developed based on four technologies for which we have received data. For the fluidised bed option, quotes were obtained for a single BFB and CFB system.

A summary of the total CAPEX for each scenario is provided in Table 28. This covers the biomass combustion plant system from fuel reception and storage to the turbine generator. Costs associated with the biomass fuel supply chain (including fuel preparation) and grid inter-connection has not been included in the CAPEX estimate in this table. Uncertainty around water supply infrastructure, potential upgrades to haulage route road infrastructure etc. is also excluded for the present.

Given the inevitable uncertainties at this stage of the project development cycle we consider the CAPEX estimates to be accurate to +/- 30%. It can also be seen there is a substantial variation in costs between different equipment vendors. The financial modelling has been based primarily on the lowest cost systems, in Table 28. We believe this to be a reasonable approach since these estimates are based on actual quotes for this project and therefore provide an indication of the lower end of the pricing range that could be expected from a competitive bid process, albeit noting the level of uncertainty.

Table 28: CAPEX summary

Scenario		Cost Basis	CAPEX	Specific CAPEX (€ per MW)
1	5MW grate	Supplier A	€ 20,877,975	€ 4.2M
2a	2x10MW grate	Supplier B	€ 32,715,774	€ 1.6M
		Supplier C	€ 48,028,242	€ 2.4M
		Supplier D	€ 57,906,091	€ 2.9M
2b	2x10MW BFB	Supplier E	€ 30,694,525	€ 1.5M
2c	2x10MW grate	Supplier B	€ 38,030,759	€ 1,9M
	2x10MW grate	Supplier C	€ 53,846,296	€ 2.7M
	2x10MW grate	Supplier D	€ 62,964,091	€ 3,1M
2d	2x10MW BFB	Supplier E	€ 35,100,045	€ 1.8M

A detailed breakdown of the estimated CAPEX for each scenario is provided in the report Appendix. The appendices are numbered as follows:

- Appendix H – CAPEX Estimate for Scenario 1 – 5 MW Plant at Otjiwarongo
- Appendix I - CAPEX Estimate for 10 MW and 20 MW Scenarios at Ohorongo

- **Error! Reference source not found.** - CAPEX Estimate for 10 MW and 20 MW Scenarios at Otjikoto Substation

4.2 Plant Operations and Maintenance Cost Estimates

Operational cost (OPEX) estimates have been developed for each scenario. Our estimates consider the following elements that make up the annual OPEX:

- Labour
- Consumables
- Maintenance
- Ash disposal

The basis behind the OPEX estimates are briefly summarised below, with more detail provided in the commercial report.

Labour

Labour assumptions are based on typical manning levels for solid fuel combustion plants, combined with typical labour costs for similar plant in Namibia.

- 5 MW plant – 27 staff
- 20 MW plant – 33 staff

The relatively small difference in staff numbers between the 5MW and 20MW plant is because regardless of the scale, the majority of staff roles are still required at both plants. However some savings will be made by reduced maintenance requirements and smaller shifts.

Consumables

All the consumables required in Sections 3.7.2 to 3.7.4 will incur a cost. Our estimates are summarised in Table 29.

Table 29: Consumable costs

Consumable	Unit Cost	Unit	Basis
Limestone (as slaked lime)	€ 99.8	per tonne	Index Mundi
Urea	€ 335.2	per tonne	Index Mundi
Boiler cleaning chemicals	€ 0.24	per tonne of fuel input	Keppel (indicative figure)
Electricity	€ 78.0	per MWh	NamPower
Water	€ 1.0	per m^3	Typical UK industrial rates
Auxiliary Fuel (oil)	€ 60.0	per MWh	Typical UK industrial rates

Maintenance

Maintenance comprises routine maintenance (day-to-day repairs and minor replacements and upgrades) and lifecycle maintenance (overhaul and replacement of major plant items). Cost estimates could not be solicited from equipment vendors, and so have been based on typical rule-of-thumb estimates for biomass combustion plant. An annual maintenance figure of 2.5% of plant CAPEX has been assumed for each scenario.

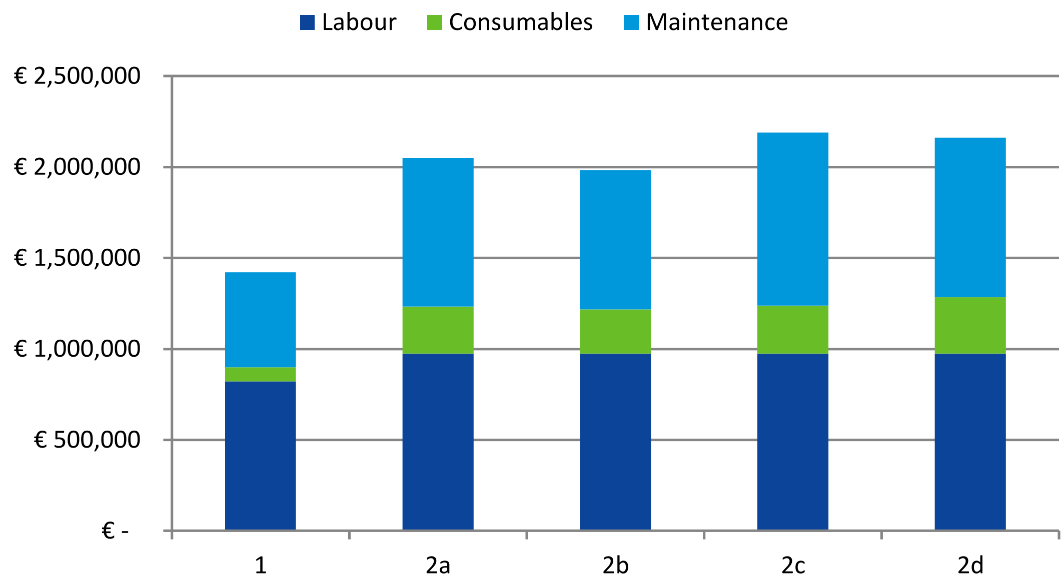
OPEX Summary

A summary of the total OPEX for each scenario is provided in Table 30. The breakdown by labour, consumables and maintenance is shown in Figure 9.

Table 30: OPEX summary

Scenario		Total plant OPEX	
		per year	per MWh
1	5MW grate	€1,420,834	€35.1
2a	2x10MW grate	€2,050,056	€12.7
2b	2x10MW BFB	€1,984,100	€12.2
2c	2x10MW grate	€2,188,851	€13.5
2d	2x10MW BFB	€2,161,954	€13.3

Figure 9: OPEX breakdown (€ per year)



4.3 Biomass Combustion Financial Summary

Detailed financial modelling is considered in the commercial assessment report, however the following observations are made around plant CAPEX and OPEX for each scenario:

- The Ohorongo Cement site offers commercial advantages due to the established biomass fuel production/handling operations, leading to lower CAPEX.
- The 5 MW system incurs a much higher CAPEX per MW and operates with a lower efficiency than the 20MW systems.
- The 5 MW system also incurs a much higher OPEX per MWh. This is largely because despite having an electrical output four times lower than the 20 MW plant, the maintenance costs are more than half and the labour costs only slightly less.

- However, it is noted that only one 5 MW quote was received. Keeping in mind the broad range in quotes received for 20 MW vendors, it is possible that the 5 MW option WSP received is on the high end of the cost spectrum.

5 Part B – Torrefaction of Biomass for Co-Firing

5.1 Overview

5.1.1 Torrefaction Basics and Potential Opportunity

Torrefaction is a biomass fuel upgrading technology. Following heat treatment in the absence of oxygen, wood is converted to a biomass material with similar characteristics to coal. The use of torrefied biomass in dedicated biomass power facilities does not tend to offer economic benefits, but this material has significant potential as a replacement for coal in coal-fired power stations. Coal power stations are typically able to accept around 10% of the input fuel as unprocessed biomass without requiring substantial modification, but this proportion can increase to over 40% biomass when torrefied. The potential to co-fire torrefied encroacher bush at the Van Eck coal power station is of considerable interest as this represents a means to utilise encroacher bush for power generation without requiring additional major capital investment in new generation plant. A major refurbishment of the Van Eck plant is proposed to improve the performance and enable continued operation for an additional 10 years, which will require significant capital investment. However, this is required regardless of the fuel input so the use of torrefied material will not incur additional costs.

5.1.2 Scope

This review has been carried out with the intention of understanding the torrefaction market and gathering technical data around typical commercial scale production facilities which could be located in Namibia.

In order to do so we have carried out a technology and market review to understand the latest position of the torrefaction industry, and contacted prominent technology suppliers and developers in order to obtain data and understand their ability and desire to contribute to a project in Namibia.

Of particular interest are two organisations are known to be actively pursuing torrefaction in Namibia at present, Green Coal (using technology developed in Namibia) and UFF Asset Management (using Topell technology developed in the Netherlands).

5.2 Technology

The basic principles of torrefaction are relatively simple and well understood. Biomass is first dried and then subjected to heat in the region of 200 – 400°C in an oxygen-free reactor for a fixed period of time. The heat removes the majority of the water as well as driving off a proportion of the volatile compounds and altering the physical properties of the remaining biomass material. The resulting material retains a high proportion of the input energy, but is very dry, hydrophobic (water repellent), highly friable (easy to grind) and once compressed can have a significantly greater energy density than the input biomass. The torrefied material typically exits the reactor in the form of chips or powder (similar to the input feedstock), but is usually compressed and reformed into pellets or briquettes prior to being used for energy generation.

Though the principles are simple, a wide range of technologies can be used with varying feedstock flexibility, utilities requirements, land take and so on. Changes in the temperature, exposure time and input material characteristics (particle size etc.) have an impact on the parameters of the output product, and conditions in the torrefier must therefore be carefully controlled.

The main challenge associated with the technology is achieving a consistent, high-quality product from a feedstock which is naturally variable. Another technical challenge is managing the risk of fire and explosion in production, handling and storage. Finally, the process should be as efficient as possible with energy losses minimised in order for the economics to be favourable.

5.3 Market Review

Torrefaction of wood for energy production and co-firing is an emerging technology, and is not well proven commercially. There are no established suppliers producing torrefied biomass on a large-scale and the vast majority of technology providers identified in this study are in the demonstration stage.

Our research uncovered only three commercial torrefaction facilities in the world at present; two in the Netherlands and one in the USA (note that there may be others but these are the only plants identified during this study). Of note is that one of the plants in the Netherlands has suffered a major fire recently and may not be operational at present.

A number of other commercial plants are planned over the next few years, but it is noted that several of those that were planned in the last few years have failed to proceed.

A significant constraint to moving from small-scale pilot/demo plant to full scale commercial plant is the ability of the technology provider/developer to establish fuel supply contracts. Despite the market for torrefied biomass potentially being large (with considerable interest from operators of coal-fired power stations in the EU in particular), suppliers need to satisfy the potential customer that the product meets their requirements, particularly given the following:

- There are no established standards for torrefied biomass fuel;
- There are a wide range of different technologies producing material with differing properties;
- The primary market for the material is for co-firing with coal; however most co-firing power stations will not have been specifically designed to combust biomass, and no long-term test data exists.

Assurance is usually carried out by providing bulk samples of material to the customer to carry out a test burn (or a number of burns), and a number of developers have had samples tested in EU coal plants in particular.

Obtaining project finance and ensuring a guaranteed supply of the biomass input are significant, related constraints. It is also known that at least one of the few commercial scale plants has recently suffered a serious fire, further impacting on investor confidence.

5.3.1 Contact with Torrefaction Companies

In order to gather additional information and confirm the current status of the market WSP identified and contacted a number of the most prominent organisations known to be active in torrefaction. Very limited reliable information and technical data around operational torrefaction plant is available in the public domain.

A total of 10 technology suppliers and developers were contacted to gather additional data and understand their ability and desire to contribute to a project in Namibia. A response was received from 6 organisations, though little solid technical data could be obtained from the majority. This would appear to be because most operators are still in the development phase and are therefore not wishing to disclose details (and in a number of cases not being as close to commercial operation as implied by promotional material).

Of the most interest to this project are the two organisations known to be active in Namibia, Green Coal and UFF Asset Management (in partnership with Topell). These are discussed in detail in the next section.

Table 31: Contact with Torrefaction Developers

Technology Supplier / Developer	Commercial Plant?	Reply?	Summary of Response
Stramproy Green (NL) / Horizon Bioenergy (NL)	Yes	Yes	Email and phone call, received some general information from Horizon Bioenergy CEO but require NDA for further technical data. Plant suffered major fire in February 2012.

Technology Supplier / Developer	Commercial Plant?	Reply?	Summary of Response
Topell Energy (NL) / UFF Asset Management (SA)	Yes	Yes	Discussions and meeting with UFF Asset Management in South Africa who are associated with Topell, and are actively looking to develop torrefaction plants in Namibia for export of material to the EU.
New Biomass Energy (USA)	Yes	No	No response to emails and no contact phone number.
Green Coal (Namibia)	No	Yes	Pilot plant in Namibia. Detailed discussions with developer and site visit. Technical and economic data received.
Torrsys (NL) / Bepex (USA)	No	Yes	Only in demonstration phase so not able to provide technical data. Some general information provided.
Rotawave (UK)/ Thermogen Industries (USA)	No	Yes	Received general company marketing material including some information on process but require NDA for further data. Currently looking to develop a commercial scale plant in the USA.
Integro Earth Fuels (USA)	No	Yes	Only in demonstration phase so not able to provide detailed data, but have provided useful comments, keen to help and open with thoughts on the market and economics of torrefaction.
Thermya (Fr)	No	No	n/a
Agri-Tech Producers (USA)	No	No	n/a
Zilkha Bioenergy (USA)	No	No	n/a

5.4 Torrefaction Activity in Namibia

Despite the limited activity worldwide there are at present two unrelated organisations either actively involved or looking to develop torrefaction capability in Namibia. These are considered to represent the best opportunity as potential suppliers of torrefied material to Van Eck power station. We are aware that both organisations have discussed the opportunity with NamPower to varying extents, although in both cases the business model is based on export of the product outside of Namibia. Despite this, both suppliers have shown a strong interest in supplying torrefied material to NamPower. The status and outcome of discussions with each organisation are summarised in this section.

5.4.1 Green Coal

Green Coal operates the only torrefaction plant in Namibia. The plant is owned by Mr Gershon Ben Tovim on his farm near Omaruru, and at present consists of a 2 tonne per hour pilot/demonstration plant which has been successfully producing torrefied material from encroacher bush for several years. A sample of the torrefied material has been tested at Van Eck coal-fired power station with broadly positive results. A meeting between Green Coal, NamPower and WSP was held at Green Coal's site hosted by Mr Ben Tovim on 13th June 2012. A summary of the key outcomes of the visit and discussions is provided below, with detailed notes provided in 0.

Overview

Green Coal currently operate a 2 tonne per hour demonstration plant located on a farm near Omaruru and plan to construct a commercial scale 10 tonne per hour plant at the same site.

- The Green Coal torrefaction process is carried out at a relatively high temperature (350°C) with a short residence time of a few minutes, and can be considered a borderline pyrolysis process. A relatively high level of volatiles driven off meaning energy losses are higher than lower temperature processes, but this results in a high energy density (25 – 27 MJ/kg compared to around 18MJ/kg for unprocessed wood).
- Around 2 tonnes of woodchip are required for every 1 tonne of torrefied chips; hence a 10 tonne per hour unit will require 20 tonnes of woodchip per hour. Assuming the plant runs at 24 hrs a day for 300 days a year (which at this initial stage appears to be Green Coal's working assumptions), this would result in 72,000 tonnes of torrefied material and around 150,000 tonnes of woodchip per annum. Green Coal estimates that this should require a 20-30km radius for the lifespan of the unit (not given).
- The pilot unit operations currently employ around 80 people, the vast majority of which are involved in the harvesting process. The full-scale system is expected to employ 150 – 200 people.
- The pilot plant requires 20 kWe to run and a total of 70 kWe is anticipated for the full scale system. At present the plant does not generate electricity from the combusted gas driven off by the process.
- By-products include charcoal for braais and ash for returning to the soil;
- Otjiwarongo is the furthest north that Green Coal would consider to be financially viable at present for transport to Van Eck or Walvis Baai (approximately 140km from Omaruru)
- Green Coal's technical partners include the Nuclear Energy Corporation of South Africa (consultant engineers and provision/manufacturing of kiln for commercial-scale plant) and the Israel Electric Corporation as the EPC contractor and possible investor.

Testing at Van Eck

- A trial run with Green Coal torrefied material was undertaken at Van Eck power station in 2010. This involved around 60-70 tonnes of material.
- The calorific value of the Green Coal pellets was 24 MJ/kg compared to 26 MJ/kg for A-grade coal from South Africa (at a cost of circa R1,730 per ton).
- The process involved starting the boiler up on coal and then feeding the torrefied pellets into the system. The boiler ran effectively with up to 80% torrefied material.
- The cylindrical shape of the pellets caused some difficulties, and the pellet binder caused some issues with clinker formation.
- It is anticipated that the proposed modifications to Van Eck required to extend the life of the plant would help to overcome the issues associated with the pellet binder. It is expected that an air spreader system would alleviate this issue, although this can only be confirmed through an operational trial.

Commercial

- Green Coal indicated the venture can be funded by purely private sector investment. No direct investment is required from NamPower or donor institutions.
- Green Coal would require a 7 year supply contract for two thirds of the supply i.e. around 50,000 tonnes of torrefied material per annum from NamPower to make the project feasible (i.e. commissioning a full-scale 10 tonne per hour unit). There is no reason why Green Coal would not be open to an even longer agreement, rather the above represents the minimum contract requirements.

5.4.2 Topell/UFF Asset Management

Topell have a 100,000 tonne per annum torrefaction facility in Duiven, Netherlands which has been operational since 2010. WSP contacted Topell to gather more information, and received a response from UFF Agri-Asset Management (UFF). UFF are in partnership with Topell and are looking at the opportunity to deploy Topell's technology in Namibia, and an interest in discussing opportunities further. Subsequently, WSP met with UFF in Cape Town to discuss in more detail. WSP was required to sign a Non-Disclosure Agreement (NDA) prior to meeting with UFF, and it is likely that NamPower/others will also need to sign an NDA to obtain further details. However, WSP did receive permission to release some of the details of our discussion. A summary of the meeting is provided below:

- UFF are agri-sector focused investment advisors in partnership with Futuregrowth (i.e. Old Mutual).
- Dutch Development Bank is a shareholder.
- UFF provide technical capacity for evaluating agri-sector investment opportunities.
- In partnership with Topell Energy, UFF have been investigating torrefaction in Namibia for around 3 years.
- UFF are very interested in possible local buyer agreement with NamPower
- The area of probable interest is the Tsumeb region where heaviest encroacher bush impacts are prevalent. 15-20t/ha of biomass estimated. Material would be transported from the plant by rail to Walvis Bay.
- Business case is based on landing torrefied material at competitive price to coal in Rotterdam, hence not completely reliant on local buyer market; current business plan is based on export.
- Business case is considered to be "conservative".
- Business case developed with assistance from Schotgroep consultants.
- Topell's torrefaction technology is a quick process (few minutes), but at the present time no details of the technology have been provided to WSP.
- Topell have an operational plant in Netherlands at Duiven. This plant produces 100,000 tonnes per year of torrefied material from an input of 150,000 tonnes of biomass. The plant has been tested with Namibian encroacher bush; trials were reportedly successful.
- UFF's intention would be to develop a similar plant in Namibia, followed (if successful) by several more.
- UFF have already undertaken discussions (to varying degrees) with Ministry of Agriculture, Namibian Development Bank and NamPower.
- They are interested in further discussions with NamPower technical managers.

Areas of uncertainty:

- Partner firm to assist Topell/UFF with the running/operations of the facility and harvesting supply chain process etc.
- UFF have held discussions with Ohorongo Cement, but have found Ohorongo Cement to be uninterested in partnering or supporting a torrefaction related development.
- UFF currently in discussion with 2-3 credible partner firms regarding this kind of relationship.
- Funding for final (comprehensive) feasibility study; this should be supported by the proposed partner firm.

5.5 Economics of Torrefaction

Reliable data on the production cost of torrefied biomass is difficult to obtain given the low level of commercial activity. The general view from our discussions with contacts in the industry is that the delivered costs of torrefied pellets are similar, on a unit energy basis, to untreated biomass pellets. The energy lost as a proportion of the volatiles that are driven off during the process is mitigated to some extent by the reduced transportation and handling costs following densification. At present the use of biomass for co-firing (whether torrefied or not) is only competitive with coal where incentives for renewable and low carbon fuels exist, such as in the EU. This is based on the economics of torrefaction operations in Western Europe and the USA; however production costs are likely to be substantially lower when using encroacher bush in Namibia where landowners pay to get rid of the biomass material and labour is substantially cheaper .For example, Green Coal suggest a price of around R850 (€80) per tonne of torrefied pellets (2011 estimate), which compares very favourably to typical biomass pellets in the UK which are currently trading at around €250 per tonne. Even with the substantial transportation required, the interest shown by UFF for producing torrefied material in Namibia for export to the EU is a good indication that the economics may be favourable and, based on Green Coal's indicative price, potentially highly competitive with coal without financial support.

However despite the potential there is currently very little torrefied biomass material on the market and it appears that only a small number of developers would be in a position to develop a large-scale plant in Namibia.

5.6 Technical Parameters of a Commercial Scale Torrefaction Plant

At the point of preparing this report, Green Coal are the only operator willing or able to provided technical data on a commercial scale plant, though it should be noted that this is yet to be constructed. The data in the tables below should be used with caution as the majority is based on a single proposed plant that does not yet exist.

Table 32: Processing Capacity

Parameter	Value / Unit
Torrefier Pellet Capacity	10 tonnes per hour
	~72,000 tonnes per annum
Input Biomass	~20 tonnes per hour
	~144,000 tonnes per annum
Energy Production Potential (based on 20% electrical conversion efficiency)	100 GWh per year 12.5 MWe (based on 8,000 hours per year operation)

Table 33: Site Requirements

Parameter	Value / Unit
Torrefier Footprint	300m^2 (19.3m x 15.7m)
Torrefier Height	6m
Kiln Size	13m in length
Total Site Area	Approx. 5,000 – 10,000 m^2

Table 34: Consumables

Parameter	Comment
Electricity	Modest, required for motors, drives, fans, pelleting plant. Varies depending on technology Green Coal expect a full scale plant (10 tonnes per hour) to consume 70kW in operation. Microwave processes such as that used by Rotowave require substantial higher electricity loads.
Heating Fuel	Small or zero, since most processes are autothermal (i.e. combustion of the gas produced is sufficient to provide heat for the entire process), though some require support fuel. Green Coal's process drives off a higher proportion of volatiles than most so should not require support fuel.
Water	Required for fire suppression and for cooling in some systems. Not all processes require water as the cooling medium. NORAM require 450kW cooling, which if using water implies approx. 750 litres/hour. However Integro Fuels state that their process does not require water for cooling, only fire suppression, and could even be a net producer of water since this is driven from the biomass as part of the process.

Table 35: Process Emissions

Parameter	Comment
Air	Primary emissions from combustion of volatile gases driven off biomass. Some concern about pollutants, but little published data. Secondary emissions from vehicle movements and dust.
Water	Effluent from cooling of torrefied material for systems that employ water as cooling medium. No data available, but should be possible to recycle water within the process or use evaporation ponds on site, so off-site emissions should be low or zero.
Land	Emissions to land should be very low. Very little solid waste from the process.

5.7 Suitability of Van Eck for Firing Torrified Biomass

During the course of the study period, the Technical team visited Van Eck to inspect it for suitability for co-firing with torrefied material. Other than some of the technical issues already discussed, it is noted that no obvious issues were identified to preclude the co-firing of torrefied material. There appear to be several options for managing the blending of torrefied material with coal, fire protection measures on the conveyer belt and other sections may need to be re-evaluated and possibly upgraded, and an expansion of the storage area to allow for a separate torrefied material stockpile will also be needed.

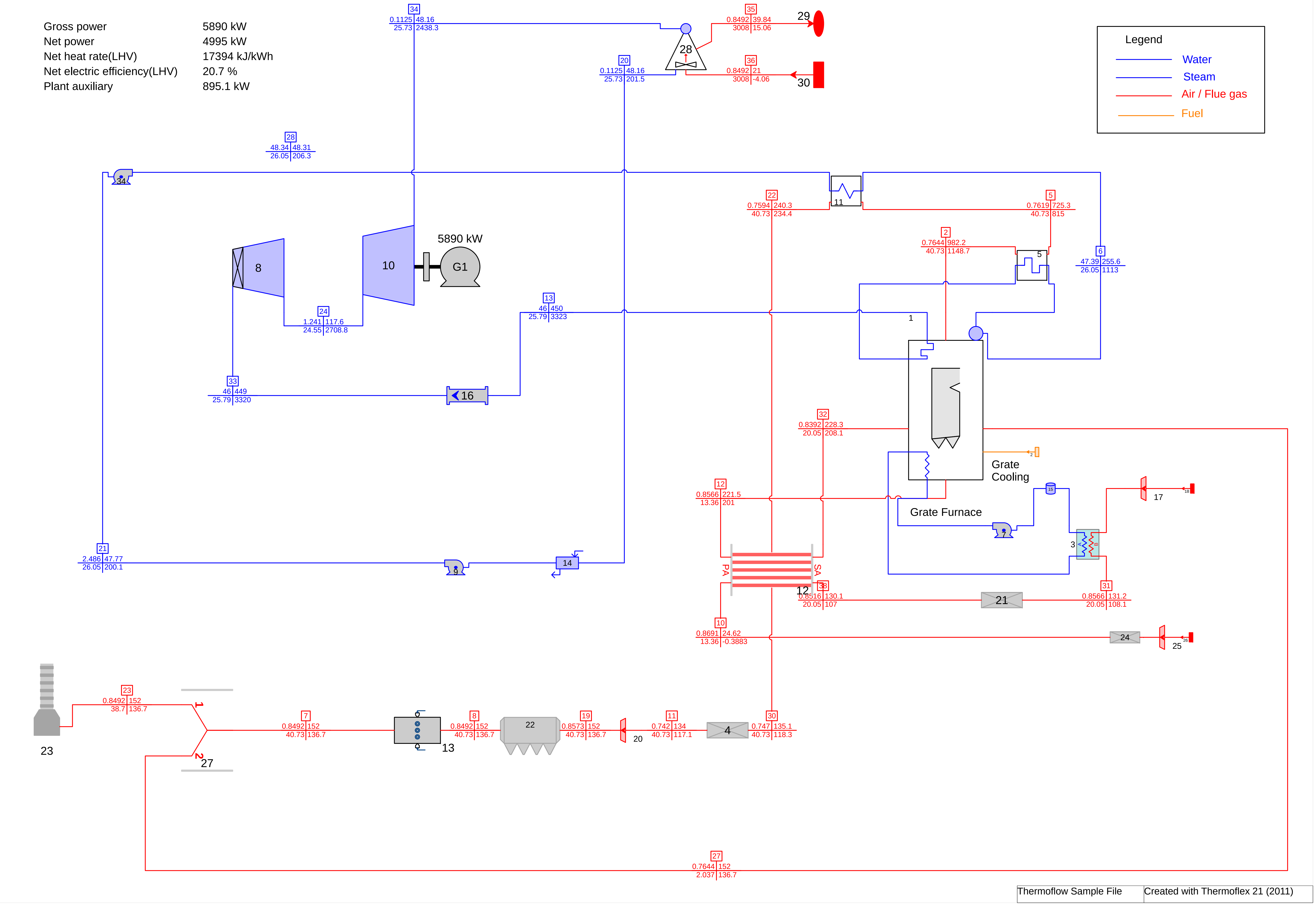
5.8 Torrefaction Summary

Given the immature status of the market, we do not recommend that NamPower invest in a torrefaction production facility. However, we consider the two developing opportunities in Namibia (Green Coal and UFF) to offer a potential opportunity. In particular, initial trials using Green Coal torrefied encroacher bush have been very promising, and they have stated their willingness to supply NamPower on a ‘take or pay’ basis.

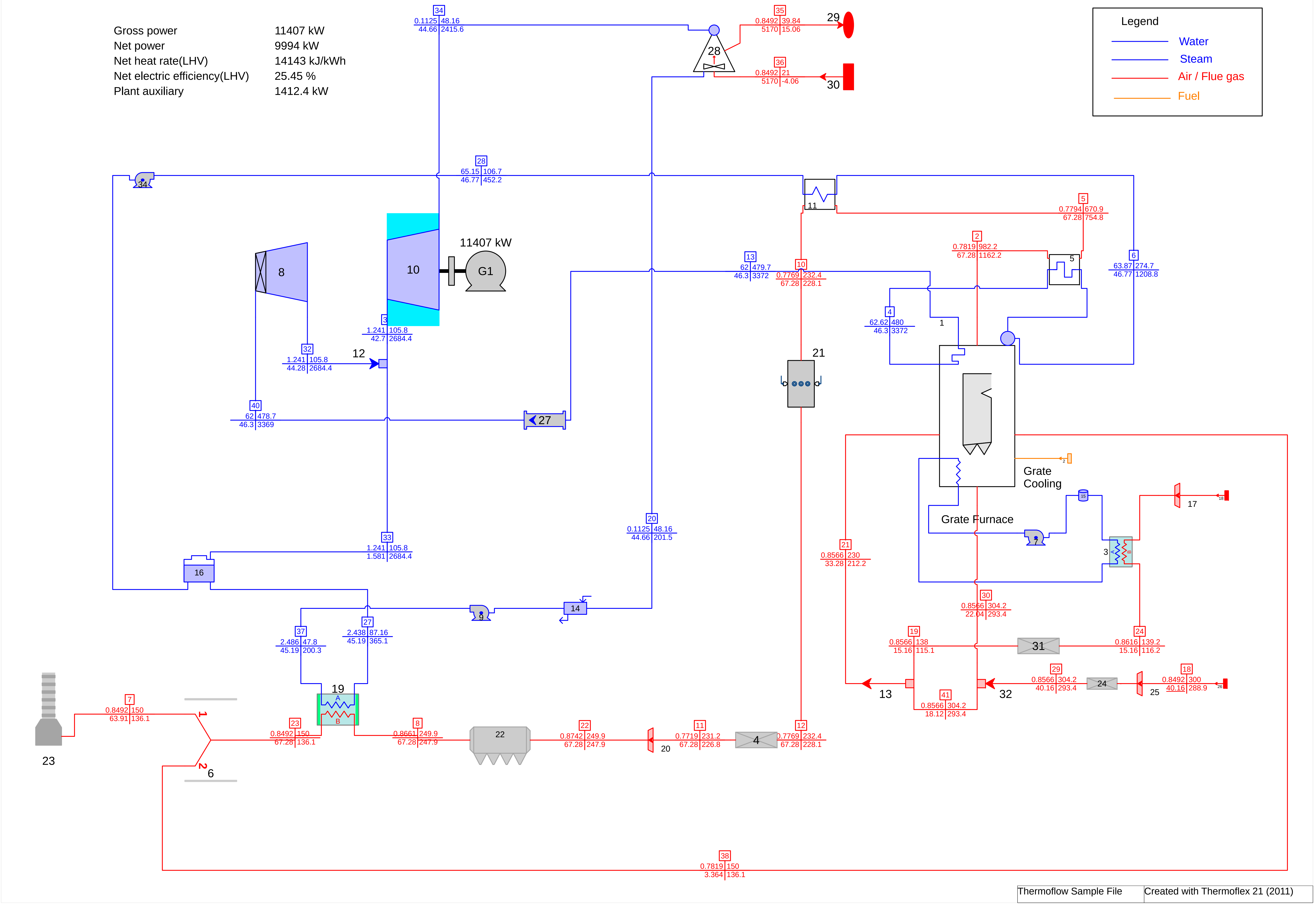
This opportunity may be worth pursuing, as it represents a means to use encroacher bush for electricity generation with minimal capital expenditure, and could help to reduce imports of coal. This is dependent on agreeing a supply contract that suits both parties.

Green Coal has suggested a minimum of a 7 year supply contract for in the region of 50,000 tonnes per year would be required. If suitable contingency plans could be put in place to ensure a supply of coal should the torrefaction venture fail or the torrefied product not be up to standard then this would be an opportunity worth following up.

Appendix A. PFD for Scenario 1 – 5 MW Grate Boiler Plant

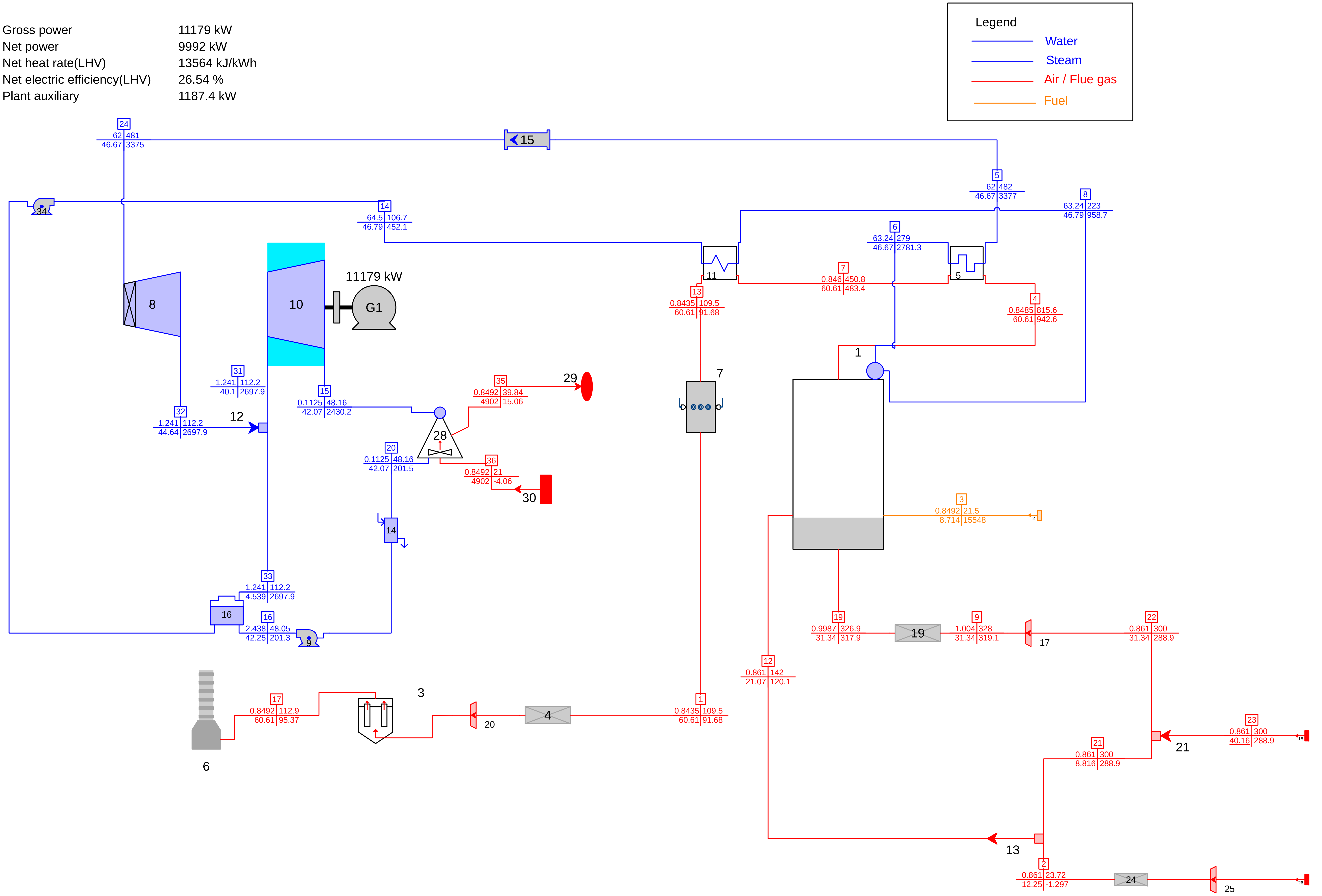

bar | C
t/h | kJ/kg
Gross power 5890 kW
Net power 4995 kW
Net heat rate(LHV) 17394 kJ/kWh
Net electric efficiency(LHV) 20.7 %
Plant auxiliary 895.1 kW
Legend
Water
Steam
Air / Flue gas
Fuel
34
0.1125 | 48.16
25.73 | 2438.3
35
0.8492 | 39.84
3008 | 15.06
29
28
20
0.1125 | 48.16
25.73 | 201.5
36
0.8492 | 21
3008 | -4.06
30
28
48.34 | 48.31
26.05 | 206.3
34
11
22
0.7594 | 240.3
40.73 | 234.4
5
0.7619 | 725.3
40.73 | 815
2
0.7644 | 982.2
40.73 | 1148.7
5
6
47.39 | 255.6
26.05 | 1113
5890 kW
8
10
G1
24
1.241 | 117.6
24.55 | 2708.8
13
46 | 450
25.79 | 3323
1
33
46 | 449
25.79 | 3320
16
32
0.8392 | 228.3
20.05 | 208.1
Grate Cooling
12
0.8566 | 221.5
13.36 | 201
Grate Furnace
17
3
21
2.486 | 47.77
26.05 | 200.1
9
14
PA
SA
12
38
0.8516 | 130.1
20.05 | 107
21
31
0.8566 | 131.2
20.05 | 108.1
10
0.8691 | 24.62
13.36 | -0.3883
24
25
23
0.8492 | 152
38.7 | 136.7
1
2
27
23
7
0.8492 | 152
40.73 | 136.7
13
8
0.8492 | 152
40.73 | 136.7
22
19
0.8573 | 152
40.73 | 136.7
20
11
0.742 | 134
40.73 | 117.1
4
30
0.747 | 135.1
40.73 | 118.3
27
0.7644 | 152
2.037 | 136.7
Thermoflow Sample File
Created with Thermoflex 21 (2011)

Appendix B. PFD for Scenario 2a – 2x10 MW Grate Boiler Plant at Ohorongo


bar | C
t/h | kJ/kg
Gross power 11407 kW
Net power 9994 kW
Net heat rate(LHV) 14143 kJ/kWh
Net electric efficiency(LHV) 25.45 %
Plant auxiliary 1412.4 kW
Legend
Water
Steam
Air / Flue gas
Fuel
11407 kW
G1
Grate Cooling
Grate Furnace
34 0.1125 48.16 44.66 2415.6
35 0.8492 39.84 5170 15.06
36 0.8492 21 5170 -4.06
28 65.15 106.7 46.77 452.2
5 0.7794 670.9 67.28 754.8
2 0.7819 982.2 67.28 1162.2
13 62 479.7 46.3 3372
10 0.7769 232.4 67.28 228.1
6 63.87 274.7 46.77 1208.8
4 62.62 480 46.3 3372
3 1.241 105.8 42.7 2684.4
32 1.241 105.8 44.28 2684.4
40 62 478.7 46.3 3369
33 1.241 105.8 1.581 2684.4
20 0.1125 48.16 44.66 201.5
21 0.8566 230 33.28 212.2
30 0.8566 304.2 22.04 293.4
37 2.486 47.8 45.19 200.3
27 2.438 87.16 45.19 365.1
19 0.8566 138 15.16 115.1
24 0.8616 139.2 15.16 116.2
29 0.8566 304.2 40.16 293.4
18 0.8492 300 40.16 288.9
41 0.8566 304.2 18.12 293.4
7 0.8492 150 63.91 136.1
23 0.8492 150 67.28 136.1
8 0.8661 249.9 67.28 247.9
22 0.8742 249.9 67.28 247.9
11 0.7719 231.2 67.28 226.8
12 0.7769 232.4 67.28 228.1
38 0.7819 150 3.364 136.1
Thermoflow Sample File
Created with Thermoflex 21 (2011)

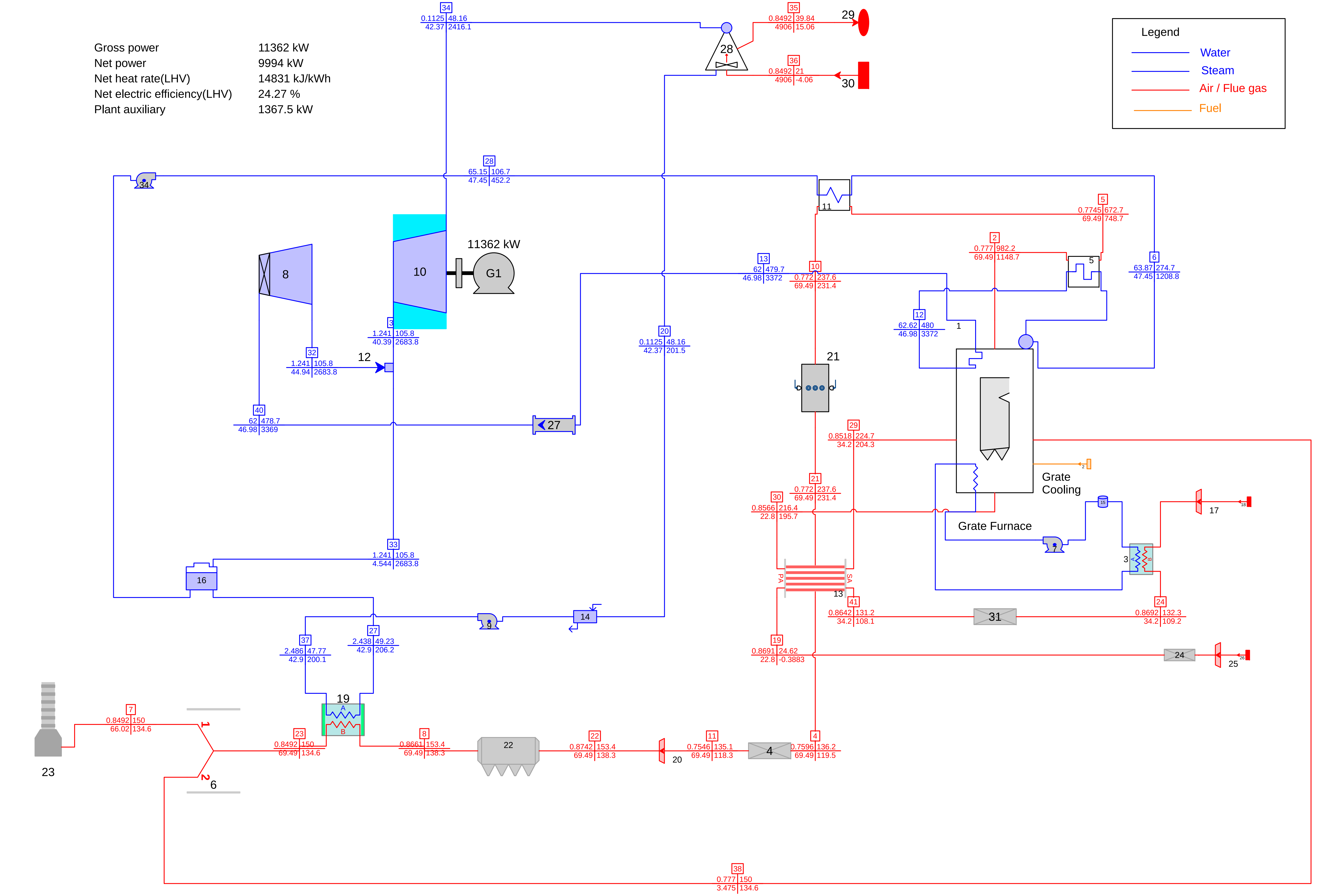
Appendix C. PFD for Scenario 2b – 2x10 MW BFB Boiler Plant at Ohorongo

Gross power	11179 kW
Net power	9992 kW
Net heat rate(LHV)	13564 kJ/kWh
Net electric efficiency(LHV)	26.54 %
Plant auxiliary	1187.4 kW



Appendix D. PFD for Scenario 2c – 2x10 MW Grate Boiler Plant at Otjikoto

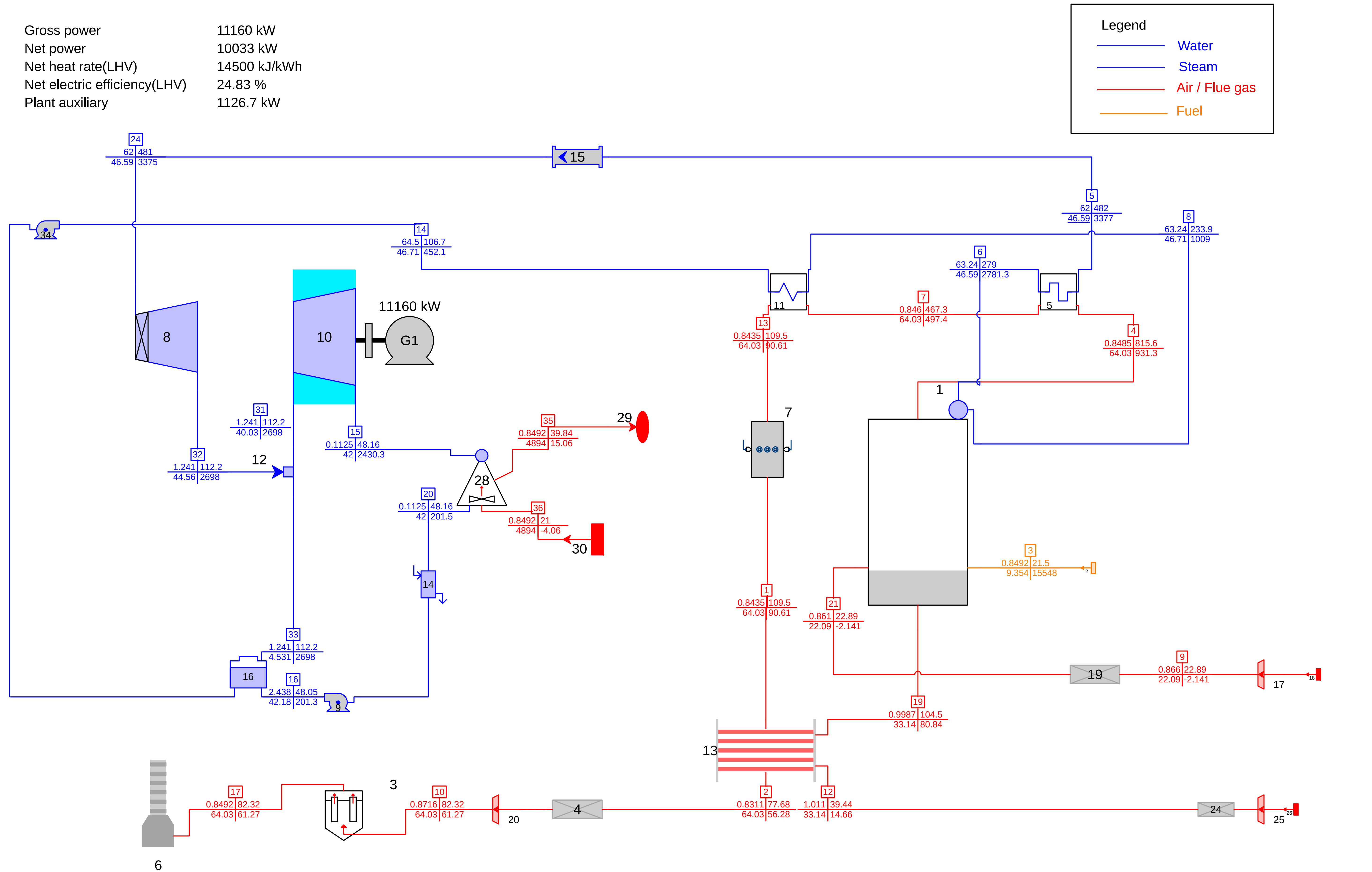
Gross power	11362 kW
Net power	9994 kW
Net heat rate(LHV)	14831 kJ/kWh
Net electric efficiency(LHV)	24.27 %
Plant auxiliary	1367.5 kW



Thermoflow Sample File | Created with Thermoflex 21 (2011)

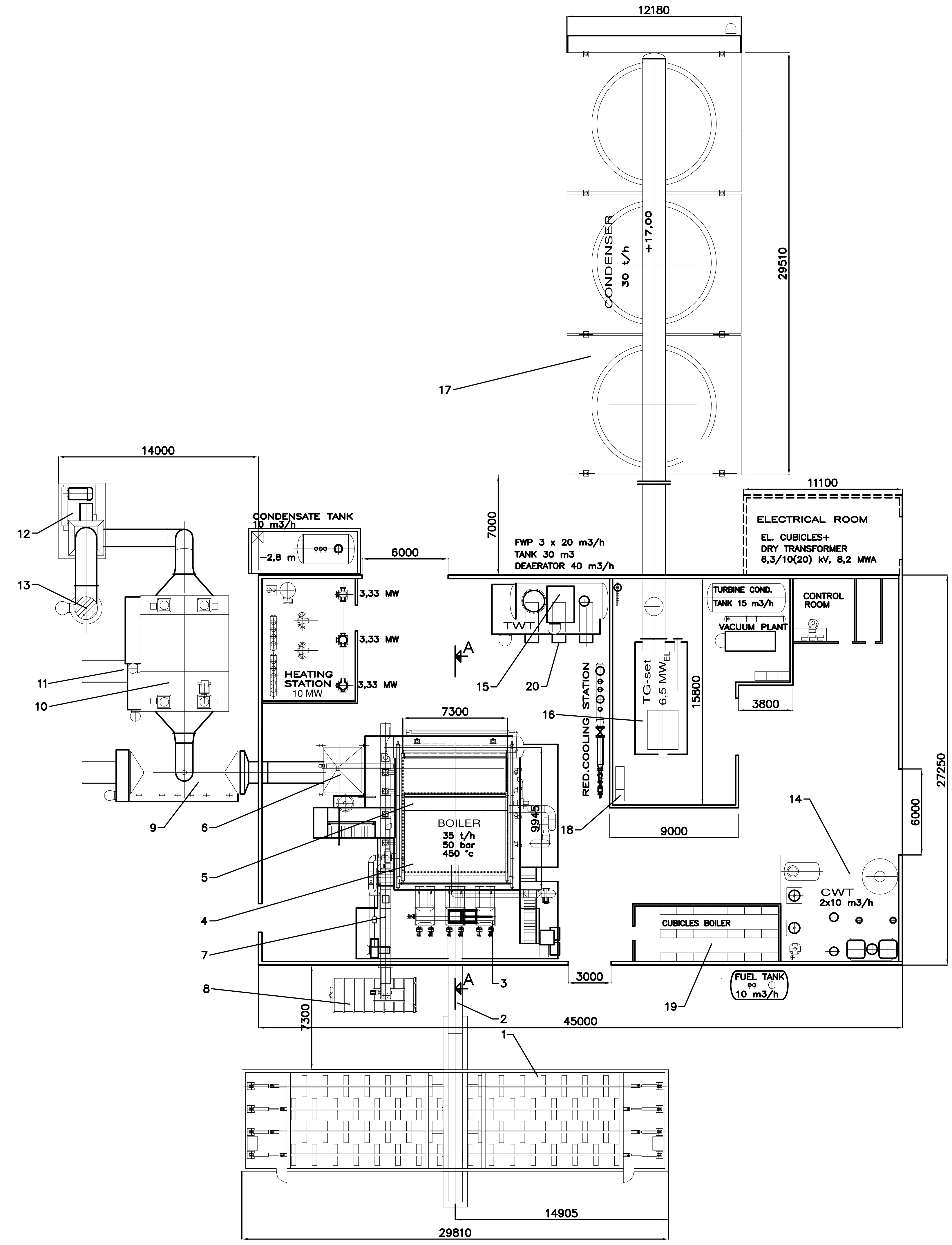
Appendix E. PFD for Scenario 2d – 2x10 MW BFB Boiler Plant at Otjikoto

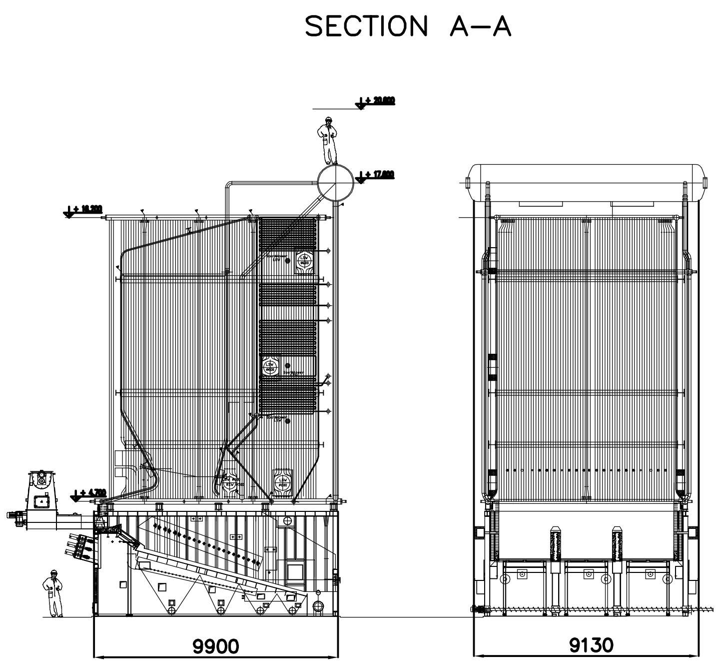
Gross power	11160 kW
Net power	10033 kW
Net heat rate(LHV)	14500 kJ/kWh
Net electric efficiency(LHV)	24.83 %
Plant auxiliary	1126.7 kW



Appendix F. Plant layout drawing for Scenario 1 – 5 MW Grate Boiler Plant

K:\Razvoj1\PONUDBE\DAVID_LAYOUT 5MWel.dwg





Poz.	Naziv	Oznaka	Opomba
20	Napojne crpke		
19	El. ormari parnog kotla		
18	El. ormari turbine		
17	Kondenzator		
16	Parna turbina + generator		
15	Termička priprema vode		
14	Hemijska priprema vode		
13	Dimnjak		
12	Ventilator dimnih plinova		
11	Kontejner za filtarski pepeo		
10	Elektro filtar		
09	Multiciklon		
08	Kontejner za odšljakivanje		
07	Odšljakivanje, otpepeljivanje		
06	Ekonomajzer		
05	Parni kotao, 35 t/h, 50bar, 450°C		
04	Ložište parnog kotla		
03	Dozirni sustav		
02	Transporter biomase		
01	Spremnik za biomasu		

Rev.Nr.	Revision Beschreibung	Datum	Unterschrift

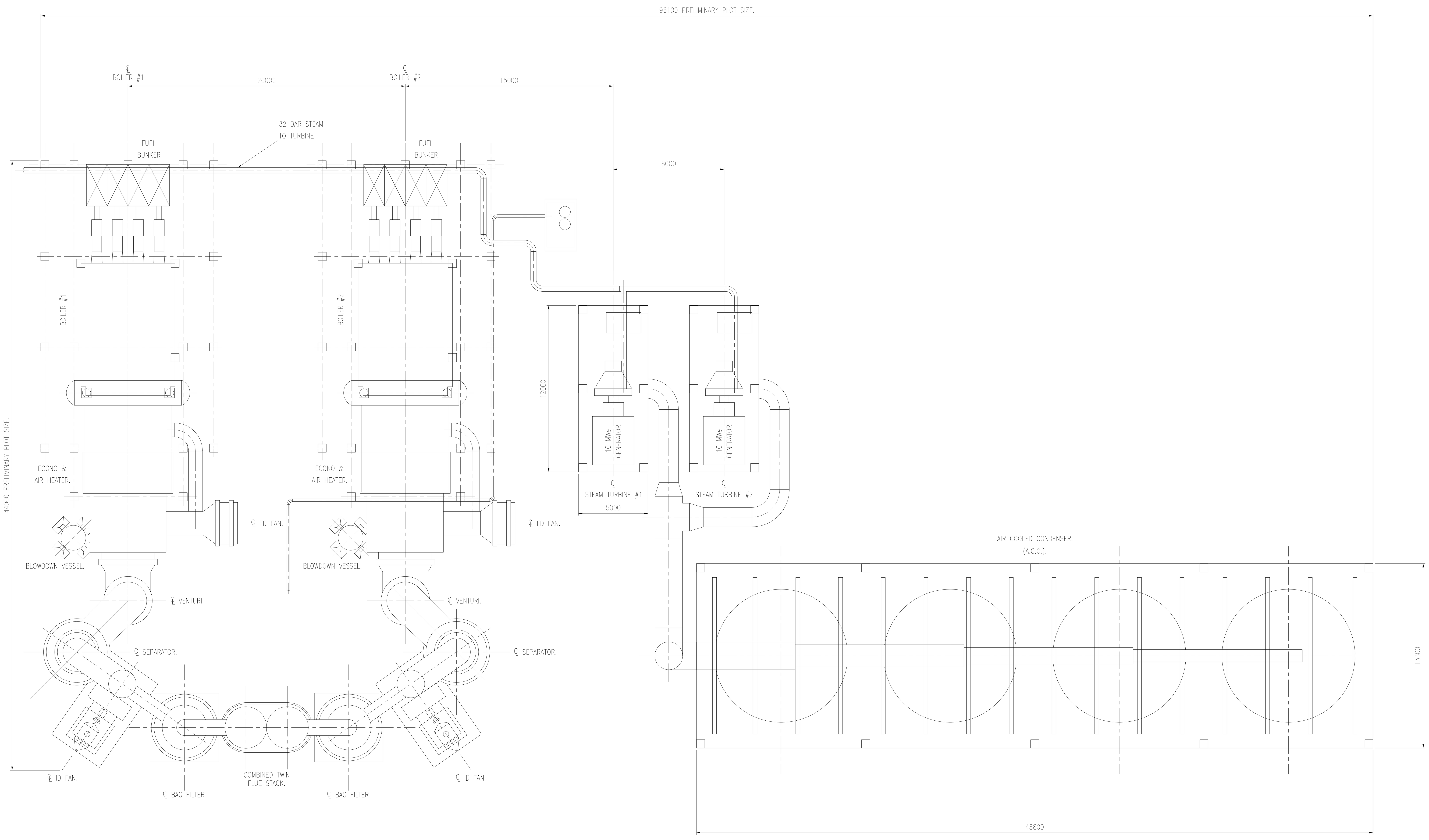
KIV

Projektant:	M.Remic	Auftraggeber:	–
Gezeichnet:	T.Mirnik	Objekt:	BRINJE COGENERATION 6,5MW
Geprüft:	T.Mirnik		
Format: A1	Maßstab: 1:150	Datum: 08.04.2010	
Projekt Nr.: –	Benennung: COGENERATION 5MWel	Darstellung Nr.: P132	Darstellung: LAYOUT
Projekt Phase: –	Zeichnung Nr.: P132-LAYOUT rev2	Baugruppe: –	

KIV Engineering d.o.o., Vransko 66, SI-3305 Vransko

Appendix G. Plant layout drawing for Scenarios 2a-2d representative of 2 x 10 MW biomass combustion plant

DO NOT SCALE



REV	DATE	BY	DESCRIPTION	CHK	APD
A	<<not-issued>>	XXX	FIRST ISSUE	@	@

DRAWING STATUS:
FOR INFORMATION ONLY

OTTO SIMON Limited
Churchfield House, 5 The Crescent
Cheadle, Cheshire, England. SK8 1PS
Tel: +44 (0) 161 491 7440. Fax: +44 (0) 161 491 7441
www.ottosimon.co.uk

WSP
WSP House, 70 Chancery Lane, London, WC2A 1AF
Tel: +44 (0)20 7314 5000 Fax: +44 (0)20 7314 5099
http://www.wspgroup.com

CLIENT:

ARCHITECT:

PROJECT:

TITLE:
BOILER & STEAM TURBINE GENERATOR SET
PRELIMINARY ARRANGEMENT.

SCALE @ A1:	CHECKED:	APPROVED:
1:125		
CAD FILE: P0310_SK001_	DESIGN-DRAWN:	DATE: July 2012

PROJECT No:	DRAWING No:	REV:
P0310	SK001	P1

O:\PROPOSALS\0310 - BIOMASS COMBUSTION PLANT LAYOUTS\DRAWING OFFICE\P0310_SK001_DWG 26/07/2012 11:30:48 A Langley

Appendix H. CAPEX estimate for Scenario 1

Build up of capex for 1 x 5MWe plan **Supplier A**

Number of lines =	1
Exchange rate - £1 =€	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (Euro)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier A Proposal 12-0026	16,000,000	1	16,000,000	14,234,875	168,800,000
Project management, design, engineering, procuremen						
Basic design		incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc		incl.	1			
Fuel delivery, storage and handling		?				
Weighbridge & station		?	1			
Wood chip store		?	1			
Conveyer system to combustor feed hopper		?	1			
Vehicles, fork lifts, etc	WSP estimate	71,547	1	71,547	63,654	754,822
Primary/secondary reactor		incl.	1			
Intermediate feed hoppers		incl.	1			
Fuel transport & dosing units		incl.	1			
Combustion grate, incl. fans, auxiliary burner systems and ducting		incl.	1			
Grate water cooling and heat exchanger for boiler feedwater pre-heat		incl.	1			
Bottom ash handling system		incl.	1			
Ash skips		incl.	1			
Urea injection system (storage, mixing, dosing)		N/A				
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Shipping costs from Slovenia to Namibian port		?	1			
Erection, testing and commissioning		incl.	1			
Waste Heat Recovery Boiler		incl.	1			
Waste heat recovery water tube boiler, incl. ancillary steam cycle equipment		incl.	1			
Flue gas ductwork (furnace-boiler)		incl.	1			
Internal pipework, valves and fittings		incl.	1			
Boiler feedwater & DI water treatment system		incl.	1			
Blowdown system and receiver		incl.	1			
Internal mechanical (rapping) cleaning system		incl.	1			
Boiler ash collection system		incl.	1			
Controls & instrumentation		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Insulated multi-cyclone		incl.	1			
Star lock under multi-cyclone		incl.	1			
Electrostatic filter		incl.	1			
ID fans + acoustic enclosure + ductwork, incl. installation and commissioning		incl.	1			
Residue conveying equipment		incl.	1			
Residue silos		incl.	1			
Thermal insulation and trace heating		incl.	1			
Support structure and access facilities		incl.	1			
All field instruments and pipework		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,339	2	9,339	8,309	98,529
Steam TG and ACC	Turbine Siemens KKK SST 120, 5 MWe,	incl.	1			
Condensing steam turbine/generator	with equipment	incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports		incl.	1			
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and softwar		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipmer		N/A				
Incoming water	WSP estimate	44,121	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissionin						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	32,576	1	32,576	28,983	343,680
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings	110,185	1	110,185	98,029	1,162,448
Fire suppression and fighting systen		?	1			
Central Control & Monitoring System		incl.	1			
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	40,720	1	40,720	36,228	429,600
Interconnecting pipework for utility package						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchgear and transformer	OSL (based on Bowers Electrical)	72,402	1	72,402	64,414	763,840
LV distribution board/system including motor controls for FGT	OSL (based on Boulting Group)	119,766	1	119,766	106,553	1,263,531
Site wiring and power cabling installation, testing and commissionir	OSL (based on Boulting Group	340,374	1	340,374	302,824	3,590,949
Site supervision and commissioning						
Commissioning of complete process	OSL (in-house estimate)	301,094	1	301,094	267,877	3,176,542
Essential spare parts during commissioning	WSP estimate	112,400	1	112,400	100,000	1,185,820
Civils & Buildings	Typically from previous bids on file	3,623,450	1	3,623,450	3,223,710	38,227,398
Foundations	21% of equipment capex					
Buildings	but this is based on UK projects					
Parking & hardstanding						
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**€ 20,877,975**		**€ 20,877,975**	**£18,574,711**	**NAD 220,262,632**

€ 20,877,975

Appendix I. CAPEX estimate for Scenarios located at Ohorongo Cement

Build up of capex for 1 x 10MWe plant for Plant at Ohorongo Cement **Supplier E**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (US$)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Vendor proposal 13/3/12 FOB US port	11,700,000	1	9,337,590	7,500,000	98,511,572
Project management, design, engineering, procurement						
Basic design	95bar, 480degC	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Provided by Ohorongo Cement	By others				
Weighbridge & station						
Wood chip store						
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier E Fluidised Bed		incl.	1			
Intermediate feed hoppers		incl.	1			
Fuel transport & dosing units		incl.	1			
Limestone injection system and storage hopper		incl.	1			
Automatic bed media cleaning & re-injection system		incl.	1			
Ash skips		incl.	1			
Urea injection system (storage, mixing, dosing)		incl.	1			
FD and ID fans		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Shipping costs from US to Namibian port		?	1			
Erection, testing and commissioning		incl.	1			
Custom biomass boiler		incl.	1			
Waste heat recovery water tube boiler, incl. ancillary steam cycle equipment		incl.	1			
Flue gas ductwork (furnace-boiler)		incl.	1			
Internal pipework, valves and fittings		incl.	1			
Boiler feedwater & DI water treatment system		incl.	1			
Blowdown system and receiver		incl.	1			
Internal mechanical (rapping) cleaning system		incl.	1			
Boiler ash collection system		incl.	1			
Controls & instrumentation		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Baghouse		incl.	1			
Interconnecting ducting between boiler & baghouse inlet		incl.	1			
Residue conveying equipment		incl.	1			
Residue silos		incl.	1			
Thermal insulation and trace heating		incl.	1			
Support structure and access facilities		incl.	1			
All field instruments and pipework		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,339	2	9,339	8,309	98,529
Steam TG and ACC	Vendor 11MWe steam turbine	3,100,000	1	2,474,062	1,987,179	26,101,357
Condensing steam turbine/generator	with equipment	incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	4,031,600	1	3,217,558	2,584,359	33,945,235
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	61,235	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	68,530	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	231,791	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System	OSL (in-house estimate)	430,301	1	310,037	275,834	3,270,895
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	70,338	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer	OSL (based on Bowers Electrical)	125,062	1	90,109	80,168	950,648
LV distribution board/system including motor controls for FGT	OSL (based on Boulting Group)	206,876	1	149,056	132,613	1,572,546
Site wiring and power cabling installation, testing and commissioning	OSL (based on Boulting Group)	587,939	1	423,618	376,884	4,469,168
Site supervision, installation and commissioning	Based on 8 weeks of Vendorsupervision and	312,000		224,800	200,000	2,371,640
Installation	commissioning included in bid					
Commissioning of complete process	WSP estimate					
Essential spare parts during commissioning	WSP estimate	156,000	1	112,400	100,000	1,185,820
Civils & Buildings	Estimates from previous bids on file	1,404,000	1	1,011,600	900,000	10,672,380
Foundations	and excluding all biomass handling,					
Buildings	storage and feeding requirements					
Parking & hardstanding	civils costs are 6.5% of equipment capex					
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**USD 22,495,011**		**€ 17,671,355**	**£14,422,201**	**NAD 186,432,793**

€ 17,671,355

Cost of power = USD 2,250 per kW

Build up of capex for 2 x 10MWe plant for Plant at Ohorongo Cement **Supplier E**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (US$)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Vendor proposal 13/3/12 FOB US port	22,700,000	1	18,116,520	14,551,282	191,129,290
Project management, design, engineering, procurement						
Basic design	95bar, 480degC	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Provided by Ohorongo Cement	By others				
Weighbridge & station						
Wood chip store						
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier E Fluidised Bed		incl.	2			
Intermediate feed hoppers		incl.	2			
Fuel transport & dosing units		incl.	2			
Limestone injection system and storage hopper		incl.	2			
Automatic bed media cleaning & re-injection system		incl.	2			
Ash skips		incl.	2			
Urea injection system (storage, mixing, dosing)		incl.	2			
FD and ID fans		incl.	2			
Controls & instrumentation		incl.	2			
FEED design costs		incl.	1			
Shipping costs from US to Namibian port		?	1			
Erection, testing and commissioning		incl.	1			
Custom biomass boiler		incl.	2			
Waste heat recovery water tube boiler, incl. ancillary steam cycle equipment		incl.	2			
Flue gas ductwork (furnace-boiler)		incl.	2			
Internal pipework, valves and fittings		incl.	2			
Boiler feedwater & DI water treatment system		incl.	2			
Blowdown system and receiver		incl.	2			
Internal mechanical (rapping) cleaning system		incl.	2			
Boiler ash collection system		incl.	2			
Controls & instrumentation		incl.	2			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	2			
Baghouse		incl.	2			
Interconnecting ducting between boiler & baghouse inlet		incl.	2			
Residue conveying equipment		incl.	2			
Residue silos		incl.	2			
Thermal insulation and trace heating		incl.	2			
Support structure and access facilities		incl.	2			
All field instruments and pipework		incl.	2			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	18,679	4	18,679	16,618	197,059
Steam TG and ACC	Vendor 22MWe steam turbine	6,200,000	2	4,948,125	3,974,359	52,202,713
Condensing steam turbine/generator	with equipment	incl.	2			
Controls & instrumentation		incl.	2			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	5,252,070	1	4,191,596	3,366,712	44,221,340
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	2			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	61,235	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	68,530	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	231,791	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System	OSL (in-house estimate)	430,301	1	310,037	275,834	3,270,895
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	70,338	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer	OSL (based on Bowers Electrical)	125,062	1	90,109	80,168	950,648
LV distribution board/system including motor controls for FGT	OSL (based on Boulting Group)	206,876	1	149,056	132,613	1,572,546
Site wiring and power cabling installation, testing and commissioning	OSL (based on Boulting Group)	587,939	1	423,618	376,884	4,469,168
Site supervision, installation and commissioning	Based on 8 weeks of Vendorsupervision and	312,000		224,800	200,000	2,371,640
Installation	commissioning included in bid					
Commissioning of complete process	WSP estimate					
Essential spare parts during commissioning	WSP estimate	312,000	1	224,800	200,000	2,371,640
Civils & Buildings	Estimates from previous bids on file	2,340,000	1	1,686,000	1,500,000	17,787,300
Foundations	and excluding all biomass handling,					
Buildings	storage and feeding requirements					
Parking & hardstanding	civils costs are 6.5% of equipment capex					
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		USD 38,916,820		€ 30,694,525	£24,951,324	NAD 323,827,241

€ 30,694,525

Cost of power = USD 3,892 per kW

Build up of capex for 1 x 10MWe plant for Plant at Ohorongo Cement **Supplier C**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (US$)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier C email dated 10/5/12	22,515,000	1	17,968,875	14,432,692	189,571,628
Project management, design, engineering, procurement						
Basic design	93bar, 482degC	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Provided by Ohorongo Cement	By others				
Weighbridge & station						
Wood chip store						
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier C TowerPak Stirling Power Boiler & Furnace		incl.	1			
Boiler & Furnace		incl.	1			
Superheater with attemperator and related piping		incl.	1			
Eonomizer (bare tube) with related piping		incl.	1			
Stoker – Air-cooled Vibrating Grate		incl.	1			
Compartmentalized undergrate air plenum		incl.	1			
Biomass feed system from inlet to live-bottom fuel feed bins to furnace		incl.	1			
Burners w/lighters and related fuel train		incl.	1			
PLC-based burner management system		incl.	1			
Tubular AH		incl.	1			
SCAH		incl.	1			
Flues & Ducts w/joints and dampers		incl.	1			
FD and ID Fans w/ motors		incl.	1			
Instrumentation and local controls for Supplier C supplied equipment		incl.	1			
All valves per ASME		incl.	1			
Sootblower System		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Multicyclone Dust Collector		incl.	1			
Electrostatic Precipitator		incl.	1			
SNCR NOx Reduction System, including ammonia storage/injection system		incl.	1			
Ash handling systems		incl.	1			
Interconnecting ducting between FGT outlet and inlet to single stack		incl.	1			
Thermal insulation and trace heating		incl.	1			
Support structure and access facilities		incl.	1			
All field instruments and pipework		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,705	2	9,705	8,635	102,393
Steam TG and ACC	Vendor 11MWe steam turbine	3,100,000	1	2,474,062	1,987,179	26,101,357
Condensing steam turbine/generator	with equipment	incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	4,031,600	1	3,217,558	2,584,359	33,945,235
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		15,000	1	11,971	9,615	126,297
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	61,235	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	68,530	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	231,791	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System	OSL (in-house estimate)	430,301	1	310,037	275,834	3,270,895
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	70,338	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer	OSL (based on Bowers Electrical)	125,062	1	90,109	80,168	950,648
LV distribution board/system including motor controls for FGT	OSL (based on Boulting Group)	206,876	1	149,056	132,613	1,572,546
Site wiring and power cabling installation, testing and commissioning	OSL (based on Boulting Group)	587,939	1	423,618	376,884	4,469,168
Site supervision, installation and commissioning	WSP estimate from previous bids	312,000		224,800	200,000	2,371,640
Installation	on file					
Commissioning of complete process						
Essential spare parts during commissioning	WSP estimate	156,000	1	112,400	100,000	1,185,820
Civils & Buildings	Estimates from previous bids on file	2,028,000	1	1,461,200	1,300,000	15,415,660
Foundations	and excluding all biomass handling,					
Buildings	storage and feeding requirements					
Parking & hardstanding	civils costs are 6.5% of equipment capex					
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		USD 33,949,377		€ 26,764,577	£21,764,835	NAD 282,366,289

€ 26,764,577

Cost of power = USD 3,395 per kW

Build up of capex for 2 x 10MWe plant for Plant at Ohorongo Cement **Supplier C**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (US$)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier C email dated 10/5/12	42,430,000	1	33,862,729	27,198,718	357,251,796
Project management, design, engineering, procurement						
Basic design	93bar, 482degC	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Provided by Ohorongo Cement	By others				
Weighbridge & station						
Wood chip store						
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier C TowerPak Stirling Power Boiler & Furnace		incl.	2			
Boiler & Furnace		incl.	2			
Superheater with attemperator and related piping		incl.	2			
Eonomizer (bare tube) with related piping		incl.	2			
Stoker – Air-cooled Vibrating Grate		incl.	2			
Compartmentalized undergrate air plenum		incl.	2			
Biomass feed system from inlet to live-bottom fuel feed bins to furnace		incl.	2			
Burners w/lighters and related fuel train		incl.	2			
PLC-based burner management system		incl.	2			
Tubular AH		incl.	2			
SCAH		incl.	2			
Flues & Ducts w/joints and dampers		incl.	2			
FD and ID Fans w/ motors		incl.	2			
Instrumentation and local controls for Supplier C supplied equipment		incl.	2			
All valves per ASME		incl.	2			
Sootblower System		incl.	2			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	2			
Multicyclone Dust Collector		incl.	2			
Electrostatic Precipitator		incl.	2			
SNCR NOx Reduction System, including ammonia storage/injection system		incl.	2			
Ash handling systems		incl.	2			
Interconnecting ducting between FGT outlet and inlet to single stack		incl.	2			
Thermal insulation and trace heating		incl.	2			
Support structure and access facilities		incl.	2			
All field instruments and pipework		incl.	2			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,705	2	9,705	8,635	102,393
Steam TG and ACC	Vendor 11MWe steam turbine	6,200,000	2	4,948,125	3,974,359	52,202,713
Condensing steam turbine/generator	with equipment	incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	6,110,763	1	4,876,906	3,917,156	51,451,356
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		15,000	2	11,971	9,615	126,297
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	61,235	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	68,530	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	231,791	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System	OSL (in-house estimate)	430,301	1	310,037	275,834	3,270,895
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	70,338	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer	OSL (based on Bowers Electrical)	125,062	1	90,109	80,168	950,648
LV distribution board/system including motor controls for FGT	OSL (based on Boulting Group)	206,876	1	149,056	132,613	1,572,546
Site wiring and power cabling installation, testing and commissioning	OSL (based on Boulting Group)	587,939	1	423,618	376,884	4,469,168
Site supervision, installation and commissioning	WSP estimate from previous bids	312,000		224,800	200,000	2,371,640
Installation	on file					
Commissioning of complete process						
Essential spare parts during commissioning	WSP estimate	156,000	1	112,400	100,000	1,185,820
Civils & Buildings	Estimates from previous bids on file	3,744,000	1	2,697,600	2,400,000	28,459,680
Foundations	and excluding all biomass handling,					
Buildings	storage and feeding requirements					
Parking & hardstanding	civils costs are 6.5% of equipment capex					
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**USD 60,759,540**		**€ 48,028,242**	**£38,950,837**	**NAD 506,697,954**

€ 48,028,242

Cost of power = **USD 3,038** per kW

Build up of capex for 1 x 10MWe plant for Plant at Ohorongo Cement **Supplier D**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (Euro)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier D email dated 30/5/12	36,286,468	1	36,286,468	32,283,334	382,822,233
Project management, design, engineering, procurement	Based on cost estimate for a					
Basic design	turnkey 20MWe plant	incl.	1			
Detailed design and complete process integration	Capex calculated using 0.6 power rule	incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Provided by Ohorongo Cement	By others				
Weighbridge & station						
Wood chip store						
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier C TowerPak Stirling Power Boiler & Furnace		incl.	1			
Boiler & Furnace		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,705	2	9,705	8,635	102,393
Steam TG and ACC		incl.	1			
Condensing steam turbine/generator		incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports		incl.	1			
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	44,121	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	49,376	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	167,009	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System		incl.	1			
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	50,679	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer		incl.	1			
LV distribution board/system including motor controls for FGT		incl.	1			
Site wiring and power cabling installation, testing and commissioning		incl.	1			
Site supervision, installation and commissioning						
Installation		incl.	1			
Commissioning of complete process		incl.	1			
Essential spare parts during commissioning	WSP estimate	156,000	1	112,400	100,000	1,185,820
Civils & Buildings	Estimates from previous bids on file	2,360,400	1	2,360,400	2,100,000	24,902,220
Foundations	and excluding all biomass handling,					
Buildings	storage and feeding requirements					
Parking & hardstanding	civils costs are 6.5% of equipment capex					
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**€ 39,123,758**		**€ 39,080,158**	**£34,768,824**	**NAD 412,295,668**

€ 39,080,158

Cost of power = **USD 4,902** per kW

Build up of capex for 1 x 20MWe plant for Plant at Ohorongo Cement **Supplier D**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (Euro)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier D email dated 30/5/12	55,000,000	1	55,000,000	48,932,384	580,250,000
Project management, design, engineering, procurement	Based on cost estimate for a					
Basic design	turnkey 20MWe plant	incl.	1			
Detailed design and complete process integration	Capex calculated using 0.6 power rule	incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Provided by Ohorongo Cement	By others				
Weighbridge & station						
Wood chip store						
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier C TowerPak Stirling Power Boiler & Furnace		incl.	1			
Boiler & Furnace		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,705	2	9,705	8,635	102,393
Steam TG and ACC		incl.	1			
Condensing steam turbine/generator		incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports		incl.	1			
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	44,121	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	49,376	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	167,009	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System		incl.	1			
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	50,679	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer		incl.	1			
LV distribution board/system including motor controls for FGT		incl.	1			
Site wiring and power cabling installation, testing and commissioning		incl.	1			
Site supervision, installation and commissioning						
Installation		incl.	1			
Commissioning of complete process		incl.	1			
Essential spare parts during commissioning	WSP estimate	312,000	1	224,800	200,000	2,371,640
Civils & Buildings	Estimates from previous bids on file	2,360,400	1	2,360,400	2,100,000	24,902,220
Foundations	and excluding all biomass handling,					
Buildings	storage and feeding requirements					
Parking & hardstanding	civils costs are 6.5% of equipment capex					
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		€ 57,993,291		€ 57,906,091	£51,517,874	NAD 610,909,256

€ 57,906,091

Cost of power = USD 3,633 per kW

Build up of capex for 1 x 10MWe plant for Plant at Ohorongo Cement **Supplier B**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55
Exchange rate - 1RAND = NAM$	1
Exchange rate - 1RAND = £1	0.075

Process item	Price origin	Capex (RAND)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier B proposal dated 13/7/12	130,000,000	1	10,959,000	9,750,000	130,000,000
Project management, design, engineering, procurement	Based on cost estimate for a					
Basic design	turnkey10MWe plant	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Provided by Ohorongo Cement	By others				
Weighbridge & station						
Wood chip store						
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Boiler & Furnace		incl.	1			
Boiler & Furnace		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	230,261	4	19,411	17,270	230,261
Steam TG and ACC	Vendor 11MWe steam turbine	26,495,726	1	2,233,590	1,987,179	26,495,726
Condensing steam turbine/generator	with equipment	incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	34,458,120	1	2,904,819	2,584,359	34,458,120
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	523,377	1	44,121	39,253	523,377
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	585,723	1	49,376	43,929	585,723
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	1,981,123	1	167,009	148,584	1,981,123
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System		incl.	1			
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	601,177	1	50,679	45,088	601,177
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer		incl.	1			
LV distribution board/system including motor controls for FGT		incl.	1			
Site wiring and power cabling installation, testing and commissioning		incl.	1			
Site supervision, installation and commissioning						
Installation		incl.	1			
Commissioning of complete process		incl.	1			
Essential spare parts during commissioning	WSP estimate	1,333,333	1	112,400	100,000	1,333,333
Civils & Buildings	Estimates from previous bids on file	12,733,333	1	1,073,420	955,000	12,733,333
Foundations	and excluding all biomass handling,					
Buildings	storage and feeding requirements					
Parking & hardstanding	civils costs are 6.5% of equipment capex					
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**R 208,942,174**		**€ 17,613,825**	**£15,670,663**	**NAD 208,942,174**

€ 17,613,825

Cost of power = **$2,445** per kW

Build up of capex for 2 x 10MWe plant for Plant at Ohorongo Cement **Supplier B**

Number of lines =	2
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55
Exchange rate - 1RAND = NAM$	1
Exchange rate - 1RAND = £1	0.075

Process item	Price origin	Capex (RAND)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier B proposal dated 13/7/12	260,000,000	2	21,918,000	19,500,000	260,000,000
Project management, design, engineering, procurement	Based on cost estimate for a					
Basic design	turnkey10MWe plant	incl.	2			
Detailed design and complete process integration		incl.	2			
Project documentation (drawings, O&M manuals, translation etc)		incl.	2			
Fuel delivery, storage and handling	Provided by Ohorongo Cement	By others				
Weighbridge & station						
Wood chip store						
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Boiler & Furnace		incl.	2			
Boiler & Furnace		incl.	2			
Erection, testing and commissioning		incl.	2			
Flue Gas Treatment System		incl.	2			
Mechanical installation		incl.	2			
Site supervision and cold commissioning		incl.	2			
Hot commissioning		incl.	2			
Emergency showers	Hughes Safety Showers (WSP estimate)	115,130	2	9,705	8,635	115,130
Steam TG and ACC	Vendor 2 x 11MWe steam turbine	52,991,453	2	4,467,179	3,974,359	52,991,453
Condensing steam turbine/generator	with equipment	incl.	2			
Controls & instrumentation		incl.	2			
Installation, testing & commissioning		incl.	2			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	44,889,487	1	3,784,184	3,366,712	44,889,487
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	523,377	2	44,121	39,253	523,377
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	585,723	1	49,376	43,929	585,723
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	1,981,123	1	167,009	148,584	1,981,123
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System		incl.	1			
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	601,177	1	50,679	45,088	601,177
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer		incl.	1			
LV distribution board/system including motor controls for FGT		incl.	1			
Site wiring and power cabling installation, testing and commissioning		incl.	1			
Site supervision, installation and commissioning						
Installation		incl.	1			
Commissioning of complete process		incl.	1			
Essential spare parts during commissioning	WSP estimate	2,666,667	2	224,800	200,000	2,666,667
Civils & Buildings	Estimates from previous bids on file	23,733,333	1	2,000,720	1,780,000	23,733,333
Foundations	and excluding all biomass handling,					
Buildings	storage and feeding requirements					
Parking & hardstanding	civils costs are 6.5% of equipment capex					
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**R 388,087,471**		**€ 32,715,774**	**£29,106,560**	**NAD 388,087,471**

€ 32,715,774

Cost of power = **$2,270** per kW

Appendix J. CAPEX estimate for scenarios located at Otjikoto Sub-station

Build up of capex for 1 x 10MWe plant for Plant at Otjikoto sub-station **Supplier E**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (US$)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier E proposal 13/3/12 FOB US port	11,700,000	1	9,337,590	7,500,000	98,511,572
Project management, design, engineering, procurement						
Basic design	95bar, 480degC	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Based on previous UK based bids	2,184,000	1	1,573,600	1,400,000	16,601,480
Weighbridge & station	from 2010 and inflated at 3% per year					
Wood chip store	includes fire suppression system					
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier E Fluidised Bed		incl.	1			
Intermediate feed hoppers		incl.	1			
Fuel transport & dosing units		incl.	1			
Limestone injection system and storage hopper		incl.	1			
Automatic bed media cleaning & re-injection system		incl.	1			
Ash skips		incl.	1			
Urea injection system (storage, mixing, dosing)		incl.	1			
FD and ID fans		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Shipping costs from US to Namibian port		?	1			
Erection, testing and commissioning		incl.	1			
Custom biomass boiler		incl.	1			
Waste heat recovery water tube boiler, incl. ancillary steam cycle equipment		incl.	1			
Flue gas ductwork (furnace-boiler)		incl.	1			
Internal pipework, valves and fittings		incl.	1			
Boiler feedwater & DI water treatment system		incl.	1			
Blowdown system and receiver		incl.	1			
Internal mechanical (rapping) cleaning system		incl.	1			
Boiler ash collection system		incl.	1			
Controls & instrumentation		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Baghouse		incl.	1			
Interconnecting ducting between boiler & baghouse inlet		incl.	1			
Residue conveying equipment		incl.	1			
Residue silos		incl.	1			
Thermal insulation and trace heating		incl.	1			
Support structure and access facilities		incl.	1			
All field instruments and pipework		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,339	2	9,339	8,309	98,529
Steam TG and ACC	Vendor 11MWe steam turbine	3,100,000	1	2,474,062	1,987,179	26,101,357
Condensing steam turbine/generator	with equipment	incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	4,031,600	1	3,217,558	2,584,359	33,945,235
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	61,235	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	68,530	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	231,791	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Included in Fuel handling system quote	incl.				
Central Control & Monitoring System	OSL (in-house estimate)	430,301	1	310,037	275,834	3,270,895
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	70,338	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer	OSL (based on Bowers Electrical)	125,062	1	90,109	80,168	950,648
LV distribution board/system including motor controls for FGT	OSL (based on Boulting Group)	206,876	1	149,056	132,613	1,572,546
Site wiring and power cabling installation, testing and commissioning	OSL (based on Boulting Group)	587,939	1	423,618	376,884	4,469,168
Site supervision, installation and commissioning	Based on 8 weeks of Supplier E supervision and	312,000		224,800	200,000	2,371,640
Installation	commissioning included in bid					
Commissioning of complete process	WSP estimate					
Essential spare parts during commissioning	WSP estimate	156,000	1	112,400	100,000	1,185,820
Civils & Buildings	Typically from previous power projects	2,652,000	1	1,910,800	1,700,000	20,158,940
Foundations	Group Five estimate 13.5% for civils					
Buildings	for a Namibian context					
Parking & hardstanding						
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		USD 25,927,011		€ 20,144,155	£16,622,201	NAD 212,520,833

€ 20,144,155

Cost of power = USD 2,593 per kW

Build up of capex for 1 x 10MWe plant for Plant at Otjikoto sub-station **Supplier E**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (US$)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier E proposal 13/3/12 FOB US port	22,700,000	1	18,116,520	14,551,282	191,129,290
Project management, design, engineering, procurement						
Basic design	95bar, 480degC	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Based on previous UK based bids	3,900,000	1	2,810,000	2,500,000	29,645,500
Weighbridge & station	from 2010 and inflated at 3% per year					
Wood chip store	includes fire suppression system					
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier E Fluidised Bed		incl.	2			
Intermediate feed hoppers		incl.	2			
Fuel transport & dosing units		incl.	2			
Limestone injection system and storage hopper		incl.	2			
Automatic bed media cleaning & re-injection system		incl.	2			
Ash skips		incl.	2			
Urea injection system (storage, mixing, dosing)		incl.	2			
FD and ID fans		incl.	2			
Controls & instrumentation		incl.	2			
FEED design costs		incl.	1			
Shipping costs from US to Namibian port		?	1			
Erection, testing and commissioning		incl.	1			
Custom biomass boiler		incl.	2			
Waste heat recovery water tube boiler, incl. ancillary steam cycle equipment		incl.	2			
Flue gas ductwork (furnace-boiler)		incl.	2			
Internal pipework, valves and fittings		incl.	2			
Boiler feedwater & DI water treatment system		incl.	2			
Blowdown system and receiver		incl.	2			
Internal mechanical (rapping) cleaning system		incl.	2			
Boiler ash collection system		incl.	2			
Controls & instrumentation		incl.	2			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	2			
Baghouse		incl.	2			
Interconnecting ducting between boiler & baghouse inlet		incl.	2			
Residue conveying equipment		incl.	2			
Residue silos		incl.	2			
Thermal insulation and trace heating		incl.	2			
Support structure and access facilities		incl.	2			
All field instruments and pipework		incl.	2			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	18,679	4	18,679	16,618	197,059
Steam TG and ACC	Vendor 11MWe steam turbine	6,200,000	2	4,948,125	3,974,359	52,202,713
Condensing steam turbine/generator	with equipment	incl.	2			
Controls & instrumentation		incl.	2			
Installation, testing & commissioning		incl.	2			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	5,252,070	1	4,191,596	3,366,712	44,221,340
Steam ejector system		incl.	2			
Condensate tank and condensate pumps		incl.	2			
Controls & instrumentation		incl.	2			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	2			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	61,235	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	85,290	1	61,452	54,673	648,321
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	288,479	1	207,853	184,923	2,192,851
Fire suppression and fighting system	Included in Fuel handling system quote	incl.				
Central Control & Monitoring System	OSL (in-house estimate)	430,301	1	310,037	275,834	3,270,895
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	70,338	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer	OSL (based on Bowers Electrical)	125,062	1	90,109	80,168	950,648
LV distribution board/system including motor controls for FGT	OSL (based on Boulting Group)	206,876	1	149,056	132,613	1,572,546
Site wiring and power cabling installation, testing and commissioning	OSL (based on Boulting Group)	587,939	1	423,618	376,884	4,469,168
Site supervision, installation and commissioning	Based on 8 weeks of Supplier E supervision and	312,000		224,800	200,000	2,371,640
Installation	commissioning included in bid					
Commissioning of complete process	WSP estimate					
Essential spare parts during commissioning	WSP estimate	156,000	1	112,400	100,000	1,185,820
Civils & Buildings	Typically from previous power projects	4,680,000	1	3,372,000	3,000,000	35,574,600
Foundations	Group Five estimate 13.5% for civils					
Buildings	for a Namibian context					
Parking & hardstanding						
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**USD 45,074,268**		**€ 35,131,045**	**£28,898,406**	**NAD 370,632,529**

€ 35,131,045

Cost of power = **USD 2,254** per kW

Build up of capex for 1 x 10MWe plant for Plant at Otjikoto sub-station **Supplier C**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (US$)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier C email dated 10/5/12	22,515,000	1	17,968,875	14,432,692	189,571,628
Project management, design, engineering, procurement						
Basic design	93bar, 482degC	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Based on previous UK based bids	2,184,000	1	1,573,600	1,400,000	16,601,480
Weighbridge & station	from 2010 and inflated at 3% per year					
Wood chip store	includes fire suppression system					
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier C Boiler & Furnace		incl.	1			
Boiler & Furnace		incl.	1			
Superheater with attemperator and related piping		incl.	1			
Eonomizer (bare tube) with related piping		incl.	1			
Stoker – Air-cooled Vibrating Grate		incl.	1			
Compartmentalized undergrate air plenum		incl.	1			
Biomass feed system from inlet to live-bottom fuel feed bins to furnace		incl.	1			
Burners w/lighters and related fuel train		incl.	1			
PLC-based burner management system		incl.	1			
Tubular AH		incl.	1			
SCAH		incl.	1			
Flues & Ducts w/joints and dampers		incl.	1			
FD and ID Fans w/ motors		incl.	1			
Instrumentation and local controls for Supplier C supplied equipment		incl.	1			
All valves per ASME		incl.	1			
Sootblower System		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Multicyclone Dust Collector		incl.	1			
Electrostatic Precipitator		incl.	1			
SNCR NOx Reduction System, including ammonia storage/injection system		incl.	1			
Ash handling systems		incl.	1			
Interconnecting ducting between FGT outlet and inlet to single stack		incl.	1			
Thermal insulation and trace heating		incl.	1			
Support structure and access facilities		incl.	1			
All field instruments and pipework		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,705	2	9,705	8,635	102,393
Steam TG and ACC	Vendor 11MWe steam turbine	3,100,000	1	2,474,062	1,987,179	26,101,357
Condensing steam turbine/generator	with equipment	incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	4,031,600	1	3,217,558	2,584,359	33,945,235
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		15,000	1	11,971	9,615	126,297
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	61,235	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	68,530	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	231,791	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Included in Fuel handling system quote	incl.				
Central Control & Monitoring System	OSL (in-house estimate)	430,301	1	310,037	275,834	3,270,895
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	70,338	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer	OSL (based on Bowers Electrical)	125,062	1	90,109	80,168	950,648
LV distribution board/system including motor controls for FGT	OSL (based on Boulting Group)	206,876	1	149,056	132,613	1,572,546
Site wiring and power cabling installation, testing and commissioning	OSL (based on Boulting Group)	587,939	1	423,618	376,884	4,469,168
Site supervision, installation and commissioning	WSP estimate from previous bids	312,000		224,800	200,000	2,371,640
Installation	on file					
Commissioning of complete process						
Essential spare parts during commissioning	WSP estimate	156,000	1	112,400	100,000	1,185,820
Civils & Buildings	Typically from previous power projects	4,056,000	1	2,922,400	2,600,000	30,831,320
Foundations	Group Five estimate 13.5% for civils					
Buildings	for a Namibian context					
Parking & hardstanding						
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**USD 38,161,377**		**€ 29,799,377**	**£24,464,835**	**NAD 314,383,429**

€ 29,799,377

Cost of power = **USD 3,816** per kW

Build up of capex for 1 x 20MWe plant for Plant at Otjikoto sub-station **Supplier C**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (US$)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier C email dated 10/5/12	42,430,000	1	33,862,729	27,198,718	357,251,796
Project management, design, engineering, procurement						
Basic design	93bar, 482degC	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Based on previous UK based bids	3,900,000	1	2,810,000	2,500,000	29,645,500
Weighbridge & station	from 2010 and inflated at 3% per year					
Wood chip store	includes fire suppression system					
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Supplier C Boiler & Furnace		incl.	2			
Boiler & Furnace		incl.	2			
Superheater with attemperator and related piping		incl.	2			
Eonomizer (bare tube) with related piping		incl.	2			
Stoker – Air-cooled Vibrating Grate		incl.	2			
Compartmentalized undergrate air plenum		incl.	2			
Biomass feed system from inlet to live-bottom fuel feed bins to furnace		incl.	2			
Burners w/lighters and related fuel train		incl.	2			
PLC-based burner management system		incl.	2			
Tubular AH		incl.	2			
SCAH		incl.	2			
Flues & Ducts w/joints and dampers		incl.	2			
FD and ID Fans w/ motors		incl.	2			
Instrumentation and local controls for Supplier C supplied equipment		incl.	2			
All valves per ASME		incl.	2			
Sootblower System		incl.	2			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	2			
Multicyclone Dust Collector		incl.	2			
Electrostatic Precipitator		incl.	2			
SNCR NOx Reduction System, including ammonia storage/injection system		incl.	2			
Ash handling systems		incl.	2			
Interconnecting ducting between FGT outlet and inlet to single stack		incl.	2			
Thermal insulation and trace heating		incl.	2			
Support structure and access facilities		incl.	2			
All field instruments and pipework		incl.	2			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	19,411	4	19,411	17,270	204,786
Steam TG and ACC	Vendor 22MWe steam turbine	6,000,000	2	4,788,508	3,846,154	50,518,755
Condensing steam turbine/generator	with equipment	incl.	2			
Controls & instrumentation		incl.	2			
Installation, testing & commissioning		incl.	2			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	6,110,763	2	4,876,906	3,917,156	51,451,356
Steam ejector system		incl.	2			
Condensate tank and condensate pumps		incl.	2			
Controls & instrumentation		incl.	2			
FEED design costs		incl.	2			
Erection, testing and commissioning		incl.	2			
Stack		15,000	2	11,971	19,231	126,297
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	92,815	1	66,874	59,497	705,526
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	85,290	1	61,452	54,673	648,321
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	288,479	1	207,853	184,923	2,192,851
Fire suppression and fighting system	Included in Fuel handling system quote	incl.				
Central Control & Monitoring System	OSL (in-house estimate)	652,214	1	469,929	418,086	4,957,749
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	70,338	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer	OSL (based on Bowers Electrical)	125,062	1	90,109	80,168	950,648
LV distribution board/system including motor controls for FGT	OSL (based on Boulting Group)	206,876	1	149,056	132,613	1,572,546
Site wiring and power cabling installation, testing and commissioning	OSL (based on Boulting Group)	587,939	1	423,618	376,884	4,469,168
Site supervision, installation and commissioning	WSP estimate from previous bids	468,000		337,200	300,000	3,557,460
Installation	on file					
Commissioning of complete process						
Essential spare parts during commissioning	WSP estimate	312,000	2	224,800	200,000	2,371,640
Civils & Buildings	Typically from previous power projects	7,488,000	1	5,395,200	4,800,000	56,919,360
Foundations	Group Five estimate 13.5% for civils					
Buildings	for a Namibian context					
Parking & hardstanding						
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		USD 68,852,187		€ 53,846,296	£44,150,459	NAD 568,078,423

€ 53,846,296

Cost of power = USD 3,443 per kW

Build up of capex for 1 x 10MWe plant for Plant at Otjikoto sub-station **Supplier D**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (Euro)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier D email dated 30/5/12	36,286,468	1	36,286,468	32,283,334	382,822,233
Project management, design, engineering, procurement	Based on cost estimate for a					
Basic design	turnkey 20MWe plant	incl.	1			
Detailed design and complete process integration	Capex calculated using 0.6 power rule	incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling		incl.	1			
Weighbridge & station		incl.	1			
Wood chip store		incl.	1			
Conveyer system to combustor feed hopper		incl.	1			
Vehicles, fork lifts, etc		incl.	1			
Boiler & Furnace		incl.	1			
Boiler & Furnace		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,705	2	9,705	8,635	102,393
Steam TG and ACC		incl.	1			
Condensing steam turbine/generator		incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports		incl.	1			
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	44,121	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	49,376	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	167,009	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System		incl.	1			
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	50,679	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer		incl.	1			
LV distribution board/system including motor controls for FGT		incl.	1			
Site wiring and power cabling installation, testing and commissioning		incl.	1			
Site supervision, installation and commissioning						
Installation		incl.	1			
Commissioning of complete process		incl.	1			
Essential spare parts during commissioning	WSP estimate	156,000	1	112,400	100,000	1,185,820
Civils & Buildings	Typically from previous power projects	4,945,600	1	4,945,600	4,400,000	52,176,080
Foundations	Group Five estimate 13.5% for civils					
Buildings	for a Namibian context					
Parking & hardstanding						
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		€ 41,708,958		€ 41,665,358	£37,068,824	NAD 439,569,528

€ 41,665,358

Cost of power = USD 5,226 per kW

Build up of capex for 1 x 20MWe plant for Plant at Otjikoto sub-station **Supplier D**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55

Process item	Price origin	Capex (Euro)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier D email dated 30/5/12	55,000,000	1	55,000,000	48,932,384	580,250,000
Project management, design, engineering, procurement	Based on cost estimate for a					
Basic design	turnkey 20MWe plant	incl.	1			
Detailed design and complete process integration	Capex calculated using 0.6 power rule	incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling		incl.	1			
Weighbridge & station		incl.	1			
Wood chip store		incl.	1			
Conveyer system to combustor feed hopper		incl.	1			
Vehicles, fork lifts, etc		incl.	1			
Boiler & Furnace		incl.	1			
Boiler & Furnace		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	9,705	2	9,705	8,635	102,393
Steam TG and ACC		incl.	1			
Condensing steam turbine/generator		incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports		incl.	1			
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	44,121	1	44,121	39,253	465,473
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	49,376	1	49,376	43,929	520,922
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	167,009	1	167,009	148,584	1,761,942
Fire suppression and fighting system	Provided by Ohorongo Cement					
Central Control & Monitoring System		incl.	1			
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	50,679	1	50,679	45,088	534,665
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer		incl.	1			
LV distribution board/system including motor controls for FGT		incl.	1			
Site wiring and power cabling installation, testing and commissioning		incl.	1			
Site supervision, installation and commissioning						
Installation		incl.	1			
Commissioning of complete process		incl.	1			
Essential spare parts during commissioning	WSP estimate	312,000	1	224,800	200,000	2,371,640
Civils & Buildings	Typically from previous power projects	7,418,400	1	7,418,400	6,600,000	78,264,120
Foundations	Group Five estimate 13.5% for civils					
Buildings	for a Namibian context					
Parking & hardstanding						
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		€ 63,051,291		€ 62,964,091	£56,017,874	NAD 664,271,156

€ 62,964,091

Cost of power = USD 3,950 per kW

Build up of capex for 1 x 10MWe plant for Plant at Otjikoto sub-station **Supplier B**

Number of lines =	1
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55
Exchange rate - 1RAND = NAM$	1
Exchange rate - 1RAND = £1	0.075

Process item	Price origin	Capex (RAND)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier B proposal dated 13/7/12	130,000,000	1	10,959,000	9,750,000	130,000,000
Project management, design, engineering, procurement	Based on cost estimate for a					
Basic design	turnkey10MWe plant	incl.	1			
Detailed design and complete process integration		incl.	1			
Project documentation (drawings, O&M manuals, translation etc)		incl.	1			
Fuel delivery, storage and handling	Based on previous UK based bids	18,666,667	1	1,573,600	1,400,000	16,601,480
Weighbridge & station	from 2010 and inflated at 3% per year					
Wood chip store	includes fire suppression system					
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Boier & Furnace		incl.	1			
Boiler & Furnace		incl.	1			
Erection, testing and commissioning		incl.	1			
Flue Gas Treatment System		incl.	1			
Mechanical installation		incl.	1			
Site supervision and cold commissioning		incl.	1			
Hot commissioning		incl.	1			
Emergency showers	Hughes Safety Showers (WSP estimate)	115,130	2	9,705	8,635	115,130
Steam TG and ACC	Vendor 11MWe steam turbine	52,991,453	2	4,467,179	3,974,359	52,991,453
Condensing steam turbine/generator	with equipment	incl.	1			
Controls & instrumentation		incl.	1			
Installation, testing & commissioning		incl.	1			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	34,458,120	1	2,904,819	2,584,359	34,458,120
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	523,377	1	44,121	39,253	523,377
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	585,723	1	49,376	43,929	585,723
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	1,981,123	1	167,009	148,584	1,981,123
Fire suppression and fighting system	Included in Fuel handling system quote	incl.				
Central Control & Monitoring System		incl.	1			
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	601,177	1	50,679	45,088	601,177
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer		incl.	1			
LV distribution board/system including motor controls for FGT		incl.	1			
Site wiring and power cabling installation, testing and commissioning		incl.	1			
Site supervision, installation and commissioning		incl.	1			
Installation		incl.	1			
Commissioning of complete process		incl.	1			
Essential spare parts during commissioning	WSP estimate	1,333,333	1	112,400	100,000	1,333,333
Civils & Buildings	Typically from previous power projects	32,533,333	1	2,742,560	2,440,000	32,533,333
Foundations	Group Five estimate 13.5% for civils					
Buildings	for a Namibian context					
Parking & hardstanding						
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**R 273,789,437**		**€ 23,080,450**	**£20,534,208**	**NAD 271,724,251**

€ 23,080,450

Cost of power = **$3,203** per kW

Build up of capex for 2 x 10MWe plant for Plant at Otjikoto sub-station **Supplier B**

Number of lines =	2
Exchange rate - £1 = US$	1.56
Exchange rate - €1 = US$	1.253
Exchange rate - £1 = €	1.124
Exchange rate - €1 = NAM$	10.55
Exchange rate - 1RAND = NAM$	1
Exchange rate - 1RAND = £1	0.075

Process item	Price origin	Capex (RAND)	Qty	Total (Euro)	Total (£)	Total (NAM$)
Total Capex (Budgetary)						
Turnkey price	Supplier B proposal dated 13/7/12	260,000,000	2	21,918,000	19,500,000	260,000,000
Project management, design, engineering, procurement	Based on cost estimate for a					
Basic design	turnkey10MWe plant	incl.	2			
Detailed design and complete process integration		incl.	2			
Project documentation (drawings, O&M manuals, translation etc)		incl.	2			
Fuel delivery, storage and handling	Based on previous UK based bids	33,333,333	1	2,810,000	2,500,000	29,645,500
Weighbridge & station	from 2010 and inflated at 3% per year					
Wood chip store	includes fire suppression system					
Conveyer system to combustor feed hopper						
Vehicles, fork lifts, etc						
Furnace & Boiler		incl.	2			
Boiler & Furnace		incl.	2			
Erection, testing and commissioning		incl.	2			
Flue Gas Treatment System		incl.	2			
Mechanical installation		incl.	2			
Site supervision and cold commissioning		incl.	2			
Hot commissioning		incl.	2			
Emergency showers	Hughes Safety Showers (WSP estimate)	230,261	4	19,411	17,270	230,261
Steam TG and ACC	Vendor 11MWe steam turbine	52,991,453	2	4,467,179	3,974,359	52,991,453
Condensing steam turbine/generator	with equipment	incl.	2			
Controls & instrumentation		incl.	2			
Installation, testing & commissioning		incl.	2			
Connection to the grid		N/A				
Air condenser for total steam flow, including construction & supports	Vendor quote 8 July 2012	44,889,487	1	3,784,184	3,366,712	44,889,487
Steam ejector system		incl.	1			
Condensate tank and condensate pumps		incl.	1			
Controls & instrumentation		incl.	1			
FEED design costs		incl.	1			
Erection, testing and commissioning		incl.	1			
Stack		incl.	1			
CEMS		N/A				
Complete CEMS systems with all piping, computers and software		N/A				
Syngas sampling		N/A				
Online syngas sampling and analysis equipment		N/A				
Incoming water	WSP estimate	523,377	2	44,121	39,253	523,377
Incoming water main						
GRP sectional water tank						
Packaged water booster pumpset						
Installation, testing & commissioning						
Additional Systems & Equipment						
Air compressor	OSL (based on Atlas Copco)	585,723	1	49,376	43,929	585,723
Back up diesel generator, incl diesel storage tank	OSL (based on Finnings)	1,981,123	1	167,009	148,584	1,981,123
Fire suppression and fighting system	Included in Fuel handling system quote	incl.				
Central Control & Monitoring System		incl.	1			
Process control system including PLC system		incl.				
Controllers, equipment & software		incl.				
Design & engineering		incl.				
SCADA and wiring installation		incl.				
Electrical control panels (additional to those included in individual packages)		incl.				
Testing and commissioning		incl.				
Utilities Pipework	OSL estimate	601,177	1	50,679	45,088	601,177
Interconnecting pipework for utility packages						
E&I Package						
Instrumentation package		incl.	1			
HV distribution switchVendorr and transformer		incl.	1			
LV distribution board/system including motor controls for FGT		incl.	1			
Site wiring and power cabling installation, testing and commissioning		incl.	1			
Site supervision, installation and commissioning		incl.	1			
Installation		incl.	1			
Commissioning of complete process		incl.	1			
Essential spare parts during commissioning	WSP estimate	2,666,667	2	224,800	200,000	2,666,667
Civils & Buildings	Typically from previous power projects	53,333,333	1	4,496,000	4,000,000	53,333,333
Foundations	Group Five estimate 13.5% for civils					
Buildings	for a Namibian context					
Parking & hardstanding						
Fencing & gates						
Lighting						
Drainage						
TOTAL CAPEX		**R 451,135,935**		**€ 38,030,759**	**£33,835,195**	**NAD 447,448,102**

€ 38,030,759

Cost of power = **$2,639** per kW

Appendix K. Torrefaction

This appendix details the site visit to Green Coal on 13th June 2012.

Green Coal Discussion Notes

The site visit was attended by:

- Kevin Whiting (WSP UK)
- Elan Theeboom (WSP SA)
- Enver Doruk Ozdemir (University of Stuttgart)
- Johan Bekker (Lithon)
- Klaus Jacobi (Lithon)
- John Langford (NamPower)
- Tangeni Tshivute (NamPower)

The team was met by Mr Gershon Ben Tovim, the owner of Green Coal. The meeting took place at Mr Ben Tovim's farm near Omaruru.

The site visit comprised:

- An initial briefing by Gershon Ben Tovim (owner of Green Coal);
- An inspection of the woodchip material after harvesting and hammer-milling;
- An inspection of the operational torrefaction plant pilot unit (2 ton per hr unit);
- An inspection of post-processing to sieve out sands (picked up from the harvesting process) and oversized chips;
- An inspection of the final torrefied material output (chips) and torrefied pellets;
- An extensive Q&A discussion session regarding the technical process as well as commercial issues. During this time, Mr Ben Tovim was extremely open with respect to financial modelling spreadsheets, process drawings, his experiences with supply chain harvesting etc. Mr Ben Tovim Mr Ben Tovim also discussed his technical partners which include:
  - Nuclear Energy Corporation of South Africa (NECSA) for engineering design input as well as production of certain key parts of a full scale facility (i.e. the kiln)
  - Israel Electric Corporation: IEC is the national electric utility provider in Israel. It is understood that the Mr Ben Tovim is in discussions with the IEC for them to act as EPC contractor as well as a possible investor and purchaser of exported torrefied material.

During the discussions, the following points of interest were noted:

- Plans are for the commissioning of a 10 ton per hour commercial unit (5 x up scaling of pilot unit);
- The dry biomass calorific content is estimated at 18 MJ/kg (compared to 25-26 MJ/kg for the torrefied material);
- Chlorine in the torrefied material is low (starts at around 1,000 ppm in raw woodchip but reduces to 300 ppm after the process);
- Woodchips come out at around 2 cm length;
- Approximately 50% of the volatiles are removed in the process. The process has a very short residence time of only 3 minutes or so (at a temperature of 350°C);

- Melting point for the chips is around 1,500°C. The chips have an ash content of around 10%;
- Torrefied material has been stored outside for up to 9 months and is relatively unaffected by rain;
- Negligible sulphur content;
- The woodchips could be used directly in a fluid bed coal boiler. Pellets are needed for a grate system. A further benefit of the fluid bed is that sand picked up in the harvesting process would not be a significant issue;
- Explosion risk is noted as being less than coal, although the combustion point is 290°C compared to 350°C for coal;
- An obvious improvement to the process is to harness the waste heat/energy to generate electricity at the same time. While technically feasible, this has not been proven at the pilot scale level (Kevin Whiting noted that the excess volatiles and waste heat could also be directed into an adjacent biomass to power combustion plant i.e. to integrate the two units. He also notes that, while an interesting concept for the future, the first step would be to prove a commercial scale torrefaction unit, and that this would then need to be followed by further R&D to prove the power generation opportunities).

With respect to the harvesting aspects:

- The sieved out ash content can be returned to the harvested land as a soil additive;
- The current harvesting method (using wheeled, tractor type vehicles with front mounted cutters rolling on a horizontal axis) results in the pick-up of a significant amount of sand (it is noted that EFF have dealt with this by raising the height at which the cutters, which are also on a horizontal axis, operate);
- Green Coal is looking at newer harvesting machines from an Italian firm (Seppi);
- Costs of the harvesting process are estimated at R100 per ton to bring it to the front of the torrefaction unit. It is assumed that the travel distance associated with this cost is of the order of 20km radius;
- Around 2 tonnes of woodchip are required for every 1 tonne of torrefied chips; hence a 10 ton per hour unit will require 20 tonnes of woodchip per hour. Assuming the plant runs at 24 hrs a day for 300 days a year (which at this initial stage appears to be Green Coal's working assumptions), this would result in 72,000 tonnes of torrefied material and around 150,000 tonnes of woodchip per annum. Green Coal estimates that this should require a 20-30km radius for the lifespan of the unit (not given);
- Green Coal estimates that the harvesting can be undertaken with 20 large harvesters operating at 1 ha per hour giving 10 tonnes of woodchip (to support the 10t per hour plant);
- The supply chain model would involve some sort of farmers' collective, SME's or similar, possibly with funding from the AgriBank. Otherwise, Green Coal could operate the harvesting. The farmers would pay for clearing;
- Green Coal indicated that around 100,000 tonnes are available on Mr Ben Tovim's farm alone. The neighbours of Mr Ben Tovim have reportedly expressed substantial interest in having their farms cleared;

Other notes:

- The price for the torrefied pellets is estimated at R850 per tonne (2011), linked to energy performance. This assumes a 190 km travel distance for delivery;
- A full-scale plant is estimated to require 6 months for commissioning, using kilns designed for fluoric acid manufacturing (from NECSA). Kevin Whiting confirmed that the kiln size for the upscaled plant is feasible;
- The pilot unit operations currently employ around 80 people. The full-scale system is expected to employ 150 – 200 people;
- The pilot plant requires 20 kW to run and 70 kW for the full scale system;
- By-products include charcoal for braais and ash for returning to the soil;
- Otjiwarongo is the furthest north that Green Coal would consider to be financially viable for transport to Van

Eck / Walvis Baai;

Key Commercial Notes

- Mr Ben Tovim indicated that the Green Coal venture can be funded by purely private sector investment. No direct investment is required from NamPower or donor institutions;
- What Green Coal would require from NamPower to make the project feasible (i.e. commissioning a full-scale 10 tonne per hour unit) is a 7 year supply contract for two thirds of the supply i.e. around 50,000 tonnes of torrefied material per annum;
- There appear to be at least two points in the process where the torrefied pellets can be blended (at the required ratio) with the coal: (i) at the initial coal loading area (where the tippers feed onto the conveyer belt); and (ii) at the coal storage area at the end of the conveyer belt. It will be a process of trial and error to determine the best technique exactly.
- It was reported that the mechanical paddle system is too destructive for the torrefied material (essential it smashes the pellets and causes dust formation). If the boilers are refurbished with an Air Schweppe type system, this should alleviate the issue.
- It is noted that further trials will be needed in order to refine the actual process for torrefied pellet use via operational experience. However, based on the team's site visit, there does not appear to be any fatal flaw or obvious impediment preventing the use of torrefied pellets at Van Eck.
- One issue that will need to be more carefully considered is the fire risk posed by a different (to coal) fuel source (including risk from flammable dust). It is advised that a comprehensive risk assessment by an industrial fire engineer be undertaken, prior to a final decision on the go-ahead with torrefied pellet use.

Initial Impressions:

- Any supply contract would be contingent on the 10 year Van Eck extension being approved and NamPower being willing to commit to a take-or-pay supply contract for 7 years for 50,000 tonnes per annum or so;
- Torrefied material is relevant as a coal replacement fuel only. It is not relevant for a biomass combustion fuel source (where directly burning the woodchips is preferable);
- Green Coal has gained substantial in-country experience with all aspects of the process: harvesting and transport, pre-processing, torrefaction, post-processing and trial burning at Van Eck. It appears to be the only torrefaction manufacturer with genuine in-country experience (although a Dutch group has also claimed to have some sort of in-country exposure). This places Green Coal well for any potential opportunities to supply NamPower;
- Despite the "low budget" appearance of the pilot plant, the engineering principles appear to be sound. Furthermore, the reputed engineering partners for full scale commercial development (NECSA, IEC etc.) are credible organisations.
- Despite the above, it is also obvious that Green Coal is still in the R&D phase of proving the commercial process. No full scale plant has been built and while there do not appear to be any obvious fatal flaws, some parts of the process have yet to be proven operationally;
- Considering the state of R&D and consequent level of risk, the project would (in WSP's opinion) be unlikely to get financing from traditional financial institutions, unless secured against other assets. However, the project may be attractive to venture capital and other higher risk profile investors;
- Considering the above, WSP would not advise NamPower to participate as a direct investor in any proposed Green Coal venture. It is simply too early in the R&D phase for this type of involvement;
- Green Coal does offer the option for NamPower to restrict its involvement to a supply contract only (i.e. no direct investment being required). Considering that there are still a number of question marks around commercial feasibility, NamPower should ensure that it is prepared for the possibility of Green Coal either

failing on a potential supply contract and/or becoming insolvent. Provided that NamPower hedges its risk appropriately (via contractual arrangements and via back-up coal supply), the only downside appears to be the requirement to sign a “take-or-pay” supply contract. If the venture proved to be successfully commercialised, there may be significant upsides;

- The upsides comprise:
  - Replacement of imported coal with a local energy fuel resource (balance of payments, local employment creation etc.);
  - Fuel cost savings as compared to coal;
  - Use of a low carbon fuel alternative to coal;
  - Relatively low risk as supply can be replaced with coal if required, and no direct NamPower investment required;
  - Development of a novel engineering technology within Namibia;
  - Promotion of encroacher bush clearing in area around the torrefaction facility;
  - Development and broadening of in-country capacity for commercial scale bush harvesting. Development of this capacity is necessary requirement if a broader encroacher-bush based energy strategy is to become a reality. It makes sense for NamPower to encourage the development of this capacity where possible;

Appendix L. Thermoflex Model Assumptions

5MW grate

The following boiler design parameters were used in the modelling of the 5 MW grate boiler scenarios:

- Furnace exit temperature of 982.2°C, excess air delivered at 20%
- Under-grate air delivery accounts for 40% of the air needs delivered at 7.5 millibar, 60% delivered at 74.7 millibar as over-fire air
- 1% of steam production is consumed for blowdown
- Circulating water is used to cool the vibrating grate and preheats the under-grate air
- Recirculation of 5% of the flue gas following cleaning
- Superheated steam is supplied at 450°C and 45 bara
- Computed thermal efficiency of 92.4% on fuel LHV

10MW grate

The following boiler design parameters were used in the modelling of the 10 MW grate boiler scenarios:

- Furnace exit temperature of 982.2°C, excess air delivered at 20%
- Under-grate air delivery accounts for 40% of the air needs delivered at 7.5 millibar, 60% delivered at 74.7 millibar as over-fire air
- 1% of steam production is consumed for blowdown
- Circulating water is used to cool the vibrating grate and preheats the under-grate air
- Recirculation of 5% of the flue gas following cleaning
- Superheated steam is supplied at 480°C and 62 bara
- Computed thermal efficiency of 92.4% on fuel LHV

10MW BFB

The following boiler design parameters were used in the modelling of the BFB scenarios:

- Furnace exit temperature of 815.6°C, excess air delivered at 20%
- Primary air delivery accounts for 60% of the air needs delivered at 150 mbar(a), 40% delivered at 12.5 mbar(a) as secondary air
- 0.25% of steam production is consumed for blowdown
- Limestone used for SO_2 control, delivered at a 2.5 to 1 calcium to sulphur molar ratio
- Superheated steam is supplied at 480°C and 62 Bara
- Computed thermal efficiency of 93.6% on fuel LHV

10MW CFB

The following boiler design parameters were used in the modelling of the CFB scenarios:

- Furnace temperature of 871.1°C, excess air delivered at 20%

- Primary air delivery accounts for 60% of the air needs delivered at 150 mbar(a), 40% delivered at 75 mbar(a) as secondary air
- 1% of steam production is consumed for blowdown
- Limestone used for SO_2 control, delivered at a 2 to 1 calcium to sulphur molar ratio
- Superheated steam is supplied at 480°C and 62 bar(a)
- Computed thermal efficiency of 93.5% on fuel LHV

WSP Environment & Energy South Africa
3rd Floor
35 Wale Street
Cape Town
8001
South Africa
Tel: +27 21 481 8646
Fax: +27 21 481 8799
www.wspenvironmental.co.za

UNITED
BY OUR
DIFFERENCE