The Clean Development Mechanism potential of a Combined Heat and Power plant in Stellenbosch, South Africa

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Abstract

Only 50-60% of the roundwood volume harvested by commercial sawmills in South Africa is sold as timber. The rest is sold as timber by-products, utilised as fuel in sawmill boilers, or disposed of as waste residues.

This dissertation assesses the Clean Development Mechanism (CDM) potential of a proposed Combined Heat and Power (CHP) plant that will utilise a sawmill's by-products, or waste residues, as its fuel source; the sawmill is located in Stellenbosch, South Africa.

The sawmill employs standard production techniques as found in large sawmills throughout South Africa, enabling the results of this dissertation to be utilised as a reference for South Africa's total sawmill CHP potential.

The CHP plant's emission neutral energy will replace fossil-fuelled energy, thus offsetting Greenhouse Gas (GHG) emissions. The plant will generate revenue from the sale of GHG emission credits, in addition to electricity and other products.

The proposed CHP plant has the potential to reduce annually more GHG than any other CDM project currently registered in South Africa. In addition to the environmental benefit, the plant will require labour for its construction and operation, resulting in job creation and skills development.

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Acronyms and Abbreviations

(in alphabetical order)

AAUs
Assigned Amount Units

CDI
Confederation of Danish Industries

CDM
Clean Development Mechanism

CER
Carbon Emission Reduction

CFL
Compact Fluorescent Light-bulb

CHP
Combined Heat and Power

CIP
Cleaning In Place

CO
Carbon monoxide

CO_2
Carbon dioxide

COP
Co-efficient Of Performance

CTR
Cape Timber Resources

DFE
Danish Forestry Extension

ERC
The Energy Research Centre, University of Cape Town

ERUs
Emission Reduction Units

GHG
Greenhouse Gas

GWh
Gigawatt-hour

h_{fg}
The specific enthalpy of evaporation of steam

IPCC
Intergovernmental Panel on Climate Change

J
Joules

JI
Joint Implementation

kW
kilowatt

kWh
kilowatt-hour

LULUCF
Land Use, Land-Use Change and Forestry

MW
Megawatt

N_2O
Nitrous Oxide
NO_x
Nitrous oxides
SO_2
Sulphur dioxide
tCO_2e
Tons of carbon dioxide equivalent
TJ
Terajoule
tNMVOC
Tons of non-methane volatile organic compounds
UNFCCC
United Nations Framework Convention on Climate Change
WFW
Working For Water

1) Introduction

Scientists from the Intergovernmental Panel on Climate Change (IPCC) have been warning for some time that unless action is taken to slow down and reduce the rate at which Greenhouse Gases (GHG) are emitted, the earth could suffer major negative effects such as higher temperatures and changes in rainfall patterns.
These effects could lead to massive loss of life due to events such as:

1) famine,
2) droughts,
3) floods,
4) increased spread of diseases associated with warmer climates,
5) uninhabitable environments,
6) and land loss due to rising sea levels. [1]

In order to reduce GHG release into the atmosphere, legislation and a Carbon Economy have been developed. The major breakthrough in this process has been the Kyoto Protocol, whereby most of the developed countries of the world have committed themselves to reducing their GHG emissions to at least 5% below that of their levels of 1990, over the period 2008 to 2012.
In order to make it easier for developed countries to reach their emission targets, three market-based mechanisms have been developed;

1) an emissions trading scheme (the Carbon Economy),
2) an incentive scheme for developed countries to work together to reduce emissions through Joint Implementation (JI) projects,
3) and the Clean Development Mechanism (CDM) which encourages developed countries to work with developing countries to reduce GHG emissions and promote sustainable development. The CHP plant, on which this dissertation is based, expects to operate within CDM guidelines and is in the process of acquiring CDM project registration. [2]

A Danish organisation with vested interest in forestry and sawmill technologies approached the Energy Research Centre (ERC), University of Cape Town, for assistance in researching the environmental and social benefits of a proposed

Combined Heat and Power (CHP) plant; benefits which are in line with CDM objectives.

This document includes and expands on that research, aiming to determine whether the CHP plant will be capable of producing and selling sufficient amounts of CHP-related products in order to be feasible and to illustrate the opportunities for similar plants elsewhere in South Africa.

Much of the focus is on elements within the design phase of the project, which includes the amount and type of energy produced, typical energy use and the associated GHG mitigation potential of the proposed CHP plant. There are other major phases of a CDM project which are briefly mentioned in this document but which fall beyond its scope and have, therefore, not been fully investigated and explained. These phases deal mainly with the administration of the project. [2]

The CHP plant in question will utilise the by-products of a South African sawmill and its associated forestry processes to produce energy. The production of this energy does release carbon dioxide, a major GHG, but the forestry process requires that trees used for its processes are replaced in order to sustain forestry production. Since trees absorb carbon dioxide from the atmosphere, storing the carbon and releasing the oxygen, the release of carbon dioxide from the combustible wood fuel will be absorbed and stored in the replacement trees, making the combination of these two processes carbon emission neutral.

However, since the energy that the CHP plant will produce will replace fossil-fuelled, GHG-intensive energy, the entire process will in fact be carbon negative. That is, overall, it will sequester carbon from the atmosphere enabling it to qualify for carbon accreditation.

The CHP plant's two main energy carriers were originally identified as electricity and steam. [3] In South Africa both of these energy sources are largely derived from coal, due to its abundance, access and resulting low cost. The CHP plant will generate revenue from the sale of its emission neutral, or 'green', energy and through the sale of the associated emission credits.

With the Carbon Economy in its infancy and with all of Africa's countries in various stages of development, South Africa is well placed to be at the forefront of CDM projects on the continent and an example for others to follow.

This dissertation contains four main sections from which the Abstract, Conclusions and Summary draw; they are;

1) Chapter 1: Introduction, introducing the concepts, markets and associated parties involved with information contained in this dissertation
2) Chapter 2: A literature survey, containing information relevant to issues covered in this dissertation: namely the proposed CHP plant, relevant markets, associated technologies and organisations
3) Chapter 3: A case study of a South African sawmill CHP plant. The study proceeds in chronological order; energy inputs to energy outputs, ending with the plant's potential in terms of CHP productivity, GHG mitigation potential as well as other potential social effects. These results are then used to evaluate the national sawmill CHP potential.
4) Chapter 4: A discussion of various key issues regarding South African sawmill CHP plants and, in particular, the proposed Stellenbosch CHP plant.

The conclusions of this thesis are found in chapter 5; followed by a summary of findings in chapter 6.

Chapter 7 contains recommendations with regard to future related studies.
The appendices are located at the back of the document; they contain the calculations and much of the information relevant to Chapter 3. The appendices are located in comparable order to the chapters with which they are associated and can be found under related headings.

2) Literature survey

This literature survey contains information relevant to the issues covered in this dissertation. The main issues of concern are:

1) Greenhouse Gases (GHGs) and their effect on the climate
2) The Kyoto Protocol and the Clean Development Mechanism (CDM)
3) Emission reductions and their trading market
4) Combined Heat and Power (CHP) concepts and the technologies involved
5) Information relating to biomass-fuelled CHP plants
6) South African forestry and the Working-For-Water government initiative
7) CHP applications suitable for use in Africa

2.1) GHGs, the Kyoto Protocol and CDM

GHGs and the need for their mitigation

GHGs are gases that trap energy within the earth's atmosphere. The containment of a certain level of energy within the atmosphere is essential to create the current living conditions found here on Earth. However, since the industrial revolution, the level of GHG has been increasing at unprecedented levels, causing increasing amounts of energy to be contained within the atmosphere. The dramatic increase in GHG is creating increased global temperatures which could well be cause for the current extraordinary weather phenomena and, if left to continue, could escalate into major changes of our existing climate, with devastating affects. [4]

The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Methane is approximately 21 times and nitrous oxide about 310 times more GHG intensive than carbon dioxide. [1] The Carbon Economy requires that all GHGs be equated to the equivalent mass of carbon dioxide so as to have a single trading commodity, the carbon credit. The ratios mentioned above are used to equate the various gases to an equivalent mass of carbon dioxide. One carbon credit, which takes on various identities, is equivalent to one ton of carbon dioxide equivalent (tCO_2eq).

The main causes of GHG release into the atmosphere

The earth has for millennia released a certain amount of GHG. However human activity has caused the recent increase in GHG levels which are of concern.
The main human activities causing their release into the atmosphere are:

1) Burning of fossil fuels
2) Industrial processes
3) Transport
4) Agriculture
5) Deforestation [2]

The Kyoto Protocol and South Africa's relationship to it

The Kyoto Protocol is an international agreement, reached in 1997 in Kyoto, Japan, which sets binding GHG emissions targets for countries which sign and ratify the agreement. The GHGs covered under the Protocol include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). [5]

The Protocol came into effect on the 16th of February 2005 whereupon it became binding on its 128 Parties. [6] However, since countries enter into the Kyoto Protocol voluntarily there is concern as to the method by which penalties will be imposed on those countries that do not reach their emission targets.
Thirty developed country signatories, those falling into Annex 1 of the Protocol, are bound by the Protocol to reduce their GHG emissions by at least 5% below 1990 levels in the commitment period 2008 to 2012. There are only 4 developed countries not yet ratified: Australia, Liechtenstein, Monaco and the United States. Australia and the United States have stated that they do not plan to do so, as they believe it will be destructive to their economy. [7] This is disturbing as together these two nations account for over one third of the GHG emitted by the developed world.

There are 98 developing countries which fall into Annex 2 of the Protocol, including Brazil, China, India and South Africa. Annex 2 countries have no commitments to reduce GHG emissions under the Protocol. [7]

The concept of attaining a carbonless global economy poses a threat to South Africa's coal-dependent economy and in 2000 South Africa began a mitigation study reflecting the requirements of the United Nations Framework Convention on Climate Change (UNFCCC). The purpose of the study, which looked at options available between 1999 and 2001, included determining an accurate GHG inventory, the vulnerability of South Africa to future changes, adaptation and mitigation options and the direction of future policies that needed to be introduced. [8]

Seven sectors were found to contain large mitigation opportunities, they were:

1) Electricity
2) Liquid fuels
3) Natural and synthetic gas
4) Commercial and residential sector
5) Transport
6) Mining industry
7) Agriculture [8]

The greatest potential for GHG mitigation came from the electricity sector where it was identified that 1 320 million tCO2eq could possibly be avoided during the 2001–2025 period. [8]

The South African government, in attempting to integrate climate change into its long-term sustainable development goals, signed the UNFCCC in 1993, ratified it in August 1997, acceded to the Kyoto Protocol in June 2001 and then agreed to ratify the Protocol in March 2002. [8]

Although emissions from Africa are low compared with those of other continents, and are expected to remain so for the immediate future, South Africa is a relatively large GHG emitter and in 1997 ranked 15th in the world for CO_2eq emissions per capita. GHG emissions in 1994 totalled 380 million tons of CO_2eq, approximately 1.6% of global emissions. This is mainly due to South Africa's large reliance on coal for power generation. [8]

Since the inception of the Protocol, the Carbon Economy with its trading market has become a legal and practical reality, enabling countries to buy and sell emission credits. However, achieving the Kyoto emission targets will be a major challenge for many countries and will require new policies and new approaches. [9]

The Clean Development Mechanism

As mentioned in the introduction, CDM is one of three market-based mechanisms introduced through the Kyoto Protocol in order to assist developed countries in reaching their emissions targets. CDM encourages signatory developing and developed countries to work in partnership to reduce GHG emissions. However, it is not mandatory for the developing country to have a developed country partner and participation can be unilateral. The other significant factor of CDM projects is to promote sustainable development in the host developing country.

Other key issues of CDM projects are:

- The host country is required to confirm that the CDM project is helping it to achieve sustainable development.
- CDM projects are open to all technologies, except nuclear powered, that contribute to GHG mitigation.
- In order to speed up the implementation of small scale projects, fast track procedures are being developed.
- It is the UNFCCC's aim that CDM projects will be spread out equitably throughout the developing nations.
- Existing official development finance from developed countries cannot be diverted to fund new CDM projects; additional funding must be used to finance new CDM projects.
- CDM projects should promote the transfer of knowledge and technologies between the participating countries.
- Land use, land use change and forestry projects (LULUCF) are limited to forestation and reforestation and there are limits to the extent at which parties can use LULUCF projects to meet their mitigation targets.
- The accounts of Certified Emission Reductions (CERs) generated through CDM projects will be maintained by the Executive Board (EB) which will in turn report to the Conference of Parties (COP) [2]

On the 10th of March 2006 a milestone in CDM history was reached when, for the first time, CERs generated from a CDM project were awarded to the project participants. [10]

In March 2006 there were 139 registered CDM activities worldwide. These activities are expected to produce in excess of 270 million CERs, meaning that 270 million tons of carbon dioxide equivalent (CO_2eq) should be sequestered from the atmosphere using these projects by the end of the first commitment period at the end of 2012. The official CDM "CER pipeline" of more than 630 activities, including the 139 registered activities, is expected to sequester more than 800 million tons of CO_2eq by the end of 2012. [10]

How emission reductions are accomplished

Emission reductions can generally be classified under four categories:

1) Energy Generation and Use which include:
   - Building efficiency
   - Commercial/Industrial efficiency
   - Fuel switching
   - Renewable energy; the main category with which this document deals
   - Transportation
   - Other
2) Capture/Recovery/Utilisation which include:
   - Animal waste recovery
   - Coal bed methane
   - Waste CO_2 recovery
   - Landfill/Capture
   - Other
3) Process changes; which deals with the modification of manufacturing processes. Various possible processes associated to the CHP plant fall under this category. e.g. CHP absorption-cooling and CHP water-heating
4) Sequestration which includes:
   - Forest sequestration
   - Land conservation
   - Soil conservation and land use
   - Other [2]

The purpose of the CDM partnership between developing and developed countries

Many developed countries have been aware of the necessity of energy efficiency for some time and have implemented strategies and technologies to reduce energy consumption and emissions, but the cost involved in further decreasing their emissions is far more expensive than that of typically energy inefficient developing countries. Since GHG emissions are a global problem and not restricted to the country of their origin, it is possible for developed countries to finance the implementation of GHG mitigation strategies and technologies in developing countries and, in return, lay claim to a share of the GHG mitigation in the form of carbon credits. The participating developed country is thus able to offset their GHG emissions through the financing of GHG sequestration elsewhere on the globe. [2] The proposed Stellenbosch CHP plant has ties to a Danish organisation which has a high level of experience regarding biomass-fuelled CHP plants.

The phases of a CDM project

There are six major phases in the CDM project cycle.

1) The Project Design
2) Authorisation, validation and registration
3) Monitoring
4) Verification and certification
5) Issuance of CERs
6) Trading of CERs

1) Project Design

The following points are all necessary features of the Project Design.

- Description and scope of the project.
- Methodology that will be used to calculate the GHG baseline level
- Emissions concerned with the project
- Statement of the operational life and selected crediting period of the project
- Environmental Impact Analysis (EIA)
- Information on the financing of the project
- Summary of public consultation
- Monitoring plan
- Design calculations [2]

2) Authorisation, Validation and Registration

The Designated National Authority (DNA) must confirm that the CDM project is helping the host country attain sustainable development before authorising the project.

An initial Designated Operational Entity (DOE) is required to perform the following tasks before validating the project as a CDM activity:

- Review the project design document against CDM requirements
- Test the assumptions made in the document
- Request revisions of the project design document, if required

After validation the EB will register the project as an official CDM activity; thereafter the project is financed, implemented and becomes operational. [2]

3) Monitoring

The project's actual performance versus expected performance, in terms of GHG mitigation, is assessed on an annual basis by the project participants in accordance with the plan described in the project design document. [2]

4) Verification and Certification

A DOE, typically different to that which conducted the validation phase, is appointed to review and examine the project's actual performance against that described in the project design document, as well as the GHG mitigation values passed on from the monitoring phase.

This DOE then issues a written Certification of assurance of GHG mitigation values achieved. [2]

5) Issuance

The EB then issues CERs according to those certified by the DOE of the Verification and Certification phase. [2]

6) Trading

The issued CERs are then available to the project participants for trading. [2]

Limits on the crediting period for renewable energy CDM projects

Project participants can select a crediting period over which the project can be awarded CERs. The crediting options available to participants are:

1) A maximum of seven years, which may be renewed not more than twice, resulting in a maximum crediting period of 21 years. For each renewal, a designated operational entity must determine and inform the Executive Board that the original project baseline is still valid or has been updated.
2) A maximum of 10 years with no option of renewal. [11]

The state of the South African CDM administration structure

The organisational structures required for approving and registering CDM projects are in place, as proved by the accomplished official registration of South Africa's first CDM projects. [12]

The first officially registered CDM project in Africa was the Kuyasa Low-income Housing Energy Upgrade project and was registered by the CDM Executive Board on August 29, 2005. At the time of registration there were only 16 CDM projects registered worldwide. [12]

Kuyasa was the first CDM project in Africa to have completed all of the government approval procedures and the first to reach the registration phase, demonstrating that all the institutional frameworks for CDM project development in South Africa are in place. The project involved the retrofit of 2 300 low-cost houses in Kuyasa Khayelitsha, with solar water heaters, insulated ceilings and compact fluorescent light bulbs (CFL's) thus reducing emissions through energy conservation. Emission reductions of 2.85 tCO_2eq per household per year are expected; a total of approximately 6 555 tCO_2eq per year, once the original 2 300 houses have all been retrofitted. [12]

Other significant benefits of the programme are the reduction in respiratory diseases due to the use of fossil fuels for cooking and lighting, as well as a reduction in energy costs of approximately R626 per household per year. [12]

Barriers to further implementation of CDM projects in South Africa

- There has been a certain amount of concern among developing countries that developed nations may take advantage of CDM by exploiting all the cheap and easy GHG mitigation options found in developing countries, leaving them only expensive options when their turn comes for GHG mitigation.

- There is concern amongst certain key private-sector players that the introduction of CDM into South Africa could impact heavily on the use of domestic technology due to the technology transfer involved in CDM projects.
- The Chamber of Mines with its large vested interest in coal, is concerned over the effect that climate-change-related initiatives, such as cleaner fuels and renewable energy projects, could have on the industry; both domestically and abroad. [8]

2.2) The emissions trading market

The current state of the emissions trading market

In recent years, the GHG market has seen significant growth, from a theory proposed by politicians and academics in the early to mid 1990's, to the cornerstone of the Kyoto Protocol. Today the trading of tons of carbon dioxide equivalent (tCO_2eq) takes place on an active market, which has seen more than 270 million tons of CO_2eq transacted. [13]

Countries required by the Kyoto Protocol to reduce their GHG emissions below that of their emission level for the year 1990 can do so by the supplementation of their emission allowance, with:

1) ERUs, which are emissions offsets from countries certified by governments under Joint Implementation (JI) and which fall under Annex 1 countries in the Kyoto Protocol.
2) CERs, which are emission offsets from countries certified by the CDM Executive board and do not fall under Annex 1 countries in the Kyoto Protocol. [13]

There are currently four markets for globally sourced emissions offsets; they are:

1) Kyoto compliance instruments (CERs and ERUs) for sale to corporations in Canada and Japan
2) Kyoto compliance instruments (CERs and ERUs) for sale to governments and multilateral agencies
3) Kyoto compliance instruments (CERs and ERUs) that are eligible for use within the European Emissions Trading Scheme and which will be for sale to corporations within Europe.

4) Voluntary markets for emission reductions which are not compliant with the Kyoto Protocol. These are typically purchased by corporations and individuals wanting to offset their emissions for non-regulatory purposes. [13]

The voluntary market is characterised by relatively small volumes of GHG trading at a relatively high price when compared to the pre-compliance market. The price per tCO_2eq rises if the projects are highly sustainable and have socially beneficial characteristics. Typical sizes of voluntary market transactions are between 5 000 to 50 000 tCO_2eq. [13]

The price per CER is highly dependent on the characteristics of individual markets; as of July 2006 the average European market price was approximately €16 per CER.[14] Certain key factors affecting the value of project CERs are:

- International and domestic policy risk
- Recognition of early credit
- Expected versus actual allocation
- Delivery risk (project financial and operational risk)
- Country risk
- Sustainability and wider social impact of the underlying project [13]

The most successful projects which have fallen under the CDM and JI mechanisms have been those concerned with renewable energy and electricity generation. The proposed bioenergy CHP plant with which this report deals would fall into this category. [13]

2.3) Combined Heat and Power (CHP)

Sawmill energy requirements

In order to operate effectively the Stellenbosch sawmill requires energy in the form of electricity and steam. The waste residues occurring as a result of the sawmill process can be used as fuel to produce steam for sawmill processes and to generate electricity. A Combined Heat and Power (CHP) plant would be a suitable method of attaining these energy requirements.

Definition of CHP

Combined Heat and Power (CHP) refers to energy producing plants that generate electricity, generally at or near the place where it is used, as well as using plant energy for space-heating, water-heating, process steam, humidity control, air-conditioning, water-cooling, product-drying and for other thermal energy needs. The end result is a significantly greater overall efficiency than that of providing energy for each of these processes separately. [15]

Types of CHP technologies available and the advantages and disadvantages of each

The most commonly used CHP technologies for solid fuels are:

1) Steam turbine
2) Steam engine
3) Steam screw engine
4) Stirling engine
5) Organic Rankine Cycle (ORC) process

The most commonly used CHP technologies for liquid or gas fuels are:

1) Gas turbine
2) Gas engine
3) Fuel cell [16]

The steam turbine

The advantages of the steam turbine are:

- Proven technology
- Broad power range

- For large installations high efficiencies can be achieved through high steam temperatures and pressures
- Separation between combustion and power generation technologies allows the use of fuels producing ash as a by-product

The disadvantages of the steam turbine are:

- Small steam turbines, less than 1 MWe, produce limited efficiencies
- Low efficiency at partial load
- High specific investment costs for small turbines [16]

The primary reasons for deciding that a steam turbine should be the chosen CHP technology at the proposed CHP plant are:

1) Steam is required for various sawmill processes
2) Steam turbines are a tried and tested method of generating electricity
3) The amount of electricity likely to be generated at the proposed Stellenbosch CHP plant will most economically be achieved using steam turbines
4) The type of sawmill residues produced by the Stellenbosch sawmill suit the fuel requirements of commonly manufactured steam boilers

The steam engine

The advantages of the steam engine are:

- Suitable for lower power outputs
- Saturated steam can be used
- Good performance at partial load
- Steam extraction at various pressures possible due to modularity
- Oil free construction avoids steam contamination

The disadvantages of the steam engine are:

- Maximum power output limited to below 1.5 MWe
- High maintenance costs
- Electrical efficiency is limited due to low steam pressures used; less than 25 bar
- Heavy vibration and noise production [16]

The Stirling engine

The advantages of the Stirling engine are:

- Engine operates independently of type of heat source
- Low quality fuel can be used
- Low maintenance due to few moving parts and external combustion
- Formation of CO and CH_4 emissions can be avoided through external combustion of biogas.

The disadvantages of the Stirling engine are:

- Relatively low electrical efficiency when using solid biomass fuels
- No reliable solution to sealing problems
- High specific investment costs
- Heat exchanger is prone to wear due to extreme temperature differential
- High temperature corrosion in ash containing flue gases. [16]

The Organic Rankine Cycle process

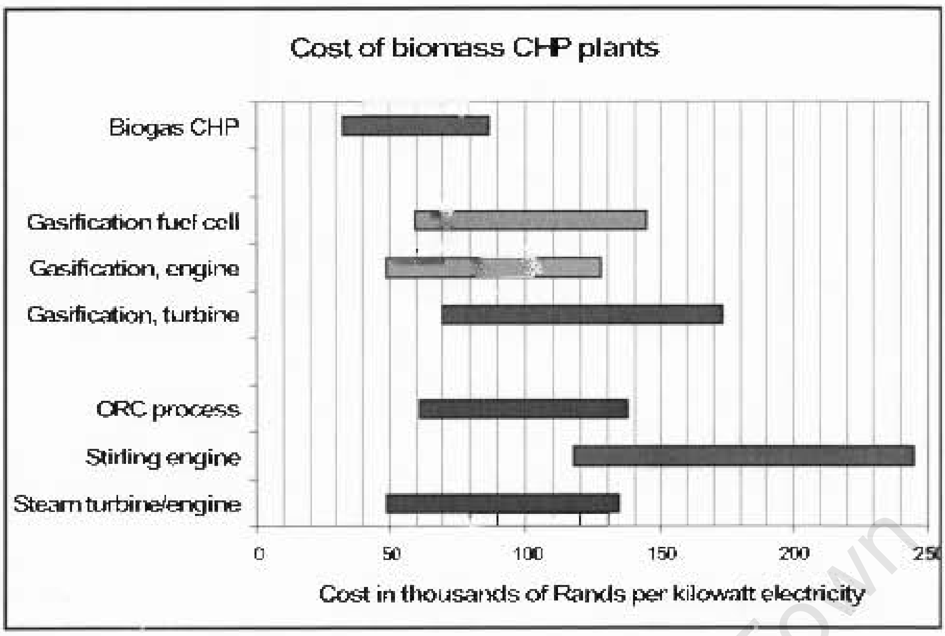
The advantages of the ORC-process are:

- Robust technology
- High degree of automation
- Low maintenance required
- Good performance at partial load
- Low temperature waste heat can be used

The disadvantages of the ORC-process are:

- Relatively high specific investment costs
- Unproven biomass technology
- Organic thermal oil is inflammable and toxic
- Limited electrical efficiency due to low pressures used (10-20 bar) [16]

Figure 1: Approximate costs of technologies per kilowatt electricity



[16]

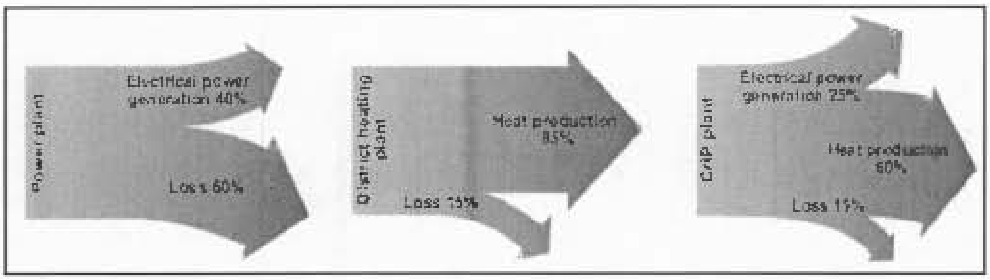
The reason for the increased overall efficiency of CHP plants, as opposed to typical fossil-fuelled power plants

Traditional coal-fired electricity plants typically convert 30-40% of the fuel energy input into electrical power; the remaining energy is lost, mostly through heat via the flue gas or cooling system. [17]

CHP plants generate electricity in much the same way but, instead of losing the waste heat energy, the majority of it is used for other processes. CHP plants typically have an overall efficiency of 60-85% depending on the balance of final energy use. The requirement of process steam/heat can lower a CHP plant's electrical generation efficiency below that of conventional power plants. The electrical generation efficiency of a biomass-fired CHP plant is between 20-30%. [18]

Generally, the more CHP energy used specifically for electricity production, the lower the overall CHP efficiency.

Figure 2: Energy flows and efficiencies of various energy plants



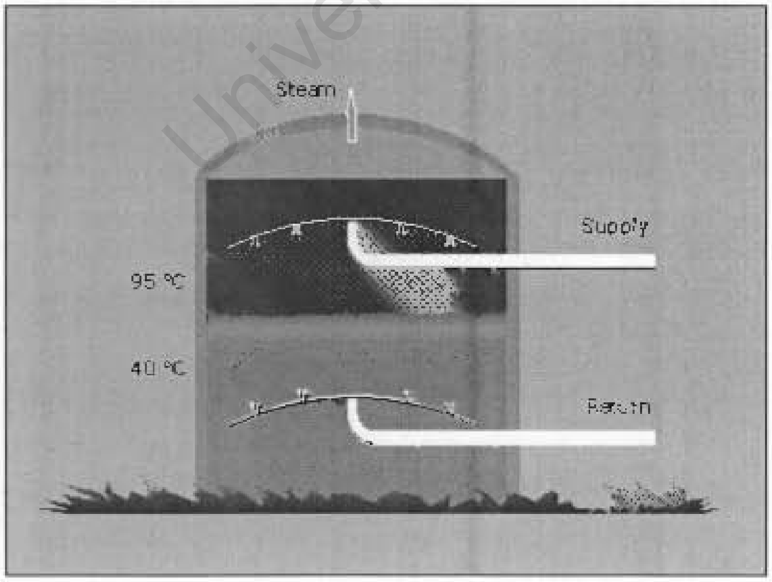
[18]

The above diagram illustrates how separate electrical power generation and heat production at a district heating plant have much higher losses than a combined heat and power (CHP) plant.

Varying process steam requirement

Process steam requirements at the sawmill or neighbouring plants may vary at certain periods of operation. The resulting excess process steam can be used to increase the efficiency of the power generation process, or the CHP plant can be equipped with a heat storage tank allowing the thermal energy to be used later when required.
The excess steam enters the top of the heat storage tank where it heats the upper layer of water in the tank, whilst the cooler water sinks to the bottom of the tank. The supply lines for the thermal energy use are inserted into the upper, hot water layer and the return lines into the lower, cool water layer. [19]

Figure 3: Heat storage tank



[19]

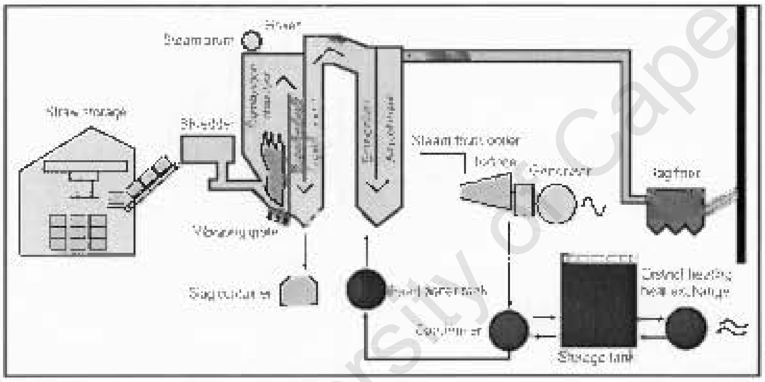
Typical components of a steam turbine CHP plant

CHP plants typically use similar components to that of normal fossil-fuelled power plants, with a few modifications in order to make use of the waste steam for process requirements. [18]

The diagrams below illustrate two configurations of CHP plants. The proposed Stellenbosch CHP plant is likely to utilise a configuration similar to that of figure 4. Figure 4 illustrates how a CHP plant fuelled by straw is used to generate electricity and then uses the waste steam for district heating. The waste steam could be used for many thermal energy uses, depending on the requirements.

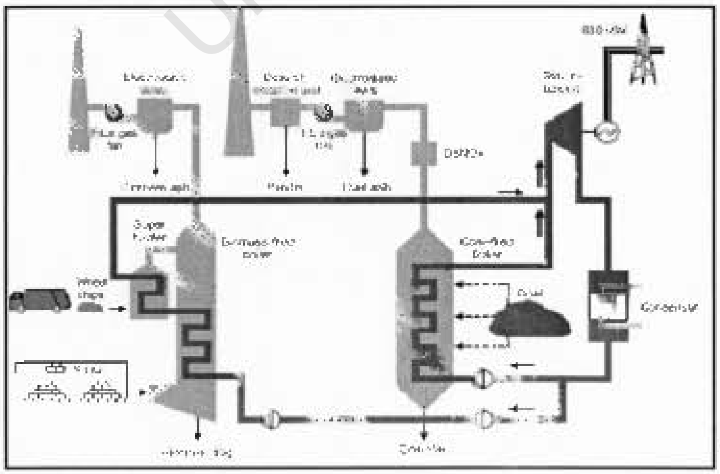
Figure 5 illustrates how a biomass boiler is used in conjunction with a coal-fired boiler to produce electricity. The biomass boiler substitutes the use of additional coal, thereby lowering the amount of CO_2 released into the atmosphere.

Figure 4: Straw-fuelled CHP plant



[18]

Figure 5: Biomass and coal boilers in conjuction



[18]

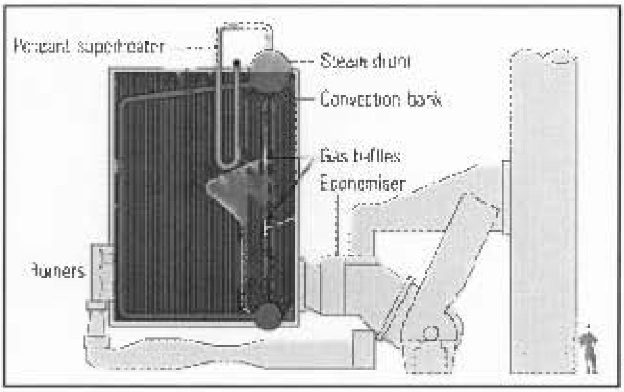
Usually the fuel handling system of biomass CHP plants is automatic; methods of fuel transport include various forms of screw stokers and ram stokers. Generally, there is a closed fireproof tunnel between the combustion chamber and the storage area; this is to prevent a back burn into the storage area. [18]
A woodchip transportation system in Denmark utilises two counter rotating screw feeders that push a gas proof plug through an almost rectangular feeding tunnel and then on to the grate. [18]

Slag and ash from the bottom of the boiler is separated from the fly ash by filtration. The slag and ash from the bottom of the boiler is often used as manure/fertiliser by farmers whereas the fly ash, due to its high heavy metal content, is generally disposed of in a controlled waste environment or used as an ingredient in fertilisers. [18]
Worldwide, more than 65% of the fly ash produced by coal power stations is disposed of in landfills [6]. However, some fly ash is used in the manufacture of bricks and roads, biomass CHP plants could utilise their fly ash for similar processes/products.

Type of boiler preferred for wood-fired steam turbine CHP plants

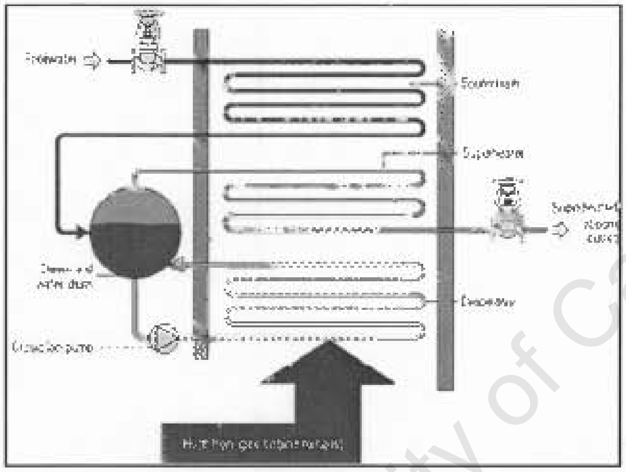
Water-tube boilers are the popular choice for biomass boilers. [18]
The walls of water-tube boiler are made out of the water/steam tubes, which can handle the high pressures required. The vaporiser system utilises a steam drum and natural circulation to precondition a high steam pressure and temperature. Water and steam are separated in the steam drum, the steam passes from the steam drum to the superheaters. After the superheater, there is a pass with an economiser and an air preheater to heat the feed water and combustion air, thus increasing the efficiency of the system. From there the steam passes through to the power generation system. The process steam is drawn from the system at whichever point is appropriate for the steam quality required. [19]

Figure 6: Water tube boiler suitable for biomass-fuelled CHP



[20]

Figure 7: Water tube boiler utilising hot waste gases for superheating steam



[20]

Advantages and disadvantages of CHP projects worldwide

Advantages of CHP plants to businesses and industry:

- Cheap energy: the cost of electricity from CHP plants is often cheaper due to its local use and negated long distance transmission costs. The combined energy bills of business utilising CHP is often less, particularly during peak demand periods.
- Protection from price hikes: industries using CHP power generally have a higher protection from energy price hikes.
- Reliable power source: having your own source of power can result in fewer outages and blackouts and fewer power surges.
- Improved indoor air quality: by using the waste heat for use in air-conditioning and dehumidification plants, the indoor environment can be

optimised for customers, employees and machines. The waste heat from cogeneration can be used to run an absorption chiller and dehumidification unit for air conditioning, either replacing or supplementing their electric counterparts. Less humidification also prevents mould, mildew and rot damage, as well as protecting moisture-sensitive manufacturing processes.

- Public relations and marketing benefits: companies that use CHP plants are often considered technologically advanced and environmentally friendly. [15]

Advantages of CHP plants for society and the environment:

- Clean energy: the energy is generally cleaner than fossil-fuelled energy and CHP plants have higher overall efficiencies than centralised power plants which means they are better for the environment due to lower GHG emissions.
- Less vulnerability to terrorist attacks: by having many localised power plants the total energy system of a country is at a much lower risk to terror attacks than one with a few large power plants.
- Reduced need for transmission lines: due to the localised nature of CHP plants there is far less need for new long distance power lines, resulting in lower transmission cost hikes and less impact on the environment.
- Reduced line losses: line losses vary from one network to the other depending on various factors, one factor being the length from power plant to end-use. A large percentage of South Africa's electricity is produced in Mpumulanga, located in the northeast of the country and far from many of the country's major cities.

  Another factor is the congestion of power lines; many of South Africa's power lines are in need of an upgrade due to congestion.

  Eskom has reported average line losses of 6.06% [73] and mentioned in the 2006 Annual report that overall thermal efficiency and lines losses were areas of relative poor performance. [74]
- Since CHP is generally located close to where the electricity is used, a correctly designed system should have negligible line losses; essentially CHP gains, on average, an extra 6.06% efficiency compared with a central power plant. [15]
- Flexible and modular: CHP plants are much smaller than centralized power plants and can be added to the system where and when needed and with

shorter lead times. This avoids the problem of large power plants having idle excess capacity whilst waiting for demand to grow. [15]

Disadvantages of CHP:

- Emissions allocation: when an existing thermal energy user, from an Annex 1 country, converts from grid electricity to CHP generated electricity it will naturally have greater GHG emissions than previously; this despite the fact that due to the increased overall efficiency the overall emissions are fewer. The centralised power plant would then be required to produce less electricity and would thus have fewer emissions than previously, allowing it to sell the leftover emissions on the market instead of being forced to give up the appropriate emissions allocation to the CHP operator. If the CHP operator is allocated emission allowances based on the previous non-CHP condition, then the operator may be forced to buy additional emission allowances on the market until it can be proved that the introduction of the CHP plant has actually lowered overall emissions. Therefore, unless the emissions regulator takes into consideration the overall effect of the CHP plant, the plant may be penalised by the emissions trading scheme and the centralised power plants rewarded.
- Wider spread of pollution: the introduction of localised CHP plants would introduce higher levels of emissions to the immediate areas which may result in health and environmental complaints from the local inhabitants. This despite a lower overall national and global GHG emission level than centralised power plants producing high emission levels and intensely high levels of local air pollution. [15]

2.4) Information relating to biomass-fuelled CHP plants

Combustion characteristics required in order for wood to be considered an environmentally desirable fuel

1) Efficient combustion
2) Complete combustion
3) Adequate mixture of fuel and oxygen; a controlled ratio should be ensured
4) The main combustion process in the boiler should transfer a percentage of its heat to the fuel infeed, drying the fuel and ensuring a continuous combustion process. [18]

Phases of wood-fuel combustion

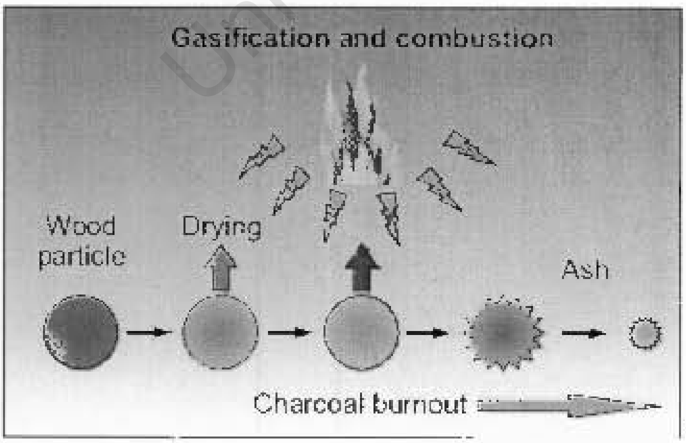
The three stages that the fuel passes through are:

1) Drying
2) Gasification and combustion
3) Charcoal burnout

The green wood particle undergoes drying, gasification and then combustion, producing flames and heat energy. The particle burns out and ash is left as the solid by-product of combustion after charcoal burnout

During the combustion of wood approximately 80% of the energy is released in the form of gas and the remaining 20% from the charcoal. [16]

Figure 8: Wood particle combustion route



[16]

Drying

Water begins to evaporate from the surface of the wood as soon as it is heated. Evaporation of surface moisture causes two things to occur: gasification at the wood surface, pyrolysis, and an increase in fuel core temperature.

Pyrolysis is the heating of a fuel without the introduction of a gasification medium. The temperature increase of the core causes evaporation of moisture within the core and thus a spread of pyrolysis.

Gasification and Combustion

The gas produced at the wood surface is ignited above the fuel and the resulting heat energy further ads to the ongoing evaporation and pyrolysis.

Charcoal burnout

The gasified wood becomes glowing charcoal with the addition of oxygen, heat being produced throughout this stage. Eventually only ash is left and no more heat energy is available.

Volatiles

Approximately 80% of wood weight is given off as volatiles in gaseous form during combustion. The high volatile content of wood means that combustion air should generally be introduced above the fuel bed (secondary air), as this is the zone where the majority of gases are burnt, as opposed to beneath the fuel bed (primary air).

Ash

Ash is the term given to the incombustible components of a fuel; the solid by-products of fuel combustion. Ash is an undesirable by-product of the combustion process due to the added requirement of an ash disposal system and a flue-gas filtration system to minimize the amount of particulate matter released into the atmosphere.

Ash contained in wood is due primarily to the absorption of soil and sand by the bark. A minor proportion of wood ash is from the salts and heavy metals absorbed during the growth period of the tree. The heavy metal content of wood ash is generally lower than other solid fuels. [18]

Wood contains potassium and sodium-based salts that are important to the combustion process; these salts are not normally high enough to create problems with traditional heating technologies. [18]

Table 1: Chemical compositions and calorific values of typical bioenergy fuels

Percentage of dry mass	Woodchips (Beach)	Woodchips (Pine)	Woodchips (Spruce)	Straw (Wheat)
Carbon	49.30	51.00	50.90	47.40
Hydrogen	5.80	6.10	5.80	6.00
Oxygen	43.90	42.30	41.30	40.00
Nitrogen	0.22	0.10	0.39	0.60
Sulphur	0.04	0.02	0.06	0.12
Chlorine	0.01	0.01	0.03	0.40
Ash	0.70	0.50	1.50	4.80
Volatiles	83.80	81.80	80.00	81.00
Net calorific value MJ/kg	18.7	19.4	19.7	17.9

[18]

Air characteristics required for maximum energy transfer from the fuel

When fuel is converted stoichiometrically, all of the fuel is converted when the exact amount of oxygen for complete theoretical combustion is present. In practice, there is a requirement for more oxygen as it is not possible to achieve complete combustion with a stoichiometric amount of air. [18]

Table 2: Excess air requirements for various combustion technologies

	Excess air ratio	Oxygen (%)
Open fireplace	>3	>14
Wood stove	2.1-2.3	11-12
District heating chips	1.4-1.6	6-8
District heating pellets	1.2-1.3	4-5
CHP wood powder	1.1-1.2	2.3

[18]

Combustion efficiency is affected by the type of fuel used. Carbon dioxide (CO_2) and water (H_2O) are formed with complete combustion; imperfect combustion conditions will produce excess amounts of carbon monoxide (CO), hydrocarbons, polyaromatic hydrocarbons (PAH) and a small amount of unburned carbon in the slag. [18]

Efficient combustion requires sufficient:

1) Temperature
2) Oxygen
3) Combustion time
4) Mixture

Unfortunately, the above requirements are also directly related to the formation of nitrogen oxides (NO_X). [18]

How fuel particle size affects combustion and energy transfer

The smaller the fuel particle size, the faster the combustion process due to the higher ratio of surface contact of fuel and air (oxygen). [18]

How moisture content affects the combustion of wood-fuel

Moisture contained in the fuel reduces the available energy, since part of the energy produced via combustion will be required to evaporate the fuel moisture, thus lowering the effective calorific value of the fuel. [18]

Combustion chambers which use fuel with a high moisture content should be well insulated to avoid a reduction in boiler efficiency and to ensure a continuous combustion process. This is often accomplished through the use of refractory linings round the walls of the chamber, the chamber being designed for wood burning within a certain moisture interval. [18]

Moisture content higher than 55-60% of the total weight of the fuel will make it very difficult for the combustion process to occur. [18]

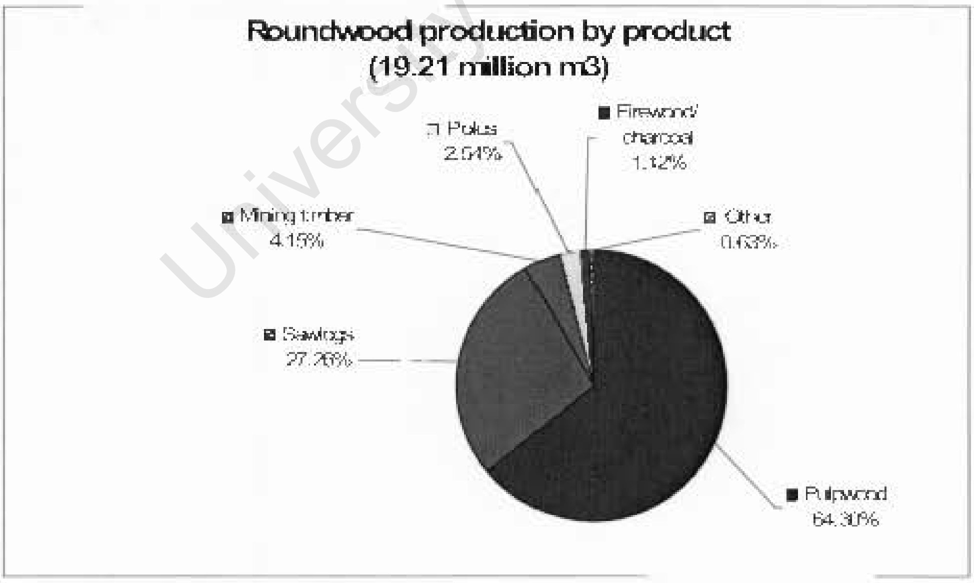
2.5) South African forestry and Working-For-Water

The fuel for the proposed Stellenbosch CHP plant will be obtained from woody residues collected at the sawmill, its associated plantations and by the Working-For-Water programme. The following information includes information relating to the amount of wood fuel available and its associated capital value. The following information is later utilised to estimate the national sawmill CHP potential, with reference to the proposed Stellenbosch plant.

Production size of the South African forestry industry

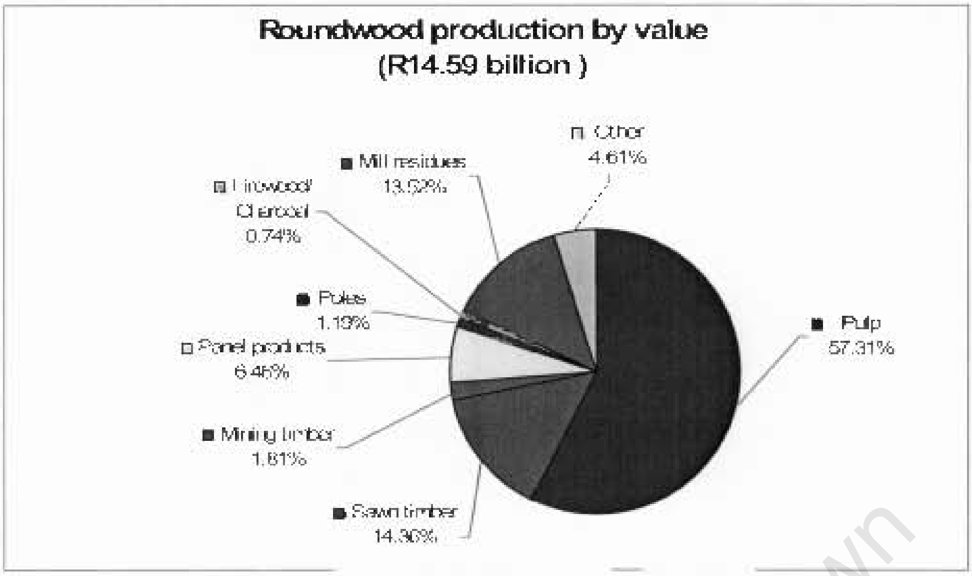
The total roundwood production of South Africa for the year 2003 was 19.21 million m^3; 10.76 million m^3 of hardwood species and 8.45 million m^3 of softwood species. The large majority, 64.3%, of roundwood grown in South Africa is used in the pulp industry which accounts for 57.31% of the money generated through the forestry industry. Sawlogs are the next highest product, utilising 27.26% of roundwood in South Africa, and the other small percentages are shared amongst the mining, pole, firewood/charcoal and other small industries. [21]

Figure 9: Roundwood production by product in South Africa, 2003



[21]

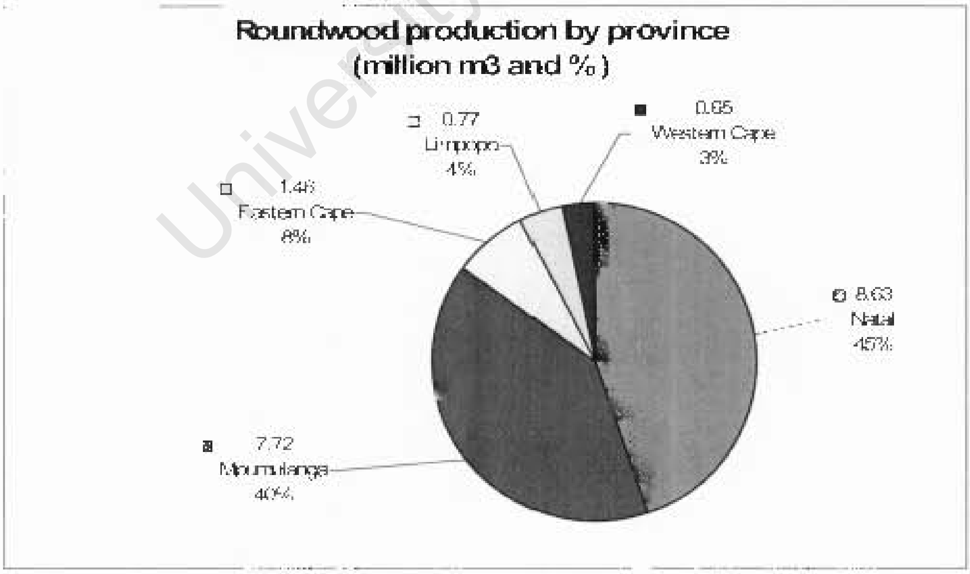
Figure 10: Roundwood production by value, 2003



[21]

Kwazulu-Natal has the highest roundwood production in the country, producing 8.63 million m^3 or 45% of the country's roundwood, followed by Mpumulanga which produces the second highest amount, 7.72 million m^3 or 40%. The Eastern Cape, Western Cape and Limpopo produce the other 15% of the country's roundwood. [21]

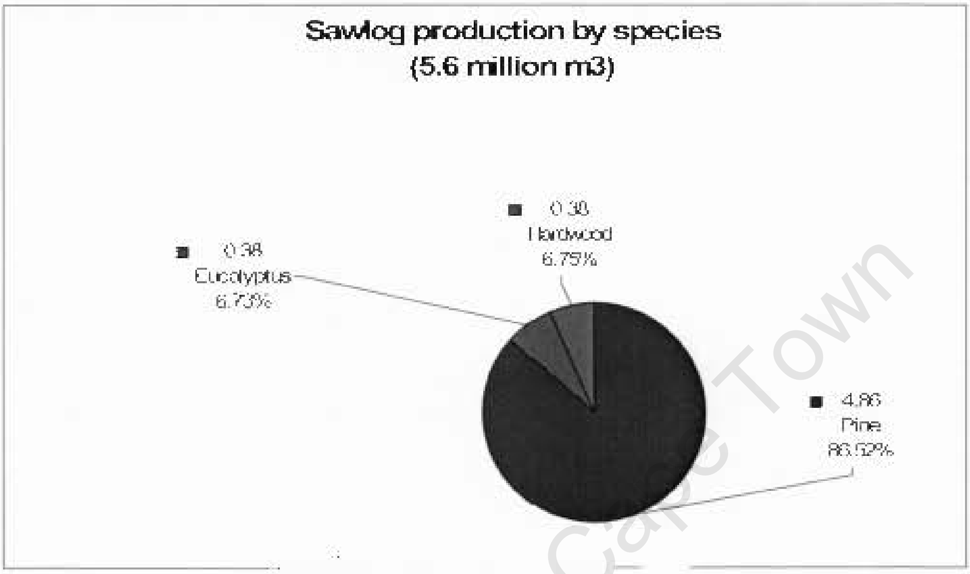
Figure 11: Roundwood production by province, 2003



[21]

Sawmills process approximately 27.7% of the country's roundwood, which amounts to 5.6 million m^3. The majority of the wood processed is pine species, 86.5% or 4.86 million m^3. Eucalyptus and hardwoods account for approximately 6.7% each or 0.38 million m^3. [21]

Figure 12: Sawlog production by species



[21]

Working-For-Water (WFW)

Working-For-Water is a government initiative combining the removal of alien vegetation from riparian zones, with job creation and entrepreneurial development. The purpose of WFW is to sustainably control invading alien species in order to optimise the potential use of natural resources such as water. The process employs local labour and, in addition to environmental concerns, the initiative strives to achieve economic empowerment of the labour force used. [22]

The alien species required to be removed through the WFW programme are mainly Acacia species originating from Australia. [22]

Substantial amounts of this type of woody biomass exist in the Cape's two main areas; the West Coast and Agulhas plains. As much as 400-600 TJ worth of fuel-wood energy and preliminary studies have shown that this material is economically accessible to the proposed CHP plant power plant. [3]

The Cape forestry company involved in the CHP plant proposal has been nominated as the primary bidder to partner the programme in the Western Cape. [3]
It has also been suggested that areas of exceptionally high production be sustainably harvested for continued future sustainable fuel-wood sources. A successful bid would lead to the development of significant entrepreneurial capacity amongst small scale enterprises in providing woodchips to a centralised transport terminal. [3]

2.6) CHP heat applications suitable for South Africa

The various technologies considered in this section are all available and utilised in South Africa. That is to say that South Africa has companies that can design, manufacture and install the equipment, or has business agencies for foreign companies that specialise in the relevant field of expertise and would be able to quote, supply and install equipment required. The fact that large companies specialising in these fields operate successfully in South Africa means that there is a market and that the technologies are applicable to South Africa.

The following technologies bear specific relevance to the proposed Stellenbosch CHP plant in that they are currently used by local plants or there is potential for their implementation. However, there is demand for all of these technologies in many other parts of South Africa.

2.6.1)Wood-drying kilns

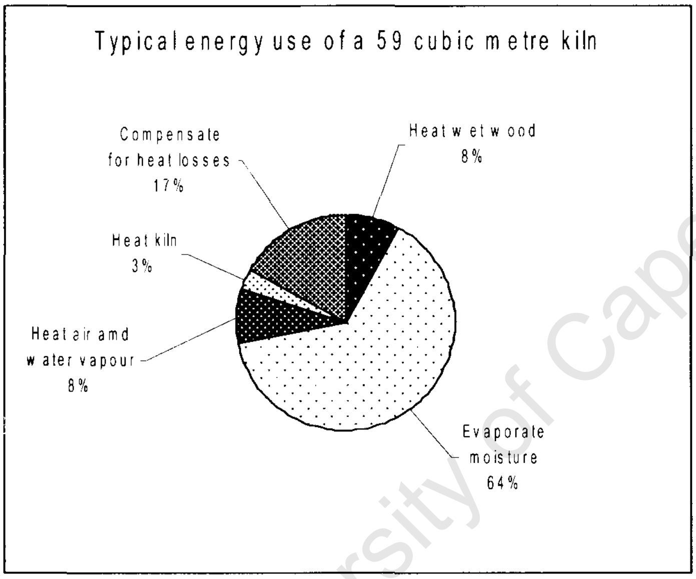
A wood-drying kiln is a structure designed specifically for removing moisture from wood by evaporation. A kiln performs five functions to accomplish this task.
They are:

1) Supplying the necessary heat to evaporate moisture
2) Supplying humidity to the air, if necessary, to maintain the proper conditions
3) Removing excess humidity from the kiln to maintain the proper conditions
4) Delivering the heat to and removing the moisture from the wood
   and
5) Effectively controlling the above four processes. [23]

Steam kilns require boilers to generate steam. This steam is piped through finned pipe heat exchangers in the kiln chamber. The steam condenses in the finned pipe and releases energy. The condensate flows through a steam trap and is pumped back to the boiler. Wood, gas, oil, coal or waste heat from other processes can be used to fire steam boilers. Low-pressure saturated steam at relatively low temperature is preferred as it dries the wood evenly and without warping. [23]

The energy required to reduce the moisture content in wood is highly dependent on the size and type of kiln construction. As kiln size changes, the energy required to heat the wet wood, evaporate moisture and heat the air and water remains relatively constant. However, the energy required to heat the kiln and to compensate for heat losses changes significantly. As kiln capacity decreases, the percentage of energy used to compensate for heat losses increases. Heat losses in kilns with capacities below 1 m^3 can account for as much as 70% of the total energy required and, in kilns of 200 m^3 capacity and more, as little as 15%. [24]

Figure 13: Wood kiln energy losses



[24]

2.6.2)Distillation

Alcoholic distillation is the process of separation of alcohol from a water/alcohol solution. Alcohol evaporates at a lower temperature than water and thus provides the ability for separation. The evaporated alcohol-rich vapours are condensed and collected as a high alcohol strength liquid (spirit). [25]

The starting material for most distillations, such as wine for brandy and beer for whisky, are usually weak alcoholic solutions consisting of 5%-7% ethanol. [25]

Distillation column stills and pot stills are heated through a separate steam circuit. If the column stills are operating correctly, the ratio of steam required to alcohol produced is approximately two to one. [26]

Ambient temperature cooling-water passes through the condenser circuit in order to condense the evaporated alcohols before they flow into the next distillation process. The cooling-water, after passing through the condenser circuit, is often used to preheat the predistillation solution in a preheater. The cooling-water is then pumped through cooling-towers before returning to the storage facility. [26]

2.6.3)Sanitation

Steam is used in the wine and spirits industry to sanitise many objects including barrels, bottles, piping, tanks, filters and floors. Water at 84°C meets the international standard to kill pathogens in the food and beverage industry. However, steam which at sea level has a temperature of 100°C is more efficient at delivering heat rapidly through the condensation process, while hot water must depend on absorption. When steam at atmospheric conditions encounters a cooler surface, it condenses, giving up the latent heat of evaporation which, combined with moisture, destroys the proteins that create microbes. Virtually all bacteria in food and wine are killed by exposure to steam at 100°C. [27]

Steam is often used to clean wooden barrels used in the maturation process of wine and spirits and, initially, there was concern that the steam might be damaging the wood and affecting the flavours produced by it. However, studies have found that wood is such an efficient insulator that the steam does not damage vital flavour compounds found in the wood; even with the interior of the barrel at 100°C, the temperature 4mm below the surface is only 35°C after 20 minutes of steam cleaning. [27]

Benefits of steam for sanitation as opposed to chemicals:

1) Delivers high amounts of heat fast
2) Leaves no toxic fumes, is not poisonous
3) Does not damage barrels
4) Chemicals typically do not cover the entire cleaning surface and this provides the possibility of contamination. [27]

2.6.4)Milk and fruit-juice pasteurisation

The milk and fruit-juice pasteurisation processes run in parallel. Milk is passed through a pasteuriser where the temperature of the milk is raised from 5°C to 76°C for 15 seconds and then cooled down to 5°C again. The milk is then sterilised either by the 'Steri-Tube' process, where the milk is heated to 138°C and cooled to 20°C, or by the 'NEXT' process where the milk is heated up to 144°C and cooled down to 22°C. The milk then goes to the filler where it is boxed, packed and palleted. [28]

The juice concentrate is received by truck at 25°C and is unloaded into juice mixing tanks and diluted to the correct consistency. The juice is pasteurised by raising its temperature to 115°C and then cooling it to 20°C. The pasteurised juice is piped to the filler where it is boxed, packed and palleted. The pallets are placed in storage and then dispatched onto trucks. [28]

The major process equipment includes a:

- Pasteuriser
- Separator
- Tubular milk steriliser
- Tubular juice steriliser
- Direct infusion milk steriliser
- Warm water tank
- Tube and drink homogeniser
- NEXT homogeniser [28]

2.6.5)Absorption-cooling

The absorption refrigeration cycle is similar to the vapour compression cycle but, instead of using a compressor to achieve the high pressures required, the pressure is obtained by applying heat to a refrigerant solution. The principle of absorption refrigeration is that variations in refrigerant solubility can be obtained by changing solution temperatures and pressures. [29]

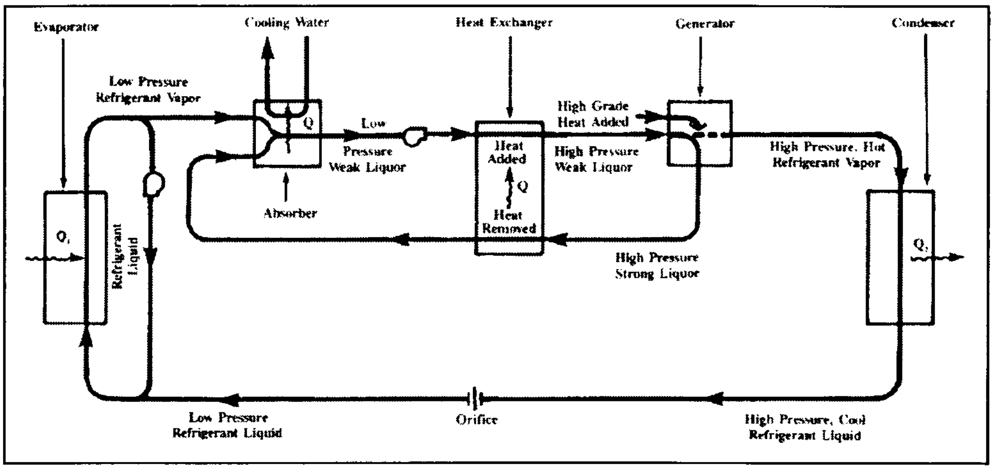
Industrial absorption refrigeration systems often use ammonia as the refrigerant in a water solvent, whereas in commercial and institutional applications water is used as the refrigerant in a lithium bromide solvent. [29]

The basic components of an absorption system are the vapour absorber, solution transfer pumps, and a vapour regenerator (solvent concentrator) in addition to the evaporator and condenser. [29]

The steps in an absorption refrigeration cycle are:

1) The liquid refrigerant is vaporized in the evaporator absorbing heat from the medium to be cooled.
2) In order to draw the refrigerant vapour through the system a low pressure is required. This is accomplished when the refrigerant meets the solvent in the absorber. The solvent's affinity for the refrigerant causes the refrigerant to be absorbed by the solution, reducing the pressure of the refrigerant vapour and giving off the heat absorbed in the evaporator. The heat emitted must be removed from the cycle. The solution (weak liquor) is pumped from the absorber at low pressure to the generator at high pressure.
3) Heat is added to the solution (weak liquor) to drive the refrigerant out of the solution. A heat exchanger is located between the absorber and generator . Heat is removed from the strong liquor (solution with high solvent and low refrigeration concentrations) leaving the generator and is added to the weak liquor entering the generator, reducing the cycle heat input.
4) Further heat added to the weak liquor in the generator drives the refrigerant out of solution, providing a high pressure refrigerant vapour. The hot solvent, still containing some refrigerant (strong liquor), returns to the absorber through the heat exchanger where the solvent cycle repeats.
5) Vapour at high pressure and temperature flows to the condenser, where heat is rejected through a coil or heat exchanger during the condensation process.
6) The pressure of the liquid refrigerant is reduced by passing through a throttling device before returning to the evaporator section. [29]

Figure 14: Absorption refrigeration cycle



[29]

The performance of an absorption chiller is measured by its Co-efficient Of Performance (COP), which for absorption chillers is less than 1 for cooling and between 1.2 and 1.4 for heating. These figures are low if compared to compression cycles but, if the energy required can be supplied by waste energy, then heating and cooling can be supplied at reasonable costs. [29]

2.6.6)Fibreboard production

The fibreboard production process requires 7 major steps; they are:

1) Chipping

Apart from chips and sawdust received from sawmills, the raw material wood is chipped and stocked in silos.

2) Cleaning of chips

The chips are taken from the silos and are cleaned for removal of any mineral or metallic particles.

3) Defibration

The aim of defibration is to reduce woodchips into fibres.

The chips are first softened by pressurized steam in pre-heaters before being transferred to the defibrators. The defibrator grinds wood between one fixed disc and one fast rotating abrasive disc, which is patterned with radial slots tightened towards the circumference. The chips are carried by centrifugal force through these slots and reduced to fibre, which is mixed with water to create the panel pulp.

4) Forming of panels

The pulp is transferred to a forming machine where the panels are formed.

The fibres pack together as the water is drained through gravity and the pulp is made into a wet mat; thereafter a top layer of refined fibres and water is added on the surface for certain qualities. The draining of water is accelerated by suction, followed by draining and compression, which reduces the thickness of the mat. It is cut to lengths suitable for either pressing for hardboard or drying for softboard.

In order to avoid sticking in the press, a release agent is sprayed on the surface of the mat at the entry to the hardboard press.

5) Pressing of hardboards

The mats are pressed at high pressure between a polished stainless steel plate, which gives the panel a smooth side, and a metallic meshed wire which enables water draining and gives the rough side its pattern.

6) Drying of softboards

For softboard production, the fibre mats are cut to lengths before entering a multi-storey dryer in which they cross several temperature zones before exiting.

Even without a press, the initial compression and humidity of the mats, as well as the drying temperatures, are sufficient for activating the natural glues of the wood fibres.

7) Cutting to sizes and packaging

   After exiting the dryers the panels are cut on sawing units to the dimensions required by the customers. [30]

2.6.7)Water-heating

Hot water has many applications and the demand in both urban and rural areas is high. The most common uses of hot water are sanitation, cooking, drinking and heating. Electric water-heating is the single largest energy consumer in the average urban residence, consuming approximately 30-50% of the total electrical energy required. [31]

The proposed CHP plant could provide the service of water-heating, thereafter the heated water could be piped to areas of demand. The CHP plant would generate revenue through the heating service and not the sale of the water itself. The CHP plant could also generate revenue from the sale of emission credits associated with the use of 'green' energy for the process.

3) Case study of a proposed CHP plant in Stellenbosch, South Africa

This case study assesses the CDM potential of a proposed CHP plant fuelled by the by-products of a sawmill located in Stellenbosch, South Africa.

After reading chapter 2, Literature survey, the reader should have a basic understanding of CHP concepts and operation. The case study thus concentrates on the vital features of the plant:

- Energy content of the fuel
- Energy available after the combustion of the fuel
- The utilisation of the available energy
- And the CHP plant's feasibility, based on expected revenue from the sale of energy and associated emission reductions.

In order to calculate the emission reductions that would occur with the introduction of a CHP plant, the pre-determinable* emissions associated with each significant CHP process have been added and compared with alternative cases utilising fossil-fuelled energy. The process and equipment used may at times appear specific to a particular location, but it is believed that similar situations are likely to be found at sawmills across the country.

3.1) Fuel sources

The fuel for the CHP plant will be combustible woody biomass.

The plant would make use of three major sources of this fuel:

1) Plantation biomass: residues collected in the forestry plantations
2) Sawmill biomass: residues collected on the sawmill site
3) Alien vegetation biomass: residues collected through the WFW programme

3.1.1)Plantation residues

The major timber species commercially grown in South Africa is the Pinus species, more commonly known as Pine. These trees are grown and harvested in plantation stands around South Africa.

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* Pre-determinable emissions: certain emissions figures will only be determinable, with any significant accuracy, once the CHP plant is running.

Fuel residues are acquired from the waste processes that occur during growth and harvesting, more specifically:

1) Tree tops, branches and foliage
2) Tree stumps
3) Breakages
4) Sawdust
5) Waste trees

3.1.2)Sawmill residues

Fuel residues are acquired from the biomass waste collected during the processing of the timber at the sawmill, more specifically:

1) Bark
2) Sawdust and fines
3) Wetmill offcuts and chips
4) Drymill offcuts and chips

3.1.3)Working-for-Water (WFW) residues

Fuel residues are acquired from alien vegetation removed from riparian zones through the WFW programme. This biomass comprises all parts of the exotic vegetation removed, including:

1) Branches
2) Foliage
3) Stems
4) Stumps

3.2) Biomass energy available

In order to accurately calculate the amount of energy generated it is necessary to determine the energy content of the available fuel; the total energy from both plantation and WFW residues was calculated to be approximately 598.6 TJ per year. Pine residues make up the vast majority of this energy, 99.2%; the other 0.8% is obtained from biomass collected through the WFW program. (see appendix 2)

In order to compare the energy available at the proposed CHP plant with that available at a national sawmill level, it is preferable that the WFW residues be equated to an additional volume of sawmill processed pine.
The total amount of fuel energy available to the proposed CHP plant, 598.6 TJ, is equivalent to that obtainable from the process residues of approximately 122 500 m^3 of commercially grown pine per year.

3.2.1)Energy available from pine residues

The majority of the biomass residues at the Stellenbosch sawmill are expected to come from the pine residues accumulated at the sawmill; other sawmills in South Africa also process eucalyptus trees which have a similar energy content. The fact that the majority of residues will come from sawmill processing is an important factor in minimising the total fuel supply cost and CHP intervention emissions. This is because the transport of this biomass to the sawmill is to supply logs for timber production and is therefore considered free of charge and CHP intervention emissions.

The Stellenbosch sawmill receives 350 m^3 of pine per day; 100 m^3 of private pine and 250m^3 of pine from its affiliated plantations. The sawmill runs for an average of 256 days per year and the total annual roundwood intake is approximately 89 600 m^3; of which 40-50% typically becomes residues. [32]
These residues are heterogeneous and constitute bark, wet off-cuts from the log making process, white chips from the canting process, sawdust, dry off-cuts from the lumber standardising process, and planing dust. Each of these varies in terms of moisture content, volume, and particle size. This means that sorting and managed mixing is required to produce a uniform fuel. [3]

The pine residues are derived from the two main pine species found growing in South Africa, namely pinus pinaster and pinus radiata. These species are considered softwoods; the average gross calorific value of softwoods found in South Africa is 20.4 MJ/kg•. The average gross calorific value of another popular pine plantation species pinus patula is 20.42 MJ/kg *. [33] Drawing upon this information it was

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• Gross calorific value given at 12% moisture content.

concluded that it would be acceptable to estimate the gross calorific values of pinus pinaster and radiata as averaging 20.4 MJ/kg at 12% moisture content.

The calorific value that corresponds most closely with the conditions of practical fuel combustion is the net calorific value. This is because water in the combustion products will generally be in the gaseous state. The difference between net and gross calorific value is the latent heat of evaporation at the reference temperature of either the reference pressure or volume. [34]

The net calorific value can be deduced from the gross calorific value and the composition of the fuel in terms of moisture and hydrogen; the net calorific values of the pinus residues for the various moisture contents most likely to occur at the CHP plant were calculated to be:

- 0% moisture content: 22.85 MJ/kg
- 12% moisture content: 18.96 MJ/kg
- 47% moisture content: 13.88 MJ/kg (see appendix 2)

The density of pine residue material used for calculations of available energy was equivalent to the average density of pinus radiata and pinaster at 12% and 47% moisture content. The kiln drying process of timber at the sawmill reduces the moisture content to 12% and the residues from the plantation, logyard and wetmill are expected to air-dry to less than 47% moisture content prior to use as a combustion fuel. Typically, air-dried woods contain a moisture content of approximately 10-15% [34] but future investigation into the exact moisture content of non-kiln treated residues should be carried out in order to improve the accuracy of the theoretical combustion efficiency.

The density of pinus residues at the relative moisture contents was calculated to be:

- 0% moisture content: 545.5 kg/m^3
- 12% moisture content: 611kg/m^3
- 47% moisture content: 800 kg/m^3 (see appendix 2)

The total energy available from the processing of 121 521 m^3 of these pinus species per year was calculated to be 593.8 TJ (see appendix 2)

3.2.2)Energy available from WFW residues

The WFW is a nationwide initiative. However, it is only considered economical to transport residues within the Western Cape to the proposed Stellenbosch CHP plant. The major WFW areas in the Western Cape are found on the West Coast and the Agulhas plains, adjacent to Cape Agulhas. [3]
The total alien biomass currently available was assumed to regenerate every twelve years. The government is considering utilising these zones as sustainable fuel wood zones and therefore one twelfth of the original total biomass would be removed each year. [22]

The acacia species collected through the WFW program are considered hardwoods; the average gross calorific value of hardwoods found in South Africa is 19.77 MJ/kg at 12% moisture content. [34]
The average gross calorific values of acacia mearnsii (black wattle) and acacia melanoxylon (Blackwood) are slightly lower at 19.22 MJ/kg and 19.32 MJ/kg respectively [34]; both species are major removal species of the WFW programme. Other major acacia species falling under the WFW programme are a.saligna (Port Jackson willow), a.cyclops (Rooikrans), a.longifolia (Long-leaved wattle) and a.pycnantha (Golden wattle). [22] However, the calorific values of these species could not be found.

It was decided to use the lower gross calorific value of the two tested acacia species, namely a.mearnsii and a.melanoxylon, as the calorific value for all of the afore-mentioned acacia species; these acacia species make up the large majority of the trees designated for removal through the WFW programme. Thus the gross calorific value of 19.22 MJ/kg, at 12% moisture content, is considered conservative if not accurate.

The net calorific values of the alien biomass were calculated in the same way as those for the pinus biomass.
The net calorific values of the alien biomass were found to be:

- 0% moisture content: 21.53 MJ/kg
- 12% moisture content: 15.73 MJ/kg (see appendix 2)

Due to the similarity of the invasive alien acacia species and the lack of density data, it was decided to use the average density of a.melanoxylon for all species.
The average density of a.melanoxylon at 12% moisture content is 670 kg/m^3. [34]

The available energy from residues obtained through the WFW programme was calculated to be approximately 4.8 TJ per year. (see appendix 2)
This is the amount of energy available from the plantation and sawmill process residues of approximately 979 m^3 of commercially grown pine.

3.3) Prioritisation of energy use

The prioritisation of CHP energy use, is the determining of which CHP process to prioritise in terms of utilising the available CHP energy.
The highest overall priority of the CHP plant will be its financial viability and its obligation to meet the sawmill's steam requirements. Therefore, the CHP product which will generate the greatest amount of revenue whilst meeting the requirements of the sawmill and sustainable development, is the product which should take priority in terms of utilising the available CHP energy.

The Danish organisation, the clients for the original research from which this dissertation has evolved, has suggested that the CHP plant be designed with the capability of producing 4-6 MW of electricity. [3]
Early indications suggested this would require the majority of the available energy, effectively prioritising electricity production. The Danish organisation has a large amount of experience with regard to biomass CHP plants and their prioritisation of electricity production is validated in part by the following:

- Electricity is a product which could utilise the majority of the available fuel energy at an expected profit
- Expected high demand
- Increasing fossil-fuelled energy prices liable to make the production of CHP electricity ever more profitable
- Easy to transport, national grid
- Transport system already installed, national grid
- No maintenance of transport system, national grid
- Large amount of associated CERs

However, it is worthwhile to consider the following: the sawmill requires steam for its wood-drying kilns and the CHP plant must produce sufficient process steam to meet this requirement. The efficiency at which process steam is used at the sawmill is low since the boiler is fuelled by the sawmill's waste residues and consequently steam is produced at relatively low cost. If the sawmill's process steam were to become more valuable, then it is likely that it would be more efficiently managed and the excess steam could be used for additional processes on site or sold to neighbouring facilities.

Producing heat from the combustion of woody residues is more efficient than producing electricity, as is the transfer of heat between steam, water and air through a well designed heat-exchanger.

Certain processes that typically utilise electricity for power supply can be modified to utilise heat e.g. urban water-heating and absorption-cooling. When this heat has been obtained directly from the combustion of fuel, the overall energy transfer efficiency is often greater; depending on the process and technology used. Greater efficiency results in less GHG produced and lower energy costs.

If CHP heat is used as a more efficient replacement than electricity, then larger amounts of emission reductions can be achieved per unit of CHP fuel energy input than straight electricity or heat substitutions. The larger amounts of CERs produced per unit of CHP fuel input energy could have a significant effect on the optimal choice of CHP products produced.

Despite the plant's potential to generate significant revenue from products such as 'green' heat, the level of feasible demand is difficult to gauge. The piping systems will be expensive and the system will have to compete with alternative energy supply options. Furthermore, changes in external markets could affect the demand and a lowering of demand could cause feasibility problems. These unknowns require future market specific, in-depth studies and trade negotiations; these are beyond the scope of this document.

Therefore, and in conclusion, for this study the prioritisation of energy use at the proposed Stellenbosch CHP plant is:

1) To provide sufficient process steam for the current operation of the sawmill; with future improvement of steam efficiency allowing additional steam use or process implementation.

   Current process steam requirement:

   - Pressure:10 bar, pressure required from the current sawmill boiler
   - Steam condition: saturated
   - Temperature: 180 °C, temperature of saturated steam at 10 bar
   - Flow rate:10 tons/hr
2) Generation of electricity for the CHP plant, sawmill and sales
   - ≥6.32 GWh/yr plus CHP plant requirement
3) To provide additional CHP products to neighbouring clients

3.4) Suitable generation technology

The current technology best suited to provide large quantities of steam and electricity from woody biomass is an efficient biomass water-tube boiler and suitable condensing steam turbine. [15]

Reasons for the technology chosen are:

1) Relatively large amounts of electricity and steam are required
2) The amount of electricity and steam required can be produced most cost effectively by a boiler and steam turbine configuration
3) A water-tube boiler is best suited for combustion of solid woodchip fuels
4) The production of electricity from steam turbines is a tried and tested technology widely utilised in South Africa.

The biomass boiler will supply steam for process and steam to a turbine. The turbine will, in turn, power an electrical generator.

It is assumed that by the time the CHP plant is operational, reputable independent power producers will be able sell power through the national grid. Then, the electricity produced by the CHP plant will be used to power the sawmill and the CHP plant, the surplus will be sold to clients through the national grid.

This will require that the plant be connected to the grid, which in turn will require a costly transforming and monitoring station.

The boilers generally found at South African sawmills are not suitable for producing steam for electricity generation; the moisture content of the steam is too high, causing damage to turbine blades and the pressures are generally too low for economical electricity generation. [35]

South Africa's largest boiler manufacturer, Alstom/John Thompson, was approached to quote on the cost of a new boiler, accompanying turbine and installation.

This company has designed and manufactured boilers adapted for biomass combustion and are in possession of turbine specifications to suit the steam production of their boilers. In order to specify the equipment required and the related costs, they needed to accurately model the thermal characteristics of the boiler and turbine.

They were sent the required information detailing:

- The type of fuel
- The likely consistency
- The moisture content
- The net and gross calorific values of fuel,
- The amount of fuel
- The chemical composition of the fuel. (see appendix 3)

3.5) Expected generation capacity and plant efficiency

The fuel energy available for combustion, for a 90% plant availability factor, is 21.09 MJ/s or 21.09 MW. (see appendix 4)

Overall efficiencies of CHP plants are regularly between 60-85%, typical energy splits would be 25% electricity generation efficiency, 60% process steam generation and 15% losses. [18]

Since electricity generation is a high priority, and the amount required justifies the cost of efficient equipment, it is believed that an electrical generation efficiency of approximately 25% percent is achievable. Therefore, the initial calculations by the author suggested that there will be sufficient biomass to generate at least 5.3 MW or 41.57 GWh of electricity per year; this was confirmed by the plant specifications received from the boiler and turbine manufacturers.

The plant specifications are:

Turbine capacity:	6MW
Turbine type:	Condensing
Boiler capacity:	45 tons/hr
Turbine steam conditions:	35 tons/hr, 45 bar, 450°C superheated
Process steam conditions:	10 tons/hour, 10 bar, 180°C
Approximate turnkey price:	R86 - R100 million
Electricity produced per year:	47.3 GWh or 170.28 TJ
Electricity available to clients[†]:	42.5 GWh or 153.25 TJ

[†] A boiler and generation plant of this size will typically consume less than 5% of the electricity produced. [35] In addition less than 5% is assumed to be consumed by the rest of the CHP plant processes. Therefore, it is safe to assume that 90% of the electricity generated will be available beyond the CHP plant.

- Plant installation cost per kW: R14 333 - R16 667 [35]

The CHP plant is expected to have a lifetime of 20 years and it has been assumed that the earliest realistic period of operation would be from January 2010 to 2030.

The amount of process steam available will be 78 840 tons per year. This is assuming the CHP plant has a load factor of 0.9, runs for 328.5 days per year and produces a constant 10 tons per hour. (see appendix 4)

Using the specific enthalpy of the process steam and that of the returning feedwater, the calculated energy available will be equal to 211.06 TJ per year or 58.63 GWh per year. (see appendix 4)

The expected overall plant efficiency will be approximately 64%. (see appendix 4) The reason for this efficiency being on the lower end of the CHP efficiency scale is the prioritisation of electricity generation and the relatively low efficiency associated with this process.

3.6) Final energy use

The thermal energy produced from the combustion of the fuel and the generation of steam will be used to produce electricity and heat.

3.6.1) Electricity; capacity required and achievable

The South African government has stipulated that the renewable electricity generation sector must contribute a minimum of 4 TWh towards the country's annual total electricity demand by 2013. [36] This will require a substantial increase in renewable generation capacity. The proposed CHP plant should be capable of exporting 42.50 GWh per year, approximately 1% of that required by 2013.

Recent market surveys have indicated that that there is increasing interest in the sale and use of 'green' energy and the government has recently issued licenses to various organisations to trade specifically in 'green' electricity. [37] The certification of use of 'green' energy is occasionally required by European markets, without which these markets are closed to imports, and in certain cases the use of 'green' energy is company policy. [3]

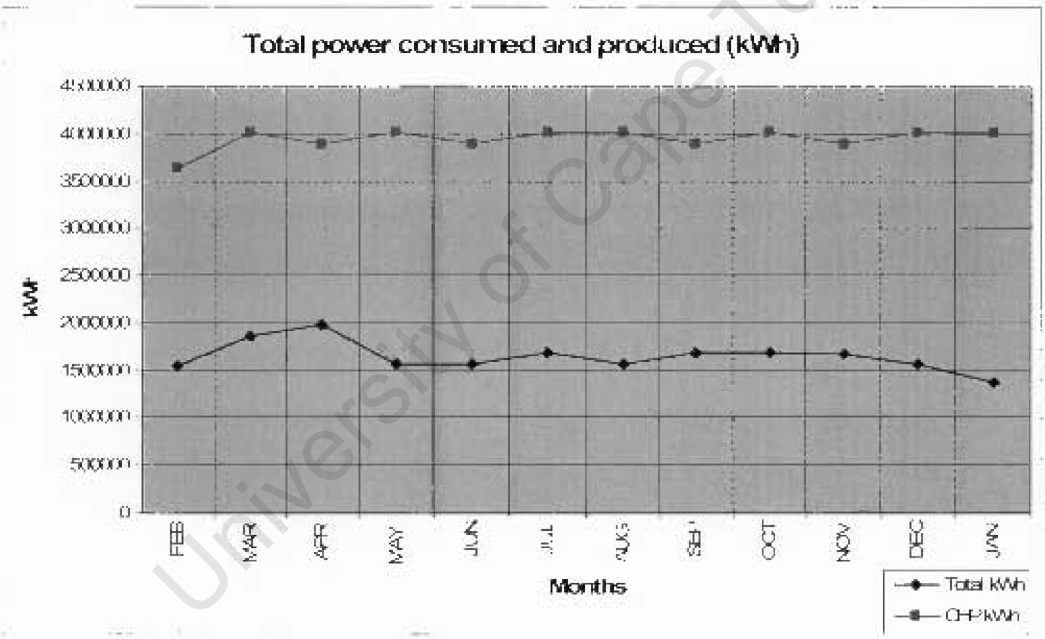
Therefore, it is expected that the market for 'green' electricity will be large enough to absorb all of that produced by the CHP plant.

The nearby distillery and neighbouring fibreboard plant have shown interest in purchasing 'green' electricity from the CHP plant. [38]

Possible users of electricity generated by the CHP plant include:

1) CHP plant ≤4.73 GWh/yr
2) Sawmill ± 6.32 GWh/yr
3) Fibreboard plant; nearby large electricity consumer ±2.76 GWh/yr
4) Distillery; nearby large electricity consumer ±5.92 GWh/yr
5) Additional clients (see appendix 5)

Figure 15 : Total energy consumption of the four plants vs CHP generation



The chart above clearly illustrates that the combined consumption total of the CHP plant, sawmill, fibreboard plant and distillery plant is far less than the generation capacity of the proposed CHP plant.

The annual generation capacity of the proposed CHP plant is approximately 47.30 GWh. The annual consumption of the sawmill, fibreboard plant and distillery plant is at present approximately 16.0 GWh; the CHP plant could consume as much as 4.73 GWh; approximately 26.57 GWh could be sold to other clients.

However, the peak combined demand of all four plants could exceed the available generation capacity of the CHP plant; the *averaged* peak demand in April is close to 6MW. Therefore, it may still be necessary to purchase additional electricity from the national grid during these peak demand periods. (see appendix 5)

3.6.2)Process steam; capacity required and achievable

The amount of steam required for current[‡] sawmill process is 10 tons per hour at 10 bar. The process steam required would be bled off from the turbine system part way through the steam expansion process. The benefit of drawing off steam part way through the turbine is that, should any amount of process steam not be required, then the energy can be used for additional electricity generation. Generally plant processes do not require steam at pressures as high as 10 bar. However, the use of higher pressure steam creates an allowance for pressure losses across piping.

Since sawmills are inherently rural enterprises, any industries located nearby are likely to be agriculturally orientated and often require process steam so, although the following potential steam clients are particularly applicable to the Stellenbosch sawmill, it is quite possible that sawmills throughout South Africa are in similar situations.

Seven potential uses of available process steam were investigated;

1) Wood-kilns
2) Distillation
3) Sanitation
4) Pasteurisation
5) Absorption-cooling
6) Fibreboard production
7) Water-heating

The following information regarding each of the above processes is given as a guide as to what could be achieved using the amount of process steam allocated. Figures

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[‡] The sawmill's current steam system is inefficient and the amount currently required could be reduced by improving the system's efficiency.

achievable solely for each individual process have been calculated but a combination of processes could also be utilised to maximise steam usage. (see appendix 6)

Table 3: Process capacities achievable using CHP process steam (saturated, 10 bar)

Process	**Using 10 tons/hr**	**Per ton of steam**
1.1) Wood-kiln capacity (95% efficient)	800 m^3	NA
1.2) Wood-kiln capacity (60% efficient)	400 m^3	NA
2) Distillation (alcohol)	5.3 tons/hr	0.53
3) Sanitation (750 ml bottles)	46 895 bottles/hr	4 689.48 bottles
4) Milk/fruit-juice pasteurisation	9.5 kilolitres/hr	0.95 kilolitres
5) Absorption-cooling	3 979 kWh/hr	397.90 kWh
6) Fibreboard production	12.2 tons/hr	1.22 tons
7) Water-heating to 90°C	61.12 kilolitres/hr	61.12 kilolitres

3.6.2.1) Wood-drying kilns; capacity required and achievable

Sawmills require wood-kilns in order to dry the timber in a controlled environment so that the finished product is suitable for its intended market. Other wood products also require heating in order to be suitable, or to add value, in their respective markets.

The Stellenbosch sawmill has sufficient geographic space and demand to facilitate additional kiln capacity, whereby the value of the thermal energy would be inherent in the value added to products which would otherwise have been air-dried. [3] In addition there is an option of renting kiln capacity out to a number of informal sawmills in the region, as limited wood-kiln capacity is a common bottleneck in the sawmilling industry.

An example of the value adding process is low-grade pallet material. Pallets produced for international trade are now required to be kiln-dried for phytosanitary reasons. Pallets have typically been manufactured by an informal sawmilling sector with little infrastructure. There are currently good business opportunities for sawmills that can produce pallets from kiln-dried timber. [3]

3.6.2.2) Distillation; capacity required and achievable

Steam is used in the distillation process at the distillery nearby the proposed CHP plant in Stellenbosch. Although the Western Cape is a large producer of alcohol due to its large grape and deciduous fruit production, the rest of South Africa also grows many varieties of fruits and vegetables which are suitable; maize, wheat and Marula being but some of the more common crops grown. Many other crops are currently, and could be, used for manufacturing alcohol and other distillation products.

Alcohol production is often seasonal, and in the case of the Stellenbosch distillery, it is only produced for four months of the year, January through to May. For the rest of the year the steam is used for bottle-washing/sanitation; the combination of these two processes results in the boiler running at a fairly high load throughout the year. [26]

3.6.2.3) Sanitation; capacity required and achievable

Agricultural businesses, being rural, are often found in close proximity to sawmills. They generally require a relatively high level of sanitation, especially those involving packaging of their products. Saturated steam is a perfect provider of the energy required; the temperature of saturated steam at 10 bar is 180°C, the temperature required for sanitation to meet legal standards is 84°C. [27] Therefore, the process steam available from the CHP plant exceeds the requirements for sanitation.

3.6.2.4) Milk/fruit-juice pasteurisation; capacity required and achievable

Milk and fruit-juice products are often pasteurised in order to kill bacteria and prolong shelf life. The temperature required for this process is 144°C [28], the temperature of saturated steam at 10 bar is 180°C; therefore the temperatures required is easily achievable from a well-designed heat exchanger.

3.6.2.5) Absorption-cooling; capacity required and achievable

Process steam from the proposed CHP plant could be used as the energy source for an absorption-cooling plant. This plant could supply cooling for various applications, including:

1) Industrial cold-storage
2) Climate control of factory floors
3) Climate control of offices

3.6.2.5.1) Absorption-cooling for industrial cold storage

An absorption-cooling plant could supply the cooling required of an industrial cold storage facility. However, the low temperature achievable is limited by the fact that commercial absorption-chillers use water as a refrigerant. [40] Since water would freeze at temperatures below 0°C (at atmospheric pressure), absorption-cooling plants generally cannot be used where temperatures are required at 0°C and below.

3.6.2.5.2) Absorption-cooling for climate control of factory floor

Many employers agree that a pleasant working environment increases the productivity of their employees. South Africa experiences extremely hot summers and relatively mild winters, therefore cooling of the work environment is required, but heating is generally not as high a priority. However, the large amount of natural ventilation common in many of South Africa's existing large factory floors may make it difficult to insulate the building from external heat and to contain the cooling provided by a cooling system. New factory building designs could incorporate a cooling system and thermal insulation to provide a more optimal working environment.

The air-conditioning load of a standard design factory floor where heavy manufacturing is conducted, at sea level in South Africa, is approximately 490 Watts per square metre. [41]

The air-conditioning capacity achievable using the proposed CHP process steam is:

- Maximum capacity using 10 tons of saturated steam per hour, at 10 bar:
  8 120 m^2 of factory floor space; 812 m^2 per ton of steam

3.6.2.5.3) Absorption-cooling for climate control of offices

The air-conditioning load of standard design offices, at sea level in South Africa, is approximately 170Watts per square metre. [41]

The air-conditioning capacity achievable using the proposed CHP process steam is:

- Maximum capacity using 10 tons of saturated steam per hour, at 10 bar:
  23 410 m^2 of office floor space; 2 341 m^2 per ton of steam

3.6.2.6) Fibreboard production; capacity required and achievable

Woodchips are the primary ingredient in the manufacture of fibreboard; many fibreboard plants are located near to sawmills in order to reduce the cost and difficulty of the chip transport process. Steam is another large requirement for the manufacture of fibreboard; it is mainly used in the fibre-softening and drying processes.

3.6.2.7) Water-heating; capacity required and achievable

Hot water has many applications and the local Stellenbosch demand is high; however, the practical capacity required is limited by the feasible piping network.

Hot water from the boiler cannot be used directly, as it contains costly chemicals essential to maintaining the efficient operation of the boiler, and a heat exchanger is required.

3.7) Emission reduction potential of CHP plant

This section evaluates the emissions generated and the emissions reduced through the intervention of the CHP plant.

The table below illustrates the GHG emission reduction potential of the CHP plant, utilising the plantation and sawmill residues of 126 213 m^3 of commercially grown pine[§]as fuel. The expected additional GHG emissions resulting from the intervention of the CHP plant have been included. (see appendices 8 and 9)

Table 4: Potential annual GHG reduction capability of the CHP plant (tCO2eq)

Process	**Current capacity**	**Maximum capacity**
1) CHP operation	NA	+ 23
2) Electricity	-5 688	-38 313
And the reductions from one of the following applications of' green' steam		
- Wood-drying kilns	NA	-7 602
- Distillery and bottling	-1 924	-11 396
- Milk/fruit-juice pasteurisation	NA	-11 396
- Absorption-cooling	NA	-9 414
- Fibreboard production	-6 662	-11 396
- *Average of above 5 uses*	*NA*	*-10 241*
- Water-heating	NA	-44 968
Additional emissions negated by use of excess residues		
- Landfill disposal	NA	-6 652
- Forest disposal	NA	-3 344

The heading 'Current capacity' refers to the GHG emission reductions possible if the CHP plant were to supply the various plants, at their current capacity, with the required steam or electricity.

[§] Pine: the residues from the WFW program have been equated to that of pine residues

The 'Not Applicable' abbreviations under the 'Current capacity' heading imply that there is either no current demand for the respective CHP product or that the technology is not currently utilised.

The heading 'Maximum capacity' refers to the GHG emission reductions possible if all of the generated electricity or process steam were used.

The emissions offset utilising the *maximum* capacity of CHP process steam, or 'green' steam, are compared with those produced by a new coal boiler of 80% efficiency. This efficiency is that of a newly installed process steam boiler and will be higher than many of the current relevant boiler plants in South Africa. Therefore, the emission reduction figures could be considered conservative compared with those of existing plants. However, none of the existing plants investigated has the capacity to utilise all of the proposed CHP process steam. If additional capacity were required, it would be likely that new high efficiency process steam boilers would be installed. Thus, the high boiler efficiency has been used for emission calculations regarding *maximum* CHP process steam use.

The absorption-cooling plant and water-heating plant substitute 'green' steam for fossil-fuelled electricity; the other technologies replace fossil-fuelled steam with 'green' steam.

The table also illustrates the additional GHG emissions that a CHP plant could negate by utilising the excess residues of a sawmill which would otherwise dispose of these residues in landfill or on the forest floor.

3.8) Economic analysis

An in-depth economic analysis of each of the CHP products investigated and the optimal mix of these products is beyond the scope of this document.

This economic analysis serves purely to point out the expected ballpark figures of capital invested and generated. The aim is to determine whether the plant will be feasible or not, as well as to evaluate three basic scenarios detailing the low, medium and high CHP return on investment (ROI) expected.

The maximum CDM crediting period available to a renewable energy project such as the proposed Stellenbosch CHP plant is 21 years. [11] It has been assumed that the CHP plant could be in full production by January 2010 and the expected lifespan of the plant is 20 years. [35]

Therefore, revenues generated through the sale of CHP associated products as well as those from existing residue markets have been calculated for the 20 year period, January 2010-2029. (see appendix 10)

Where applicable all economic calculations have utilised real[**] interest rates in order to obtain Net Present Value's (NPVs) of capital invested and generated. The future value of possible CHP products has been estimated using a combination of relevant historic market data and expected future changes obtained from relevant specialists.

This section includes:

1) CHP construction costs
2) Expected revenue from CHP associated products
3) Expected revenue from current sawmill residue sales
4) Lifetime economic summary

[**] As of the 14th June 2006 the prime interest rate and rate of inflation were 11% and 3.4% respectively. [42]

3.8.1)CHP construction cost

The current total turnkey construction cost is approximately R86 – R100 million. [35] It is assumed that a bank loan would be taken out over a 20-year period in order to cover construction costs.

The net present value of the expected total loan repayments to cover construction costs was calculated to be between R168 and R195 million, using a net discount rate of 7.6%.

3.8.2)Expected revenue from CHP products

The lower range value of all CHP associated revenues has utilised conservative market prices in order to determine the lowest expected return on investment and the plant's ultimate financial feasibility. The higher range values utilise existing higher market prices to determine the higher range of return on investment.

Table 5: Annual value of CHP products based on current market prices (1€:R7.73)

➢ Electricity	R8.13 - R15.39 million @ (19c–36c)/kWh
➢ Process steam	R4.73 - R7.88 million @ (R60–R100)/ton
➢ Water-heating	R9.54 - R18.06 million @ (1.98c–3.75c)/litre
➢ CERs (electricity)	R4.53 million @ €15.30/CER
➢ CERs (steam average)	R1.21 million @ €15.30/CER
➢ CERs (water-heating)	R5.32 million @ €15.30/CER

Table 6: Expected revenue from product sales, 2010-2029

➢ Electricity	R325 - R471million
➢ Process steam	R158 – R264 million
➢ Water-heating	R383 – R553 million
➢ CERs (electricity)	R59 – R237 million @ (€10-€40)/CER
➢ CERs (steam average)	R16– R63 million @ (€10-€40)/CER
➢ CERs (water-heating)	R70 – R278 million @ (€10-€40)/CER

3.8.2.1) Revenue: electricity

The CHP plant could export approximately 42.57 GWh of 'green' electricity per year.

The Stellenbosch Municipality currently sells electricity to bulk business users at 36.16c per kWh. [43]

Eskom currently sells electricity to rural bulk users, such as sawmills, on the Ruraflex tariff; the lowest general public tariff in South Africa. Ruraflex is a time-of-use-tariff and in order to calculate the annual average price per kWh it was necessary to assume a constant demand throughout the year. The average annual price was calculated to be 19.09 c/kWh [44], which according to specialist 'green' electricity brokers Amatola Green Power (AGP) is approximately the price at which Eskom is currently prepared to buy 'green' electricity. [45]

The total revenue generated from the sale of 42.57 GWh of 'green' electricity per year over the 20 year period, 2010-2029, was calculated using expected future prices derived from both the current Eskom offer of 19c/kWh and an assumed municipal offer of 36.16c/kWh.

The future price of 'green' electricity was calculated by adding the current respective Eskom and municipal offers to expected real future electricity production price increases, excluding the effect of inflation, as determined in the second and latest National Integrated Resource Plan. [46]

It was found that an expected price for 'green' electricity for the years 2010-2029 ranged from 29c/kWh to 40c/kWh from Eskom and from 46c/kWh to 58c/kWh from the Stellenbosch municipality.

Table 7: Present value of annual revenue from 'green' electricity

Amount of electricity available	*19.09c/kWh*	*36.16c/kWh*
42.57 GWh	R8.13 million	R15.39 million

Table 8: Expected revenue from 'green' electricity sales, 2010-2029

Amount of electricity available	*29c-40c/kWh*	*46c-58c/kWh*
851.40 GWh	R325 million	R471 million

3.8.2.2) Revenue: steam

The cost of coal extraction[††] is expected to increase linearly at approximately 10% per year. [47] In addition the increasing cost of coal transportation, chemicals, boiler-operators and maintenance will result in an increase in the price of coal-fuelled process steam. Taking into account all of the above, a likely linear annual real increase of at least 5% can be expected, excluding the effect of inflation.

The basic cost of coal-fuelled steam currently varies from R60-R100 per ton depending on the age and efficiency of the boiler. (see appendix 7)

The assumed CHP operation period is from January 2010-2029; taking into account real increases the price per ton of coal-fuelled steam during this period can be expected to vary from R72–R120 in 2010 to R129-R215 by 2029.

Coal-fuelled steam is generally considered the cheapest form of steam in South Africa and 'green' steam cannot be expected to be cheaper, all else remaining the same. Accordingly a price increase equivalent to that of coal-fuelled steam is the least to be expected.

Therefore, assuming that all of the process steam is purchased, the revenue given in the tables below represents a conservative value for the 'green' process steam produced. In addition, since the 'green' price used is the same as that of coal-fuelled steam, the revenue generated from associated CERs can be added as a separate commodity.

Table 9: Present value of annual revenue from 'green' process steam

Amount of steam	*R60/ton*	*R100/ton*
78 840 tons	R4.73 million	R7.88 million

Table 10: Expected revenue from 'green' steam sales, 2010-2029

Amount of steam available	*(R72–R120)/ton*	*(R129-R215)/ton*
1 576 800 tons	R158 million	R264 million

[††] The pithead price is approximately 25-30% of that paid by industrial boiler plants in the Cape [47]

3.8.2.3) Revenue: water-heating

The use of CHP energy to heat 482 megalitres of water to 90°C could offset as much as 49.95 GWh of grid electricity per year. Therefore, revenue generated by the CHP plant through water-heating can be equated to the cost of 49.95 GWh of 'green' electricity utilising the same pricing scheme as that used for CHP electricity sales.

Table 11: Present value of annual revenue from 'green' water-heating

Amount of electricity offset	*19.09c/kWh*	*36.16c/kWh*
49.95 GWh	R9.54 million	R18.06 million
Amount of hot water produced	*1.98c/litre*	*3.75c/litre*
482 megalitres at 90°C	R9.54 million	R18.06 million

Table 12: Expected revenue from 'green' water-heating, 2010-2029

Amount of electricity offset	*(29c-40c)/kWh*	*(46c-58c)/kWh*
999.00 GWh	R383 million	R553 million
Amount of hot water produced	*(3.01c–4.15c)/litre*	*(4.77c–6.01c)/litre*
9.64 gigalitres at 90°C	R383 million	R553 million

3.8.2.4) Revenue: CERs

In early June 2006 the value of CERs on the European market plummeted from almost €30 to €13 per CER. This was due to the emergence of an extremely large number of Russian CERs that effectively flooded the Carbon Market. However, by the end of the month the price had risen again to approximately €16 per CER. [14] This event illustrates the dynamic nature of the Carbon Market and highlights the risks involved within its trading scheme.

There are concerns regarding the trading of carbon on the Carbon Market after the first phase of the Kyoto Protocol, 2008-2012. However, the common perception of Market brokers is that the price will continue to rise rapidly, reaching €25-€40 per CER as the first phase deadline looms and will then slowdown to a more gradual increase in the following phases. [14]

CERs are often sold in lump amounts equivalent to many, if not all, of the emission reductions expected to be achieved during the lifetime of a project. However, the sale of CERs before their maturation date involves a certain amount of risk due to possible project failure. This risk affects the price of CERs and, therefore, the closer to project maturation, the higher the price per CER.

Due to the uncertainty involved in the Carbon Market this study has calculated a range of expected CER revenues utilising values from €10-€40 per CER; results are given for a single year and for an expected project lifetime of 20 years.

Table 13: Annual value of CHP CERs at varying market prices (1€:R7.73)

Amount of CERs	*€10/CER*	*€20/CER*	*€30/CER*	*€40/CER*
Electricity (38 313)	€383 130	€766 260	€1 149 390	€1 532 520
Electricity (38 313)	R2 961 594	R5 923 190	R8 884 785	R11 846 380
Av. Steam (10 241)	€102 410	€204 820	€307 230	€409 640
Av. Steam (10 241)	R791 629	R1 583 259	R2 374 888	R3 166 517
Hot water (44 968)	€449 680	€899 360	€1 349 040	€1 798 720
Hot water (44 968)	R3 476 026	R6 952 053	R10 428 079	R13 904 106
Note: 23 credits will be subtracted due to the running emissions of the CHP process				

Table 14: Expected revenue from CER sales, 2010-2029 (1€:R7.73)

Amount of CERs	*€10/CER*	*€20/CER*	*€30/CER*	*€40/CER*
Electricity (766 260)	€7.66 mill	€15.33 mill	€22.99 mill	€30.65 mill
Electricity (766 260)	R59.23 mill	R118.46 mill	R177.70 mill	R236.93 mill
Av. Steam (204 820)	€2.05 mill	€4.10 mill	€6.14 mill	€8.19 mill
Av. Steam (204 820)	R15.83 mill	R31.67 mill	R47.50 mill	R63.33 mill
Hot water (899 360)	€8.99 mill	€17.99 mill	€26.98mill	€35.97 mill
Hot water (899 360)	R69.52 mill	R139.04 mill	R208.56 mill	R278.08 mill
Note: 460 credits will be subtracted due to the running emissions of the CHP process				

3.8.3)Revenue: Sawmill residues

The sawmill produces 47 897 m^3 of woody residues per year. Presently all white chips, off-cuts and shavings are sold to the fibreboard plant, all sawdust and 50% of bark from timber is used in the sawmill's two boilers to generate process steam, the other 50% of the bark is sold to nurseries and gardening services. [38]

The burning of 12 059 m^3 per year of woody residues in the sawmill's boilers leaves 35 838 m^3 available for sale at a current average value of R70 per m^3. [48]
The real average price of residues sold has increased linearly at 4.1% for the last 3 years, excluding inflation. This annual increase was used to calculate the total expected revenue which could be generated over the period 2010-2029.

Table 15: Present value of annual revenue from sawmill residues

Amount of residues	*R70/m^3*
35 838 m^3	R2.51 million

Table 16: Expected revenue from residue sales, 2010-2029

Amount of residues available	*(R81-R136)/m^3*
716 760 m^3	R77.94 million

3.8.4)Lifetime Economic Summary

The table below contains the expected range of net present values for the CHP plant's construction costs and product sales for the twenty year period 2010-2029. The net present value of the revenue that would otherwise be generated by the sawmill's current residue markets is included to enable a comparison of possible revenues generated.

Table 17: NPV of construction costs and potential CHP revenues

NPV of plant construction costs	R168 - R195 million
NPV of CHP electricity sales	R325 - R471 million
NPV of CHP steam sales	R158 – R264 million
NPV of CHP water-heating sales	R383 – R553 million
NPV of CHP electricity CER sales	R59 – R237 million
NPV of CHP process steam CER sales	R16 – R63 million
NPV of CHP water-heating CER sales	R70 – R278 million
NPV of sawmill residue sales to current markets	*R78 million*

3.8.4.1) Baseline ROI: electricity and associated sales

For this comparison, the lowest expected return on CHP investment is the balance of total loan repayments to cover plant construction and the sum of the lowest range of revenues generated from the sale of CHP electricity and its associated CERs. Since it is the lowest revenue expected, it has been termed the baseline revenue; assuming all the electricity and associated CERs are sold.

Table 18: Return on investment - electricity and associated sales

NPV of plant construction costs	-R168 million
NPV of running costs	unknown
NPV electricity sales	+R325 million
NPV of electricity CER sales	+R59 million
Return on investment	*+R216 million (129%)*
NPV of sawmill residue sales to current markets	*+R78 million*

Even though running costs and other additional costs are not known at this time, it appears that the CHP plant will be feasible and will generate more revenue than current residue market sales over the same period.

3.8.4.2) ROI: electricity, process steam and associated sales

For this comparison, the return on CHP investment is the balance of total loan repayments to cover plant construction, and revenue generated from the sale of CHP electricity, process steam and their associated CERs.

The revenue generated by the CHP plant is the sum of the lowest range of CHP sales from electricity, process steam and the associated CERs. CHP water-heating and process steam compete for the same CHP energy, but the sale of process steam is expected to generate less revenue for the same amount of CHP energy used.

Table 19: Return on investment - electricity, process steam and associated sales

NPV of plant construction costs	-R168 million
NPV of running costs	unknown
NPV electricity sales	+R325 million
NPV CHP steam sales	+R158 million
NPV of electricity CER sales	+R59 million
NPV of process steam CER sales	+R16 million
Return on investment	*+R390 million (232%)*
NPV of sawmill residue sales to current markets	*+R78 million*

3.8.4.3) Highest ROI: electricity, water-heating and associated sales

For this comparison, the highest expected return on CHP investment is the balance of total loan repayments to cover plant construction and the sum of the highest range of revenues generated from the sale of CHP electricity, water-heating and the associated CERs.

Table 20: Return on investment - electricity, water-heating and associated sales

NPV of plant construction costs	-R168 million
NPV of running costs	unknown
NPV electricity sales	+R471 million
NPV water-heating sales	+R553 million

NPV of electricity CER sales	+R237 million
NPV of water-heating CER sales	+R278 million
Return on investment	*+R1 371 million (816%)*
NPV of sawmill residue sales to current markets	*+R78 million*

4) Discussion

The following chapter discusses key issues of the proposed CHP plant in Stellenbosch, the conclusion from which follows in the next chapter.

4.1.1)Utilisation of CHP energy

Although electricity production was originally prioritised in terms of CHP energy utilisation, [3] the results of this study show that technologies that are able to replace fossil-fuelled electricity, with lower cost 'green' CHP heat energy, have significant potential to generate large amounts of revenue and GHG reductions e.g. water-heating and absorption-cooling. The inclusion of both a water-heating and an absorption-cooling plant within the CHP plant is relatively simple, utilising well-known technology and achievable within the CHP spatial boundary.

These technologies obtain their required energy from a direct heat transfer as opposed to indirect, from fossil-fuelled electricity; the latter up to 3 times more inefficient overall The efficiency difference results in as much as 3 times less GHG produced than a straight fossil-fuel/'green' electricity substitution, which in-turn results in 3 times more CERs and 3 times the associated revenue.

Unfortunately there are major questions regarding the feasibility of producing these fluid CHP products. The most pertinent questions are:

- The cost of installing a piping network for CHP fluids.
  In order to maximise the distribution and sale of these products an extensive piping system will be required, the cost of which is high. The cost of piping liquids is less than piping steam but it is still expensive; the price increasing relative to the size of the network required.
- The practicality of retrofitting a piping network for CHP fluids.
  The retrofitting of a piping network in order to reach clients is likely to cause costly production delays and the diversion of valuable client resources e.g. capital and labour.

- The stability of non-electrical CHP energy markets.

  The high cost of the infrastructure required to produce and transport non-electrical CHP products requires the commitment, if not guarantee, of clients to continued purchase of these products. The lifetime of the plant is expected to be a minimum of twenty years and it is expected that many clients will find it difficult to commit to a period as lengthy as this.

The answers to the above feasibility questions, as well as the formulation of the optimal amount of CHP energy contributed to these products, are beyond the scope of this dissertation and should be included in a future study.

Despite the potential shown by other forms of energy produced by the CHP plant, the generation and sale of electricity is relatively free of feasibility issues such as those surrounding the other CHP products.

The prioritisation of electricity generation is validated by the following:

- It can utilise the majority of the available fuel energy
- Expected high demand at a profitable price
- Increasing fossil-fuelled energy prices liable to make the production of CHP electricity ever more profitable
- Easy to transport, national grid
- Transport system already installed, national grid
- No maintenance of transport system, national grid
- Large amount of associated CERs

The amount of energy set aside in this study for processes other then electricity generation is sufficient to cover the sawmill's current process steam requirement. However, an inspection of the process steam system at the sawmill found it to be very inefficient. An efficient system would allow an increase in electricity production, kiln capacity or the introduction of additional technologies such as water-heating, absorption-cooling and others investigated in this study.

In order to maximise plant efficiency and product sales, the CHP plant may have to provide a variety of products. The clientele group may be required to reorganise their production schedules so as to best utilise the available CHP energy.
An example of a possible mix of CHP products is:

- Electricity for internal and external clients
- Water-heating for the surrounding area
- Absorption-cooling for the surrounding area
- Process steam to surrounding plants

4.1.2)Contribution to national renewable energy targets

The South African government has set a renewable energy contribution target for overall national energy consumption of 10 TWh per year by the year 2013. [48] The proposed CHP plant could contribute 106 GWh per year; approximately 1% of the overall national total required.

In addition the government has stipulated that a minimum of 4 TWh per year should be provided by the renewable electricity generation sector. [36] The proposed CHP plant could contribute approximately 1.2% towards this minimum amount, a significant amount for a single independent producer.

4.1.3)'Green' electricity price

A 'green' electricity tariff was negotiated at the World Summit on Sustainable Development in Johannesburg, 2002. An agreement was reached on a price of 50c/kWh based on the then current price of grid-connected wind power. [48]

Currently, any South African grid-connected electricity customer is forced to buy his electricity from either Eskom or their local municipality. The Wholesale Electricity Pricing System (WEPS) largely dictates the price paid for energy in the South African wholesale market and the current price is well below that agreed upon at the World Summit. However, the WEPS price does not consider nor promote the environmental and socio-economic benefits of 'green' electricity.

The World Summit Price of 50c/kWh is currently too high to be economically viable for either Eskom or a municipality and requires a 'subsidy'. This 'subsidy' could potentially be recovered from revenue generated by emission credits whereby the producer would be required to hand over emission credits to the purchaser. However, the rate at which the price of fossil-fuelled power is increasing is higher than that of 'green' power. This is good news for 'green' power producers as it means that their prices will be increasingly competitive, eventually enabling them to benefit from both straight forward electricity sales and emission credit sales.

Public interest in 'green' electricity is increasing due to growing awareness of the problems associated with climate change.

The municipality of Cape Town has recently agreed to purchase 'green' electricity from a local wind farm at 37c/kWh; phase one of the wind farm is expected to be running by mid 2007. The public will be able to purchase this electricity on a voluntary market at a premium of 25c/kWh* above their current electricity price. Despite the high premium, municipality market surveys have shown that a promising number of Cape Town business and residential customers are willing to pay the price in order to reduce atmospheric pollution. However, until the voluntary market is able to completely cover the purchase cost of the municipality, it will be subsidised either through revenue earned via carbon credits or through funding by the Global Environment Fund (GEF). [37]

According to the Cape Town municipality's 'green' energy project manager, further 'green' electricity purchase agreements will be subject to the success of this voluntary market, unless the price is competitive with that of Eskom. [37]

Amatola Green Power (AGP) is a licensed South African energy broker which is also aiming to create a trading market whereby 'green' electricity producers and willing purchasers can trade freely. AGP aim to create a market whereby the electricity price is determined largely by those involved in its specific trading. Unfortunately, this market will initially only be available to large customers and the price is expected to

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* excluding VAT and increasing annually at the rate of national inflation

be only marginally higher than the 19c/kWh offered by Eskom, and not as determined by the 2002 World Summit on Sustainable Development. [45]

This study has utilised a price range derived from that currently offered by Eskom, 19c/kWh, to determine the lower range value of revenue generated from electricity sales over the expected lifetime of the plant. This price is considered to be conservative and for this reason was used to determine the plant's ultimate financial feasibility.

A price range derived from that currently paid by Stellenbosch's bulk electricity consumers has been used to determine the higher range value of revenue generated from electricity sales over the plant's expected lifetime. This price is equivalent to that offered by the Cape Town municipality for the wind farms 'green' electricity

4.1.4)Financial feasibility

The results of the study prove that unless the electricity market experiences major future changes, resulting in prices well below the lowest prices expected, the efficient operation of the proposed CHP plant should see it produce and sell sufficient electricity and associated CERs alone to be feasible and more profitable for the sawmill than if it were to continue with its current residue markets.

There is significant potential for additional CHP revenue through products such as cooling, process steam, water-heating and the associated CERs. However, the success of these products will depend on future market-specific, in-depth, feasibility studies and trade negotiations.

4.1.5)Affect of CHP residue use on the fibreboard plant

All white chips, off-cuts and shavings from the sawmill are presently sold to the fibreboard plant; 53 584 m^3 of pine residues per year. This is 11% of the total residue intake at the fibreboard plant but 58% of the total fuel energy available for the proposed CHP plant. [49]

Based on expected market price increases, the sawmill will generate more revenue from these residues by utilising them as fuel for the CHP plant then it would by selling them to the fibreboard plant. The fibreboard plant would therefore have to purchase the residues at a price significantly higher than normal market value in order to compete with profits obtained from the proposed CHP plant.

It is highly likely that the price increase required will make these residues non-profitable and the fibreboard plant will either source replacement residues elsewhere or lower its residue intake.

According to the plant's materials acquisition manager, the lowering of its residue intake by 11% will be the worst case scenario as it will reduce production output; however, it will not cause the plant to shut down. [49]

4.1.6)Effect on the inhabitants of Stellenbosch

In addition to the products from which the Stellenbosch inhabitants could benefit, the CHP plant will require personnel to run and maintain the plant. The plant will create a variety of jobs from basic-skilled labour through to high-level management.

The 'green' power CHP plant will aid in marketing Stellenbosch as an environmentally friendly city, putting it on the 'green' energy map so to speak.

The CHP plant has potential educational and tourism value due to its association with 'green' power, climate change and CDM.

Despite the national reduction in GHG, the burning of woody residues may add to the overall atmospheric pollution in the local area of Stellenbosch. Stellenbosch is well known for its beautiful setting and the increase in local atmospheric pollution will cause concern.

This concern could be minimised by:

- Educating the public in terms of the plant's contribution to overall GHG reduction
- Replacing the fossil-fuelled process steam, of neighbouring plants, with 'green' steam"

In addition the necessary Social and Environmental Impact Assessment will need to consider this aspect of the plants operation.

4.1.7)Effect on the inhabitants of the West Coast and Agulhas Plains

The collection of WFW residues for combustion in the CHP boiler will result in less wood fuel available for the local inhabitants. However, the extremely large amount of wood fuel available and the low human population densities of both the West Coast and Agulhas Plains will result in no noticeable effect on local fuel requirements.

The use of WFW residues for the CHP plant will create further jobs above those required for the standard government WFW initiative; this will increase the overall income of the local communities.

The WFW areas of concern are in remote rural areas; the communities could possibly negotiate wage agreements with the plant's executive in return for various required supplies to be brought to the communities at a price lower than would otherwise be possible. This could be achieved using the residue trucks returning from the CHP plant to fetch WFW residues.

4.1.8)Decentralisation of electricity supply

The majority of South Africa's electricity is derived from power stations to the north of the country, requiring high voltage transmission lines to carry the power to southern areas of the country. The increasing demand for electricity in South Africa is placing strain on these transmission lines and they will require costly upgrades if they are to handle the future capacity required; the increased production of electricity in southern areas of the country will reduce both dependency on northern power stations and strain on transmission lines.

The proposed Stellenbosch CHP plant will not produce sufficient power to single-handedly relieve the strain on the long-distance transmission lines, but it will make a contribution and, together with other small-to-medium power producers, could have a significant effect on the overall scenario.

4.1.9)CDM and GHG

The two key issues of CDM projects are to promote sustainable development in the host country and to reduce global GHG.

The CHP plant will create a variety of jobs and will produce 'green' power both of which will aid the sustainable development of Stellenbosch, and South Africa as a whole.

The 'green' energy from the CHP plant will replace fossil-fuelled energy reducing global GHG.

The table below contains the list of currently registered or registering South African CDM projects and the proposed amount of annual CER reductions. The table illustrates how, through the production and sale of 42.57 GWh/yr of 'green' electricity alone[†], the proposed Stellenbosch CHP plant will achieve more GHG reductions than any other current CDM project in South Africa.

Table 21: List of registered/registering CDM projects in South Africa

Date registered	*Title*	*Reductions*
06 Mar 06	Lawley Fuel Switch Project	19 159/yr
27 Aug 05	Kuyasa housing energy upgrade	6 580/yr
Requesting Registration	PetroSA Biogas to Energy Project	29 933/yr
Review Requested	Rosslyn Brewery Fuel- Switching Project	10 0941/yr
Proposed project	Stellenbosch 'green' elec. 42.57 GWh/yr	38 313/yr

4.1.10) National sawmill CHP potential

South Africa's sawmills process approximately 5.6 million m^3, 27.7%, of the country's total harvested roundwood.

[†] The proposed CHP plant has the potential to achieve far greater reductions but the electricity market is largely guaranteed and is therefore the figure quoted.

Commercially grown pine species accounts for 4.86 million m^3, 86.5%, the rest is split between the processing of eucalyptus and other hardwoods. [21]
The calorific values of hardwoods, including eucalyptus, are slightly lower than those of commercially grown South African pine. However, for approximating the total energy available from residues of South African sawmills, the difference is insignificant.

There are 47 large sawmills in South Africa, processing 3.81 million m^3, 68%, of the country's total harvested roundwood. [50] The average processing capability of these mills is 81 000 m^3, large enough to utilise steam turbine technology. The rest of the country's roundwood is processed by small and micro-sawmills, each processing less than 15 000m^3 per year and too small to install viable CHP plants.

The Stellenbosch sawmill utilises the standard roundwood processing procedure used in large sawmills throughout the country and therefore can be used as the reference for approximating the national large sawmill CHP potential.
The proposed Stellenbosch CHP plant acquires 598.6 TJ of fuel energy from the process residues of the equivalent of 122 500 m^3 of commercially grown pine per year, this is approximately 3.2% of the national large sawmill capacity.
The data from the Stellenbosch sawmill study have been used to approximate a national sawmill CHP capacity[‡]; the results are in the table below.

Table 22: National sawmill CHP capacity

Processing capacity of sawmills:	3.81 million m^3
Energy available from fuel:	18 139 TJ/yr
Useful output (60-85% eff.):	3.02-4.28 TWh/yr
Electrical output (28% eff., 0.9 load factor):	179 MW, 1.41 TWh/yr

The South African government has set a renewable energy contribution target for overall national energy consumption of 10 TWh per year by the year 2013, with a

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[‡] national capacity: only to be used as a guide since each sawmill would have custom requirements

minimum of 4 TWh per year to be provided by the renewable electricity generation sector. [36] The large sawmills of South Africa have the potential to contribute 42.80% towards the overall national renewable energy target and 35.25% of that required by the renewable electricity sector.

The table below illustrates the potential national sawmill CHP annual revenue from the generation and sale of 'green' electricity and its associated CERs.

Table 23: Annual revenue from electricity and associated CERs (1€:R7.73)

Electricity:	R246 million @ 19.09c/kWh
CERs (electricity):	R133 million @ €15.30/CER
Total:	R371 million

The national revenue generated from sawmill residues is currently approximately R80-R96 million per year. [50] Therefore, the sale of electricity and its associated CERs from South Africa's large sawmills has the potential to increase the total revenue generated from residues by 464%. There is also the additional revenue that could be generated from the sale of other CHP products such as water-heating, cooling and process steam.

5) Conclusions

The efficient operation and management of the CHP plant will enable it to produce and sell sufficient products for it to be feasible. Furthermore it will generate more profit than the sawmill's current residue markets over the same period.

The energy contained within the sawmill's residues is sufficient to produce 47.3 GWh of 'green' electricity per year which, if sold into the national grid, will offset the equivalent of 38 313 tons of carbon dioxide. In addition, there is potential for considerable amounts of additional GHG reductions and revenue through the sale of other CHP products.

The CHP plant will generate more CERs than any other CDM project currently registered, or in the process of registering, in South Africa; potentially making it the most successful CDM project in South Africa in terms of GHG reduction.

It is expected that electricity generation will utilise the majority of the plant's available energy. However, there is significant potential for additional revenue and GHG reductions from other CHP technologies, especially those that could utilise CHP heat as a substitute for electrical energy.

The CHP plant could contribute approximately 1% towards governmental objectives in terms of the renewable energy contribution to overall national final energy consumption by the year 2013.

The CHP plant will utilise woody residues previously sold to the neighbouring fibreboard plant. The fibreboard plant will be forced to source replacement residues elsewhere, but it will not be forced to shut down.

Apart from possible concern over the increase in localised atmospheric pollution caused by the CHP plant, it will have a positive affect on the Stellenbosch inhabitants.

In addition the necessary Social and Environmental Impact Assessment will need to consider this aspect of the plants operation.

The proposed Stellenbosch CHP plant would contribute to the decentralization of power production in South Africa. This would result in lower transmission line losses and reduced need for the upgrading of a struggling South African power transmission system.

The combined effect of the large sawmills of South Africa has the potential to contribute as much as 42.80% towards the Government's 2013 overall national renewable energy target and 35.25% of that required by the renewable electricity sector. The sale of sawmill CHP electricity and associated CERs alone, has the potential to increase the total revenue generated from sawmill residue related products by 464%.

6) Summary

The following tables summarise the CHP plant's technical specifications as well as its process and financial capabilities.

Table 24: General technical specifications of the proposed CHP plant

Processing capacity of sawmill:	122 500 m^3/yr
Energy available from fuel:	598.6 TJ/yr
CHP boiler plant capacity:	45 tons/hr
Turbine capacity:	6 MW
Turbine type:	Condensing
Turbine steam conditions:	35 tons/hr, 45 bar, 450°C superheated
Process steam conditions:	10 tons/hr, 78 840 tons/yr, 10 bar, 180°C
Electricity produced per year:	47.3 GWh or 170.28 TJ
Electricity available to clients:	42.5 GWh or 153.25 TJ
Approximate turnkey price:	R86 - R100 million
NPV of plant construction costs:	R168 - R195 million
Plant installation cost per kW:	R16 667
Overall efficiency:	64%

Table 25: Potential capability of the process steam available from the CHP plant

Wood-drying kilns:	800 m^3 kiln volume	
Distillation:	5.3 $\text{tons}_{\text{alcohol}}$/hr,	41 785 $\text{tons}_{\text{alcohol}}$/yr
Sanitation:	46 895, bottles/hr,	369.72 million bottles/yr
Milk/fruit-juice pasteurisation:	9.5 kilolitres/hr,	74.89 megalitres/yr
Absorption-cooling:	3 979 kWh/hr,	31.37 GWh/yr
Fibreboard production:	12.2 tons/hr,	96 185 tons/yr
Water-heating (1°C -90°C0:	61.2 kilolitres/hr,	482.50 megalitres/yr

Table 26: Potential annual GHG reduction capability of the CHP plant (tCO2eq)

Process	**Current capacity**	**Maximum capacity**
CHP operation	NA	+ 23
Electricity	-5 688	-38 313
And the reductions from one of the following applications of 'green' steam		
- Wood-drying kilns	NA	-7 602
- Distillery and bottling	-1 924	-11 396
- Milk/fruit-juice pasteurisation	NA	-11 396
- Absorption-cooling	NA	-9 414
- Fibreboard production	-6 662	-11 396
- *Average of above 5 uses*	*NA*	*-10 241*
- Water-heating	NA	-44 968

Table 27: Potential annual revenue available from the products of the CHP plant

Electricity	R8.13 - R15.39 million @ (19c–36c)/kWh
Process steam	R4.73 - R7.88 million @ (R60–R100)/ton
Water-heating	R9.54 - R18.06 million @ (1.98c–3.75c)/litre
CERs (electricity)	R4.53 million @ €15.30/CER
CERs (steam average)	R1.21 million @ €15.30/CER
CERs (water-heating)	R5.32 million @ €15.30/CER

Table 28: Potential revenue generated by sawmill and CHP options over 20 years

NPV of sawmill residue sales	R78 million
NPV of CHP electricity sales	R325 - R471 million
NPV of CHP steam sales	R158 – R264 million
NPV of CHP water-heating sales	R383 – R553 million
NPV of CHP electricity CER sales	R59 – R237 million
NPV of CHP process steam CER sales	R16 – R63 million
NPV of CHP water-heating CER sales	R70 – R278 million

7) Recommendations

Further studies should be conducted in the following areas.

1) The thorough investigation of the optimal balance of final energy production taking into account number, type, size and distance to potential clients as well as the costs and logistics of electricity production versus other potential CHP products.

2) The expected emissions that will be produced in the construction and decommission phases; these emissions should be taken into account when calculating the total GHG reduction potential of the plant.

3) The amounts of additional emissions produced in normal sawmill activities due to the introduction of the CHP plant. It is expected that this could only be achieved with any real level of accuracy once the CHP plant is in operation.

4) The expected running costs of the proposed CHP plant.

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The nutrient content of Pinus radiata trees
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Pg 510-522
Found online at: www.forestresearch.co.nz/search.asp
Scion has been recognised as a leader in forestry science since its beginnings as theNew Zealand Forest Research Institute in 1947

71) **Virginia Jumat, 2005**
Personal telephonic conversation
Sales, CTR sawmill, Stellenbosch
Tel: +27(21) 808 7440

72) **Wikipedia.org**
Found online at: www.wikipedia.org/wiki/Fly_ash
Wikipedia is an online encyclopaedia

73) **Eskom**
Found online at: www.eskom.co.za/enviroreport99/Sustain.htm
Eskom is South Africa's largest electricity producer

74) **Eskom**
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Found online at: http://www.eskom.co.za/annreport06/pdf/directorsreport.pdf
Eskom is South Africa's largest electricity producer

Appendices

Appendix 1) Fuel collection and storage techniques

Appendix 1.1) Biomass harvesting

Plantation residues

Trees are typically delimbed and topped in the stand; in order to harvest the maximum amount of biomass residues it would be preferable if the entire felled tree was extracted to the access roads. The felled tree would then be delimbed by static-delimbers and the branches placed in large localised piles; the localised piles would make their collection at a later stage far easier since many areas of the plantations are inaccessible to large vehicles.

Wheeled loaders would collect the piles of biomass for transport to an on-site chipper where they would be chipped and blown into standard container bins, to be fetched when full by road hauling trucks.
Large stand alone or tractor driven chippers would be preferable to smaller in-field chippers due to the higher output and concentration of residues from larger units. [3]

Sawmill residues

The sawmill requires a large bin for accumulating breakages, rejected logs and off-cuts. These can be chipped by a stationery chipper and then transported to the CHP combustion chamber.
The sawmill currently uses conveyor systems to transport the sites' woody residues to the required areas; these same systems could be used for the accumulation and transportation of residues to the CHP boiler.

The present conveyor systems in use are:

- Bark conveyor system whereby the bark, which is currently accumulated at the debarker, is transported to the boiler via an open conveyor.
- Sawdust conveyor system whereby sawdust from the sawmill is fed into the sawmill boilers.
- White chip conveyor system whereby all white chips and off-cuts are transported to the neighbouring fibreboard factory. [3]

Working-For-Water residues

The alien species required to be removed through the WFW programme are mainly Acacia species originating from Australia. [22]

The technology for harvesting these residues has already been in place for several years and harvesting teams consist of operator/assistant pairs. A typical harvest procedure would be for a brushcutter operator and an assistant to cut and sort trees into windrows. They would be followed by a chainsaw operator who would fell the larger diameter trees and then reduce the timber into manageable lengths. [3]

In order to use this resource for the CHP plant it will be necessary to implement new technologies to accumulate and chip the woody biomass. It has been suggested that a high-side "sugar cane" type trailer should traverse the windrows collecting the biomass before taking it to the access roads where it can be chipped. [3]

Appendix 1.2) Biomass transport

The transport of residues from both the plantations and WFW plains can be divided into two stages; a primary and a secondary stage.

The primary stage is when the tree has been felled and requires transport to the main access roads (roadside or landing). This is typically achieved using off-road-terrain going vehicles such as 4×4 tractors and off-road terrain loaders. [38]

The secondary stage is the transport of the residues and timber to the sawmill site; typically performed by road hauling trucks. [38]

Appendix 1.3) Biomass receiving, handling, storage and feeding mechanisms

The residues arriving from the plantations and WFW programme would need to be weighed and sent to covered storage utilising a rapid and efficient process. A practical method would be the use of a weigh bridge and a rapid residue sampling process. Many sawmills already use weighbridges to weigh incoming timber, a laboratory to test moisture content, chip size, impurities and calorific value would need to be installed for fuel quality control as well as allowing the option of paying the supplier on an energy content basis. There is a software package available and used by biomass CHP plants in Europe which assists in managing biomass stock; namely 'Biomass Manager'. [3]

In order to ensure continued CHP production, biomass plants generally ensure that there is a fuel safety stock buffer of at least a few days. The climate of South Africa is such that the biomass residues could be stored outside, but undercover in order to maintain relatively low moisture content. In order to reduce the risk of spontaneous combustion biomass piles should not exceed 7-8 metres in height. [3]

Wheeled front-end loaders are used for unloading timber trucks, and could quickly exchange the timber grab for a bucket to offload these residues. The residues could be placed either on stock piles or on conveyor systems to be taken to the combustion chamber. [38]

The sawmill currently uses conveyor systems to transport white woodchips to the neighbouring fibreboard plant, these same conveyor systems could be used to transport chips from storage to the combustion chamber. [38]

Appendix 2) Biomass fuel accounting

Appendix 2.1) Pinus residues

The calorific value that corresponds most closely with the conditions of practical fuel combustion is the net calorific value this is because water in the combustion process will generally be in the gaseous state. The difference between net and gross calorific value is the latent heat of evaporation of the water at the reference temperature at either the reference pressure or volume. [34]
The net calorific value can thus be deduced from the gross calorific value and the composition of the fuel in terms of moisture and hydrogen; the hydrogen will combust to water. [34]

Calculation set 1: Net calorific values of pinus residues

$$\mathrm{GCV}_{\mathrm{dry}} = \frac{\mathrm{GCV}_{\mathrm{moist}} \times (100 + m)}{100}$$

$\mathrm{GCV}_{\mathrm{dry}} = \mathrm{NCV}_{\mathrm{dry}}$

$$\mathrm{NCV}_{\mathrm{moist}} = \frac{(100 \times \mathrm{GCV}_{\mathrm{dry}} - 22 \times \mathrm{h} - 2.4 \times \mathrm{m})}{(100 + \mathrm{m})}$$

Where:
W = percentage by mass of water in fuel
m = moisture content (%)
h = 6% (for wood)
NCV = Net Calorific Value
GCV = Gross Calorific Value [34]

Calculating the net calorific value of the pinus residues at 12% moisture content
$\mathrm{GCV}_{\mathrm{pinus}}$ at 12% moisture content = 20.4 MJ/kg [34]

$$\mathrm{GCV}_{\mathrm{dry}} = \frac{20.4 \times (100 + 12)}{100} = 22.85 MJ/kg$$

$\mathrm{GCV}_{\mathrm{dry}} = \mathrm{NCV}_{\mathrm{dry}}$

$$\mathrm{NCV}_{12\%\,\mathrm{moist}} = \frac{(100 \times 22.85 - 22 \times 6 - 2.4 \times 12)}{(100 + 12)} = 18.96 MJ/kg$$

Using the same equations as for those used above, the net calorific values of the pinus residues for the other various moisture contents most likely to occur at the plant were calculated to be:

- 0% moisture content: 22.85 M J/kg
- 12% moisture content: 18.96 M J/kg
- 47% moisture content: 13.88 M J/kg

"Moisture content (MC) is a measure of how much water is in a piece of wood relative to the wood itself. MC is expressed as a percentage and is calculated by dividing the weight of the water in the wood by the weight of that wood if it were oven dry. For example, 200% MC means a piece of wood has twice as much of its weight due to water than to wood." [52]

Calculation set 2: Approximate densities and moisture contents of pinus residues

$$m = \frac{M_{water}}{M_{dw}}$$ [52]

Rearranging, $M_{water} = m \times M_{dw}$

$M_{water} = M_{ww} - M_{dw}$

Equation 1 = Equation 2

Therefore, $m \times M_{dw} = M_{ww} - M_{dw}$

Rearranging, $M_{dw} = \frac{M_{ww}}{1 + m}$

Where:

m = moisture content (%)
M_{dw} = mass of dry wood
M_{ww} = mass of wet wood
M_{water} = mass of water

The density of the pinus residues with 12% moisture content is 611 kg/m^3 [34], thus the density of wood with 0% moisture content will be 545.54 kg/m^3.
(611 kg/m^3 ÷ (1 + 0.12) = 545.54 kg/m^3)

Thus, the moisture content of pinus residues with a density of 800 kg/m^3 is 46.6%
((800 kg/m^3 – 545.54 kg/m^3) ÷ 545.54 kg/m^3) = 0.466)

The density of pinus residues at the moisture contents relevant to this study were calculated to be:

- 0% moisture content: 545.5 kg/m^3
- 12% moisture content: 611kg/m^3
- 47% moisture content: 800 kg/m^3
- 83% moisture content: 1 000 kg/m^3

Calculation set 3: Energy available from pinus residues

$\text{Energy}_{\text{residues}}$ (J/yr) = volume (m^3/yr) × density (kg/m^3) × NCV (J/kg)

Where:

$\text{Energy}_{\text{residues}}$ = energy available after combustion of fuel
volume = volume of residues available
density = density of residues
NCV = net calorific value of residues

Table 29: Energy available from pine residues

Biomass fuel accounting							
Energy available from pine plantations				**Density**	**Gross CV**	**Net CV**	**GJ/year**
Material	**% of total harvest**	**% of each process**	**m3/year**	**(kg/m3)**	**(MJ/kg)**	**(MJ/kg)**	**(NCV)**
Total pine harvest	100.00%	100.00%	121521.33				
CTR's total pine harvest in forest	***74.18%***	***100.00%***	***90140.85***				
Top, branches and foliage	-4.45%	-6.00%	-5408.451	800	15.65	13.88	-60055.44
Stumps, breakages	-7.42%	-10.00%	-9014.085				
Sawdust	-3.71%	-5.00%	-4507.0425				
Other market (eg. Poles)	-5.93%	-8.00%	-7211.268				
Volume remaining for logyard	***52.67%***	***71.00%***	***64000.00***				
Note: At this stage it appears that the sawmill purchases additional debarked logs ready for the wetmill.							
Amount purchased = 25600 m3 (100 m3 x 256days)							
Purchase of private pine	***21.07%***		***25600.00***				
Residues left in private plantations	*4.76%*		*5780.48*	800	15.65	13.88	
Logyard							
Volume to logyard	***73.73%***	***100.00%***	***89600.00***				
Bark	-7.37%	-10.00%	-8960.0004	800	15.65	13.88	-99491.84
offcuts	-2.21%	-3.00%	-2688.0001	800	15.65	13.88	-29847.55
Volume remaining for wetmill	***64.15%***	***86.48%***	***77952.003***				
Wetmill							
Volume to wetmill	***64.15%***	***100.00%***	*77952.003*				
Slabs, edging	-8.98%	-14.00%	-10913.28	800	15.65	13.88	-121181.07
White chips	-12.83%	-20.00%	-15590.401	800	15.65	13.88	-173115.81
Sawdust and fines	-4.81%	-7.50%	-5846.4002	800	15.65	13.88	-64918.43
Volume remaining for wetmill	***37.53%***	***50.59%***	***45601.9218***				
Kilns							
Volume to kilns	***37.53%***	***100.00%***	***45601.9218***				
shrinkage in volume (kilns)	-1.88%	-5.00%	-2280.0961				
Volume remaining for drymill	***35.65%***	***35.65%***	***43321.8257***				
Drymill							
Volume to drymill	***35.65%***	***100.00%***	***43321.8257***				
Sawdust and fines	-1.43%	-4.00%	-1732.873	611	20.4	18.96	-20074.57
Offcuts	-1.78%	-5.00%	-2166.0913	611	20.4	18.96	-25093.21
Volume remaining as product	***32.44%***	***100.00%***	*40717*				
Total energy available from pine plantation residues (GJ/yr)							**593777.9**

Appendix 2.2) WFW residues

The net calorific values of the alien biomass were calculated in the same way as that for the pinus biomass.
The net calorific values of the alien biomass were found to be:

- 0% moisture content: 21.53 M J/kg
- 12% moisture content: 15.73 M J/kg

Due to the similarity of the invasive alien acacia species and the lack of density data it was decided to use the average density of a.melanoxylon for all species.
The average density of a.melanoxylon at 12% moisture content is 670 kg/m^3. [34]

Table 30: Energy available from alien biomass

Energy available from alien biomass				**Density**	**Gross CV**	**Net CV**	**GJ/year**
Area	**Dimensions**		**Tons**	**(kg/m^3)**	**(MJ/kg)**	**(MJ/kg)**	**(NCV)**
West coast aliens	>50mm		169.45	670.00	19.22	15.73	
	25-50mm		189.77	670.00	19.22	15.73	
	<25mm		460.55	670.00	19.22	15.73	
	Annual cut on 12yr cycle		68.313	670.00	19.22	15.73	-1074.56
Agulhas plains	>50mm		764.87	670.00	19.22	15.73	
	25-50mm		698.02	670.00	19.22	15.73	
	<25mm		1389.39	670.00	19.22	15.73	
	Annual cut on 12yr cycle		237.69	670.00	19.22	15.73	-3738.86
Total energy available from alien biomass residues (GJ/yr)							**4813.43**

[3]

The total energy available after combustion of both pine and WFW residues is equal to 598.6 TJ per year.

Appendix 3) Fuel chemical characteristics

In order to accurately model the thermal characteristics of the boiler and turbine Alstom/John Thompson was sent the following information detailing the type of fuel, likely consistency, moisture content, net and gross calorific values of fuel, amount of fuel as well as the chemical composition of the fuel.

Chemical content by mass of Pinus radiata (0% moisture content)

Carbon	51%
Hydrogen	6.1%
Oxygen	42.3%
Nitrogen	0.1%
Sulphur	0.02%
Chlorine	0.01%
Ash	0.5%
Volatiles	81.8%

Chemical content by mass of Pinus radiata (12% moisture content)

Carbon	44.88%
Hydrogen	5.37%
Oxygen	37.22%
Nitrogen	0.09%
Sulphur	0.02%
Chlorine	0.01%
Ash	0.44%
H_20	12.00%
Volatiles	71.98%

Chemical content by mass of Pinus radiata (47% moisture content)

Carbon	27.03%
Hydrogen	3.23%
Oxygen	22.42%
Nitrogen	0.05%
Sulphur	0.01%
Chlorine	0.01%
Ash	0.27%
H_20	47.00%
Volatiles	43.35%

Approximate chemical content by mass of Alien species (0% moisture content)

Carbon	49.3%
Hydrogen	6.2%
Oxygen	43.9%
Nitrogen	0.22%
Sulphur	0.04%
Chlorine	0.01%

[34]

Ash	0.7%
Volatiles	83.8%

Approximate chemical content by mass of Alien species (12% moisture content)

Carbon	43.38%
Hydrogen	5.46%
Oxygen	38.63%
Nitrogen	0.19%
Sulphur	0.04%
Chlorine	0.01%
Ash	0.62%
H_20	12.00%
Volatiles	73.74%

[34]

The requirements of the plant were stated as:

1) Electrical generation: approximately 6 MW
2) Process steam requirement:
    - Pressure 10 bar
    - Temperature ≥ 180 °C, Note:180 °C is the temperature of saturated steam at 10 bar
    - Flow rate 10 tons/hr.

Appendix 4) Energy available from combustion

Calculation set 4: Power available from combustion of residues

$$Power_{combustion} = \frac{Energy_{residues}}{\frac{seconds}{yr} \times availability\,factor}$$

Where:

$Power_{combustion}$ = energy available after combustion of residues

$Energy_{residues}$ = energy available after combustion (GJ/yr)

Availability factor = the percentage of the year that the plant is operational

Therefore, the combustion power for a 90% plant availability factor is:

$Power_{combustion} = 598\ 591.35$ GJ/yr $\div (31.536 \times 10^6$ seconds/yr $\times 0.9)$

$Power_{combustion} = 21.09$ MJ/s = 21.09 MW

Overall efficiencies of CHP plants are regularly between 60-85%, typical energy splits would be 25% electricity generation efficiency and 60% process steam generation. [18]

Since electricity generation at the proposed Stellenbosch CHP plant is the priority, it is believed that an electrical generation efficiency of 25% percent is possible. Therefore, it is estimated that there is sufficient biomass to generate 5.3 MW or 41.57 GWh of electricity per year.

(21.09 MW × 0.25 = 5.3 MW)

Plant specifications received from Alstom/John Thompson:

- Turbine capacity: 6MW
- Turbine type: Condensing
- Boiler capacity: 45 tons/hr
- Turbine steam conditions: 35 tons/hr, 45 bar, 450°C superheated
- Process steam conditions: 10 tons/hour, 10 bar, 180°C
- Approximate turnkey price: R86 - R100 million
- Electricity produced per year: 47.3 GWh or 170.28 TJ [35]

Calculation set 5: Process steam available per year

Process steam per year = tons/hr × hrs/yr × availability factor

Therefore the amount of steam available per year, 90% plant availability factor is:

Process steam per year = 10 tons/hr × (24 hrs/day × 365 days/yr) × 0.9

Process steam per year = 78 840 tons/yr

Calculation set 6: Energy extractable from process steam

$Energy_{Process} = M_{process\ steam} \times (hg_1 - hf_2)$

Where:

$Energy_{Process}$ = total energy extractable from process steam (kJ/yr)
$M_{process\ steam}$ = mass of process steam produced per year, 78 840 tons/yr
hg_1 = the specific enthalpy of dry saturated steam at 10 bar, 2 777 kJ/kg
hf_2 = the specific enthalpy of feedwater at 1 bar and at 25°C, 104.75 kJ/kg

Therefore, the total amount of energy potentially available from the process steam per year, excluding losses, is:

$Energy_{Process} = 78\ 840 \times 10^3\ kg/yr \times (2\ 777 - 104.75)\ kJ/kg = 210.68\ TJ/yr$
$Energy_{Process} = 210.68 \times 10^9 \text{kJ} \div 3600 \text{ kJ/kWh} = 58.52\ GWh/yr$

Calculation set 7: Potential efficiency of proposed Stellenbosch CHP plant

$$Eff_{CHP\ plant} = \frac{Energy_{electricity} + Energy_{process\ steam}}{Energy_{residues}}$$

Where:

$Eff_{CHP\ plant}$ = potential efficiency of proposed Stellenbosch CHP plant
$Energy_{electricity}$ = electricity produced per year, 170.28 TJ/yr
$Energy_{process\ steam}$ = total energy in process steam, 210.68 TJ/yr
$Energy_{residues}$ = energy available after combustion, 598.6 TJ/yr

Therefore the potential efficiency of proposed Stellenbosch CHP plant is:

$Eff_{CHP\ plant} = (170.28 \text{ TJ} + 210.68 \text{ TJ}) \div 598.6 \text{ TJ}$
$Eff_{CHP\ plant} = 0.6364$ or 63.64%

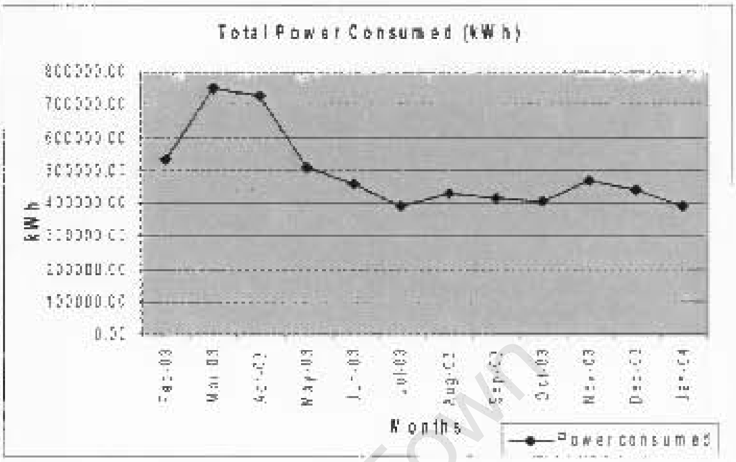
Appendix 5) Electricity required

Appendix 5.1) Distillery plant's electricity demand

This is the demand at the nearby distillery site. [53]

Table 31: Energy consumption of the distillery

Month	Year	kWh
February	2003	531600
March	2003	749300
April	2003	726200
May	2003	508700
June	2003	460400
July	2003	391400
August	2003	430400
September	2003	415900
October	2003	404900
November	2003	470700
December	2003	438600
January	2004	390700



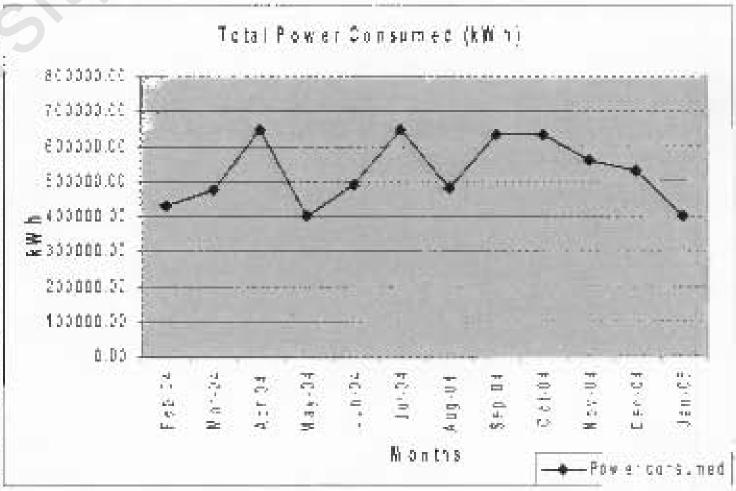
The total electricity consumption from February 2003 to February 2004 is equal to 5.921 GWh. The peak consumption period is from February to June. The average demand of the peak month assuming an average of 26 working days per month and 12 working hours per day is approximately 2.4 MW.

Appendix 5.2) Sawmill plant's electricity demand

This is the demand at the sawmill site. [54]

Table 32: Energy consumption at the sawmill

Month	Year	kWh
February	2004	432000
March	2004	472000
April	2004	648000
May	2004	400000
June	2004	488000
July	2004	648000
August	2004	480000
September	2004	632000
October	2004	632000
November	2004	560000
December	2004	528000
January	2005	400000



The total electricity consumption from February 2003 to February 2004 is equal to 6.32 GWh. For the majority of the year there is no definite peak consumption period.

monthly consumption is generally irregular. However, consumption remains relatively high between September and December.

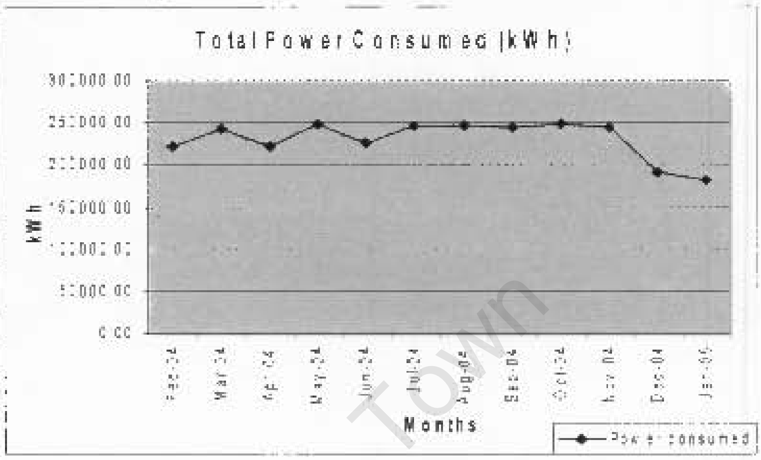
The average demand of the peak month assuming an average of 26 working days per month and 12 working hours per day is approximately 2.1 MW.

Appendix 5.3) Fibreboard plant's electricity demand

This is the demand at the fibreboard plant site. [55]

Table 33 : Energy consumption of the fibreboard plant

Month	Year	kWh
February	2004	221018.7
March	2004	241872.94
April	2004	221172.04
May	2004	247671.98
June	2004	224768.56
July	2004	246554.33
August	2004	246453.04
September	2004	244456.18
October	2004	249115.52
November	2004	245498.02
December	2004	190135.8
January	2005	181670.85



The total electricity consumption from February 2004 to February 2005 is equal to 2.76 GWh. From February to November, monthly consumption varies between 2.0 GWh and 2.5 GWh per month, in December and January consumption drops to approximately 1.75 GWh per month. The average demand of the peak month assuming an average of 26 working days per month and 12 working hours per day is approximately 0.8 MW.

Appendix 6) Process steam applications; capacity required and achievable

The amount of steam proposed to be set aside for process steam is 10 tons per hour, 78 840 tons per year, dry saturated at 10 bar.

Appendix 6.1) Wood-drying kilns

Appendix 6.1.1) Wood-drying kilns; capacity required

The Stellenbosch sawmill's wood-drying kilns have a current capacity of 72 m^3 [32] and use approximately 10 tons/hr of saturated steam at 9 bar, consuming approximately 30 GWh of energy per year. [51]

The Stellenbosch sawmill's wood-drying kilns run for 82 hours a drying cycle and a further 8 hours to empty and restock. Therefore the kiln requires 90 hours for a full cycle. [32] However, the sawmill's working hours are from 8 o'clock in the morning to 5 o'clock in the evening. Therefore, in practice a cycle starting at 8 in the morning on day one would end at 6 in the evening on day 4, and day 5 would be used to empty and restock the kiln, with the next cycle starting at 8 in the morning the following day. Thus, each cycle is effectively 5 days long.

Appendix 6.1.2) Wood-drying kilns; capacity achievable

Tests were conducted in the USA to deduce the energy required for various kiln sizes to reduce the moisture content in their common timber species 'Southern Pine''. Southern Pine has very similar properties to Pinus Radiata and Pinus Pinaster, the two species used at the Stellenbosch sawmill. [38]
In the table below are the original test values of the energy required to reduce the moisture content from 105% to 10%, removing approximately 520 kg of water per cubic metre The standard moisture content of kiln-dried board timber is 12%, thus it is typical for kilns to be set to achieve a moisture content of 10% in order to ensure an acceptable standard. . The test kilns ran for 82 hours per cycle with a kiln temperature of 87.7°C.

Table 34: Energy required to reduce moisture content in wood for full kiln cycle

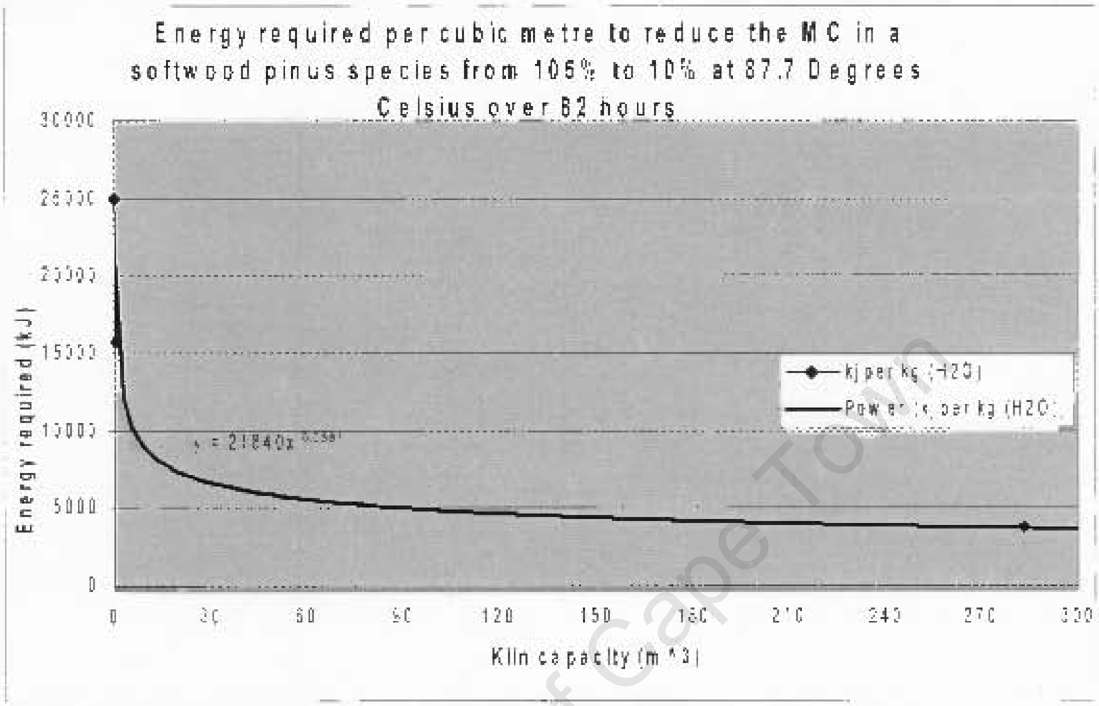
Energy required to reduce the MC of Southern Pine from 105% to 10%					
Kiln volume per surface area	**Kiln size board feet**	**Kiln size m^3**	**btu per lb (H_20)**	**kWh per kg (H_20)**	**kJ per kg (H_20)**
0.3	3*	0.007	10600**	683276000	24602.60
1.3	120 *	0.283	6770**	436394200	15713.17
3	120000 *	283.200	1630**	105069800	3783.23

*1 board feet = 2.36×10^{-3} m^3
**1 btu/lb = 2.32 kJ/kg

[24]

Although the above data is useful, the kiln sizes tested do not represent a wide enough range of capacity. In order to determine the energy requirements for a larger range of kiln sizes it was necessary to plot the initial points on a chart and then determine the equation that best described the energy requirements per cubic metre.

Figure 16: Wood-kiln energy required per m^3 of capacity



Calculation set 8: Wood-kiln energy required per m^3 of capacity

The equation that was found to best describe the energy requirements is:

$Y = 21\,840 \times X^{-0.2581}$

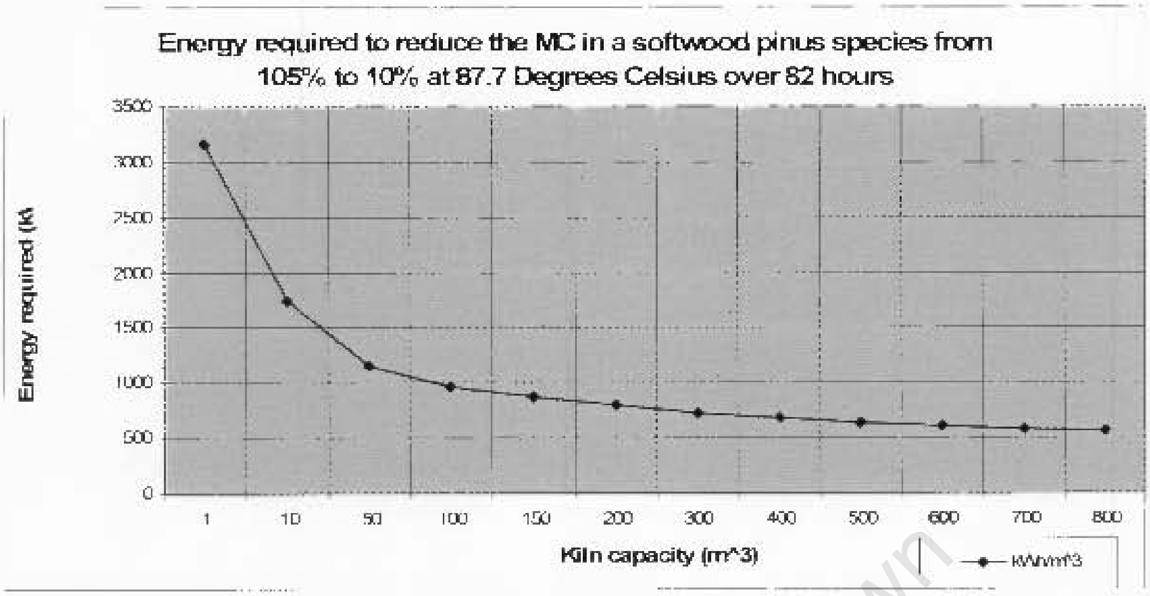
Where:

Y= energy required (kJ/kg_{H2O})

X = kiln capacity (m^3)

Kiln sizes varying from 1 m^3 to 800 m^3 were substituted into the equation and the energy required was determined. The graph below illustrates how with increasing kiln capacity the energy required per m^3 of timber decreases; the ratio of kiln volume to kiln surface area increases with an increase in kiln capacity and a subsequent increase in ratio of useful heat energy to heat losses.

Figure 17: Energy required to reduce the moisture content in wood



The energy required to reduce the moisture content in wood is highly dependent on the size and type of kiln construction but direct steam-heated kilns can achieve 95% efficiency; the range of a well-designed system is between 60-95%. [56]

Calculation set 9: Steam required for current sawmill wood-kiln capacity

Specific enthalpy of evaporation at 10 bar (hfg_1):	2 014 kJ/kg
Reduction in moisture content:	520 kg/m^3
Maximum efficiency:	95%
Low efficiency:	60%
Kiln cycles per year:	65
Hours per cycle:	82

Y = 21 840 × X$^{-0.2581}$
Where:
Y= energy required (kJ/kg$_{H2O}$)
X – kiln capacity (m^3)

Energy required for 72 m^3 kiln capacity:

$$Energy_{reqd} = 21\,840 \times 72^{-0.2581} = 7\,242\ \frac{kJ}{kg_{H_2O}}$$

$$Energy_{reqd} = \frac{7\,242\left(\frac{kJ}{kg}\right)\times\left(520\,\frac{kg_{h2o}}{m^3}\times 72\,m^3\right)\times 65\,\frac{cycles}{yr}}{3\,600\,\frac{kJ}{kWh}} = 4.9\times10^6\,\frac{kWh}{yr}$$

$Energy_{reqd}$ – 4.9 GWh/yr

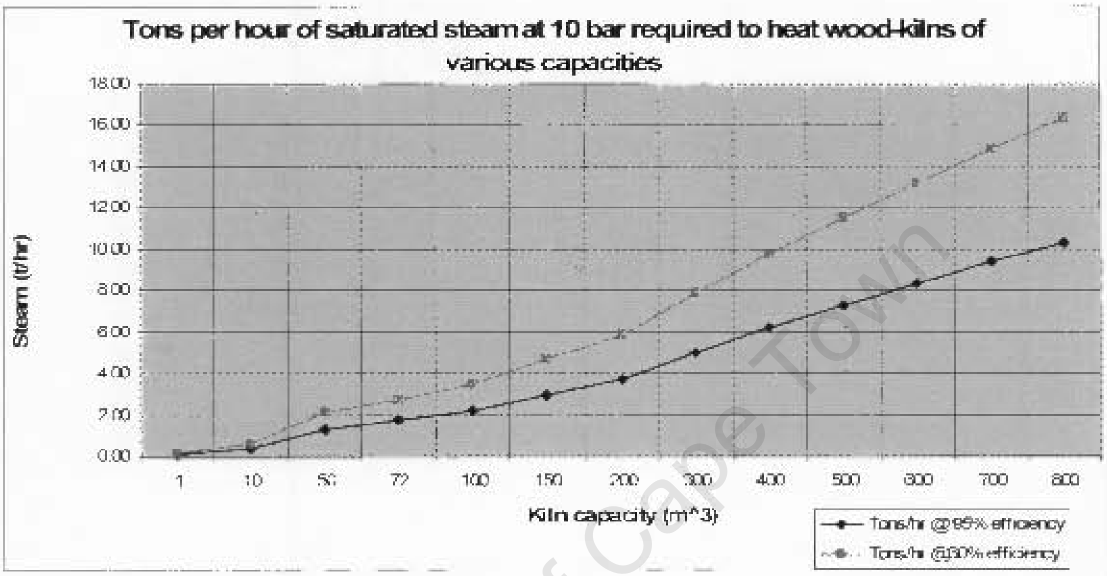
Steam required for 72 m^3 kiln @ 95% efficiency:

$$Steam_{reqd} = \frac{4.9 \times 10^{6}\left(\frac{kWh}{yr}\right) \times 3\,600\ \frac{kJ}{kWh}}{2014\ \frac{kJ}{kg}} \times \frac{1}{0.95} \times \frac{1}{65\ \frac{cycles}{yr} \times 82\left(\frac{hrs}{cycle}\right)} = 1\,730\ \frac{kg}{hr}$$

$Steam_{reqd} = 1.73$ tons/hr

Steam required for 72 m^3 kiln @ 60% efficiency – 2.74 tons/hr

Figure 18: Kiln capacity achievable from process steam supplied



Taking into consideration high and low kiln efficiencies the following kiln capacities are achievable:

- Current capacity of 72 m^3 (95% eff.) = 1.7 tons/hr of saturated steam at 10 bar
- Current capacity of 72 m^3 (60% eff.) = 2.7 tons/hr of saturated steam at 10 bar
- Maximum (10 tons/hr of saturated steam at 10 bar, 95% eff.) ≈ 800m^3
- Minimum (10 tons/hr of saturated steam at 10 bar, (60% eff.) ≈ 400m^3
- The CHP plant is expected to have an availability factor of 90%, therefore the steam would be available for the kilns for approximately 65 cycles

Appendix 6.2) Distillation

Appendix 6.2.1) Distillation; capacity required

Steam is used in the distillation process at the distillery in Stellenbosch; alcohol is only produced for four months of the year, January through to May. [26]
The distillery has a maximum steam usage of 5 tons per hour of saturated steam at 2 bar, 12 hours a day, 26 days a month, for the period January through to May.
The steam coil units produce approximately 0.518 kg of alcohol per kg of steam; approximately 1.93 kg of saturated steam at 2 bar per kg of alcohol [26]

Appendix 6.2.2) Distillation; capacity achievable

Process steam is to be supplied at 10 bar, dry saturated. The distillation steam coils operate at 2 bar. In order to reduce the steam down to this pressure the high-pressure steam would be passed through a throttling valve, this is an adiabatic process meaning the specific enthalpy of the steam does not change. However, the steam will become superheated and superheated steam does not afford the same heat transfer capability as saturated steam. Superheated steam requires a larger heat exchanger surface for the same degree of heat transfer as that of saturated steam. However, for the sake of simplistic calculation the heat transfer complications associated with superheated steam have been neglected in the calculations of distillation capacity.

Calculation set 10: Enthalpy after throttling for distillation

$hg_2 = hf_2 + (x \times hfg_2)$

$hg_1 = hg_2$

$$hfg_2 = \frac{hg_1 - hf_2}{x}$$

Where:

hg_1:	Specific enthalpy of dry saturated steam at 10 bar	2 777 kJ/kg
hg_2:	Specific enthalpy after throttling to 2 bar	
hf_2:	Specific enthalpy of water at 2 bar, 120.6°C	505 kJ/kg
hfg_{2bar}:	Specific enthalpy of evaporation at 2 bar	2 202 kJ/kg
x:	dryness fraction, which cannot physically be greater than 1	

Therefore,

$$hfg_2 = \frac{\left(2\,777\frac{kJ}{kg} - 505\frac{kJ}{kg}\right)}{x} = \frac{2\,272\frac{kJ}{kg}}{x}$$

$$x = \frac{2\,272\frac{kJ}{kg}}{2\,202\frac{kJ}{kg}} = 1.03 \qquad x \leq 1\text{, therefore superheated after throttling}$$

Therefore, the specific enthalpy of evaporation after throttling (hfg_2) = 2 272 kJ/kg

Calculation set 11: Distillation capacity achievable

$$Disillation\ capacity = Distillation_{2bar} \times \frac{hfg_2}{hfg_{2bar}}$$

Where:

Distillation capacity:	Capacity expected from proposed CHP process steam	
$\text{Distillation}_{2bar}$:	Existing capacity at distillery	
hfg_{2bar}:	Specific enthalpy of evaporation at 2 bar,	2 202 kJ/kg
hfg_2:	Specific enthalpy of evaporation after throttling,	2 272 kJ/kg

$$Distillation\ capacity = 0.518\ \frac{kg_{alcohol}}{kg_{steam}} \times \frac{2\,272\ \frac{kJ}{kg}}{2\,202\ \frac{kJ}{kg}} = 0.534\ \frac{kg_{alcohol}}{kg_{steam}}$$

Distillation capacity = 0.534 tons of alcohol per ton of saturated steam at 10 bar

The distillation capacities achievable from the proposed CHP process steam are:

- Current capacity using 5 tons of saturated steam per hour, at 2 bar: 2.59 tons of alcohol per hour
- Maximum capacity using 10 tons of saturated steam per hour, at 10 bar: 5.34 tons of alcohol per hour; 0.534 tons per ton steam
- Maximum capacity using 78 840 tons of saturated steam per year, at 10 bar: 42 101 tons of alcohol per year

Appendix 6.3) Sanitation

Appendix 6.3.1)Sanitation; capacity required

Steam is used at the distillery in Stellenbosch to clean equipment and product bottles. Data detailing the exact amount of steam used for the various types of equipment at the distillery site were not available. Therefore, it became necessary to estimate the level of steam use according to the steam pipe pressures and assuming a steam velocity through the pipes of 30 m/s. [57]

Bottle washing

The distillery in Stellenbosch requires saturated steam, at 2 bar, to sanitise 10 000, 750 ml bottles per hour; 4 545, 750 ml bottles per ton of steam. [58]
1 × 100mm steam pipe, steam pressure approximately 4 bar.
Appropriate steam flow equal to 2 196 kg/hr. [39]

CIP

There are various CIP points around the plant, these are generally 50 mm pipes with an operating pressure of approximately 2 bar. It is assumed that there will not be more than one such point used at any one time.
These points should be fitted with upstream pressure monitoring valves to ensure they do not drop the boiler pressure significantly.
The appropriate steam flow for a pipe of this diameter and pressure is 245 kg/hr. [39]

Approximate total steam required for sanitising: 2 441 kg/hr of saturated steam at 2 bar.

Appendix 6.3.2)Sanitation; capacity achievable

The temperature of saturated steam at 10 bar is 180°C, the temperature required for sanitation to meet legal standards is 84°C. [27] Therefore, all of the process steam available exceeds that required for sanitation.

The sanitation system operates at 2 bar. In order to reduce the steam down to this pressure the high-pressure steam would be passed through a throttling valve, this is an adiabatic process meaning the specific enthalpy of the steam does not change. However, the steam will become superheated and superheated steam does not afford the same heat transfer capability as saturated steam. Superheated steam requires a larger heat exchanger surface for the same degree of heat transfer as that of saturated steam. However, for the sake of simplistic calculation the heat transfer complications associated with superheated steam have been neglected in the calculations of sanitation capacity.

Calculation set 12: Sanitation capacity achievable

$$Sanitation\ capacity = Process\ steam \times Sanitation_{2bar} \times \frac{hfg_2}{hfg_{2bar}}$$

Where:

Sanitation capacity: Capacity expected from proposed CHP process steam
$Sanitation_{2bar}$: Existing capacity at bottling plant
hfg_{2bar}: Specific enthalpy of evaporation at 2 bar, 2 202 kJ/kg
hfg_2: Specific enthalpy of evaporation after throttling, 2 272 kJ/kg

$$Sanitation\ capacity = 4\ 545\ \frac{bottles}{ton\ of\ steam} \times \frac{2\ 272\ \frac{kJ}{kg}}{2\ 202\ \frac{kJ}{kg}} = 4\ 689.48\ \frac{bottles}{ton\ of\ steam}$$

Sanitation capacity = 4 689.48, 750ml bottles per ton of saturated steam at 10 bar

The sanitation capacities achievable from the proposed CHP process steam are:

- Current capacity using 2.2 tons of saturated steam per hour, at 2 bar:
  10 000, 750 ml bottles per hour; 4 545, 750 ml bottles per ton of steam
- Maximum capacity using 10 tons of saturated steam per hour, at 10 bar:
  46 895, 750 ml bottles per hour; 4 689.48, 750ml bottles per ton of steam
- Maximum capacity using 78 840 tons of saturated steam per year, at 10 bar:
  369.68 million, 750 ml bottles per year

Appendix 6.4) Milk and fruit-juice pasteurisation

Appendix 6.4.1) Pasteurisation; capacity required

A well known pasteurisation plant in South Africa produces 924 litres of milk and fruit juice products per ton of saturated steam at 2 bar; the steam is produced by a coal boiler. [29]

Appendix 6.4.2) Pasteurisation; capacity achievable

The temperature of saturated steam at 10 bar is 180°C, the highest temperature required in the pasteurisation process is 144°C [28]; easily achievable from a well designed heat exchanger. Therefore, all of the process steam available exceeds that required for pasteurisation.

The pasteurisation system operates at 2 bar. [28] In order to reduce the steam down to this pressure the high-pressure steam would be passed through a throttling valve, this is an adiabatic process meaning the specific enthalpy of the steam does not change. However, the steam will become superheated and superheated steam does not afford the same heat transfer capability as saturated steam. Superheated steam requires a larger heat exchanger surface for the same degree of heat transfer as that of saturated steam. However, for the sake of simplistic calculation the heat transfer complications associated with superheated steam have been neglected in the calculations of pasteurisation capacity.

Calculation set 13: Pasteurisation capacity achievable

$$\text{Pasteurisation capacity} = \text{Pasteurisation}_{2bar} \times \frac{hfg_2}{hfg_{2bar}}$$

Where:

Pasteurisation capacity: Capacity expected from proposed CHP process steam

$\text{Pasteurisation}_{1bar}$: Existing capacity at pasteurisation plant

hfg_{2bar}: Specific enthalpy of evaporation at 2 bar 2 202 kJ/kg

hfg_2: Specific enthalpy of evaporation after throttling, 2 272 kJ/kg

$$\text{Pasteurisation capacity} = 924\ \frac{litres}{ton\ of\ steam} \times \frac{2\,272\ \frac{kJ}{kg}}{2\,202\ \frac{kJ}{kg}} = 952.53\ \frac{litres}{ton\ of\ steam}$$

Pasteurisation capacity = 952.53 litres per ton of saturated steam at 10 bar

The milk/fruit-juice pasteurisation capacities achievable using the proposed CHP process steam are:

- Current capacity per ton of saturated steam at 1 bar: 924 litres of product
- Maximum capacity using 10 tons of saturated steam per hour, at 10 bar: 9 525 litres of product per hour; 952.53 litres of product per ton steam
- Maximum capacity using 78 840 tons of saturated steam per year, at 10 bar: 75.10 million litres of product per year

Appendix 6.5) Absorption-cooling

Appendix 6.5.1)Absorption-cooling; capacity achievable

The absorption-cooling system operates at 1.83 bar. [40] In order to reduce the steam down to this pressure the high-pressure steam would be passed through a throttling valve, this is an adiabatic process meaning the specific enthalpy of the steam does not change. However, the steam will become superheated and superheated steam does not afford the same heat transfer capability as saturated steam. Superheated steam requires a larger heat exchanger surface for the same degree of heat transfer as that of saturated steam. However, for the sake of simplistic calculation the heat transfer complications associated with superheated steam have been neglected in the calculations of pasteurisation capacity.

Trane manufacture absorption-chillers capable of producing 330 kW to 770 kW cooling capacity.
The general specifications of the Trane units are:
COP: 0.61
Steam rate: 2.6 kg/kWh
Cooling capacity: 0.385 $\text{kW/kg}_{\text{steam}}$
Operating steam pressure: 1.83 bar [40]

Calculation set 14: Enthalpy after throttling for absorption-cooling

$hg_2 = hf_2 + (x \times hfg_2)$
$hg_1 = hg_2$

$$hfg_2 = \frac{hg_1 - hf_2}{x}$$

Where:
hg_1: Specific enthalpy of dry saturated steam at 10 bar 2 777 kJ/kg
hf_2: Specific enthalpy of water at 1.83 bar, 118.22°C 495 kJ/kg
$hfg_{1.83\text{bar}}$: Specific enthalpy of evaporation at 1.83 bar 2 208 kJ/kg
x: dryness fraction, which cannot physically be greater than 1

Therefore,

$$hfg_2 = \frac{\left(2\,777\frac{kJ}{kg} - 495\frac{kJ}{kg}\right)}{x} = \frac{2\,282\frac{kJ}{kg}}{x}$$

$$x = \frac{2\,282\frac{kJ}{kg}}{2\,208\frac{kJ}{kg}} = 1.03 \qquad x \leq 1\text{, therefore superheated after throttling}$$

The specific enthalpy of evaporation after throttling (hfg_2) = 2 282 kJ/kg

Calculation set 15: Absorption-cooling capacity achievable

$$Cooling\ capacity = Cooling_{1.83\,bar} \times \frac{hfg_2}{hfg_{1.83\,bar}}$$

Where:
Cooling capacity: Capacity expected from proposed CHP process steam
$Cooling_{1.83bar}$: Absorption-cooling capacity at 1.83 bar
$hfg_{1.83bar}$: Specific enthalpy of evaporation at 1.83 bar 2 208 kJ/kg
hfg_2: Specific enthalpy of evaporation after throttling 2 282 kJ/kg

$$Cooling\ capacity = 0.385\ \frac{kW_{cooling}}{kg_{steam}} \times \frac{2\,282\ \frac{kJ}{kg}}{2\,208\ \frac{kJ}{kg}} = 0.398\ \frac{kW_{cooling}}{kg_{steam}}$$

Cooling capacity = 397.90 kW of cooling per ton of saturated steam at 10 bar
Cooling capacity, 10 tons per hour = 3 979 kW, or 31.37 GWh/yr

Assuming the COP of a mechanical-chiller is 3 than the use of absorption-cooling technology would offset grid electricity by 10.46 GWh per year.

$$GWh_{elec} = \frac{31.37\ \frac{GWh}{yr}}{3} = 10.46\ \frac{GWh}{yr}$$

The cooling capacity achievable from the proposed CHP steam is:

- Maximum cooling capacity using 10 tons of saturated steam per hour, at 10 bar: 3 979 kW; 397.90 kW of cooling per ton of steam
- Maximum cooling capacity using 78 840 tons of saturated steam per year, at 10 bar: 31.37 GWh of cooling per year

Appendix 6.5.2)Absorption-cooling for climate control of factory floor

Capacity required

The air-conditioning load of a standard design factory floor conducting heavy manufacture at sea level in South Africa is approximately 490 W/m^2 [41]

Capacity achievable

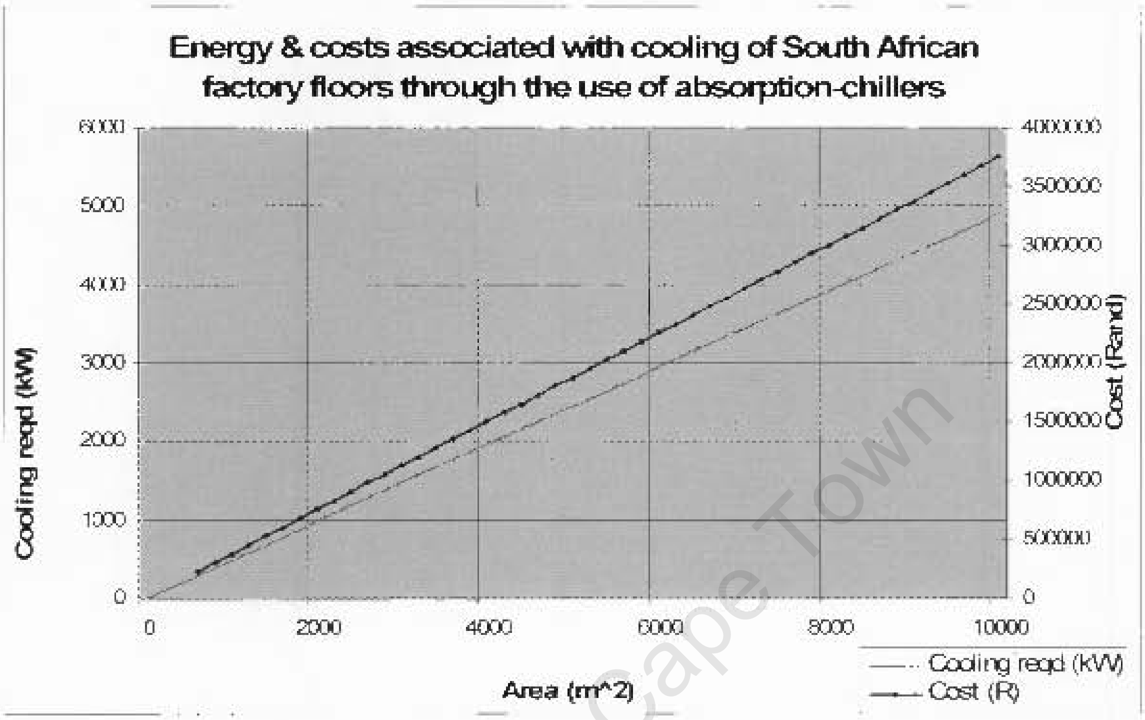
- Cooling capacity per ton of saturated steam at 10 bar = 812.04 m^2

$$Cooling\ capacity = \frac{397.90\ \frac{kW}{ton\ of\ steam}}{0.49\ \frac{kW}{m^2}} = 812.04\ \frac{m^2}{ton\ of\ steam}$$

- Since the smallest commercial absorption-chiller units available are 330kW it is assumed that cooling loads below this value are generally uneconomical. Therefore, the use of absorption-chillers becomes viable at a minimum of 673 m^2 of factory floor space.

$$Viability_{factory\ floors} = \frac{330\ kW}{\frac{0.49\ kW}{m^2}} = 673\ m^2$$

Figure 19: Cost versus cooling capacity for factory floor space



The air-conditioning capacity achievable using the proposed CHP process steam is:

- Maximum capacity using 10 tons of saturated steam per hour, at 10 bar: 8 120 m^2 of factory floor space: 812.04 m^2 per ton steam
- The use of absorption-chillers becomes viable at a minimum of 673 m^2 of factory floor space

Appendix 6.5.3) Absorption-cooling for climate control of offices

Capacity required

The air-conditioning load of offices of standard design at sea level in South Africa is approximately 170W/m^2 [41]

Capacity achievable

- Cooling capacity per ton of saturated steam at 10 bar = 2 340.59 m^2

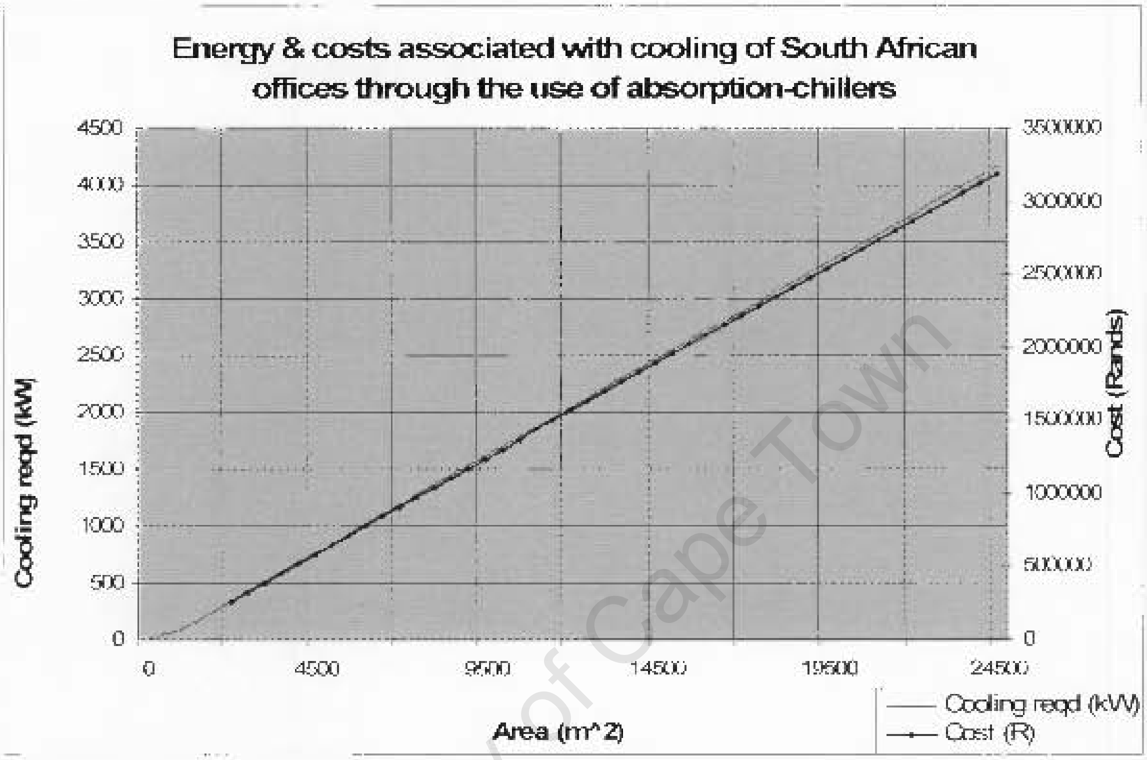
$$Cooling\ capacity = \frac{397.90 \frac{kW}{ton\ of\ steam}}{0.17 \frac{kW}{m^2}} = 2\,340.59 \frac{m^2}{ton\ of\ steam}$$

- Since the smallest commercial absorption-chiller units available are 330kW it is assumed that cooling loads below this value are generally uneconomical.

Therefore, the use of absorption-chillers becomes viable at a minimum of 1 941.18 m^2 of office floor space.

$$Viability_{factory\ floors} = \frac{330\,kW}{\frac{0.17\,kW}{m^2}} = 1\,941.18\,m^2$$

Figure 20: Cost versus cooling capacity for office floor space



The air-conditioning capacity achievable using the proposed CHP process steam is:

- Maximum capacity using 10 tons of saturated steam per hour, at 10 bar: 23 406 m^2 of office floor space; 2 340.59 m^2 per ton steam
- The use of absorption-chillers becomes viable at a minimum of 1 941 m^2 of office floor space

Appendix 6.6) Fibreboard production

Appendix 6.6.1) Fibreboard production; capacity required

The fibreboard plant in Stellenbosch uses approximately 0.15 litres per second, 12.96 kilolitres of fuel-oil per day, in an oil fired boiler, to generate the steam required to produce 240 m^3 of fibreboard. [55]

The plant runs for 333 days a year and produces 80 000m^3 of fibreboard. [55]

The average density of fibreboard is 700 kg/m^3, therefore the plant produces 56 000 tons of fibreboard per year: 0.077 litres of fuel oil per kg of fibreboard produced.

The plant requires 4 315.7 kilolitres of fuel-oil to generate the steam required per year.

Appendix 6.6.2) Fibreboard production; capacity achievable

Calculation set 16: Fibreboard capacity achievable

Gross calorific value of fuel oil:	40.19 MJ/kg [59]
Density of fuel oil:	825.1 kg/m^3 [59]
Fuel oil used per year:	4 315.7 kilolitres
Fibreboard produced:	56 000 tons/yr
Gross calorific value of South African coal:	27.32 MJ/kg
Efficiency of new coal boiler:	80% [60]
Boiler pressure:	10 bar
Specific enthalpy of dry saturated steam at 10 bar:	2 777 kJ/kg
Specific enthalpy of boiler feedwater at 70°C:	293 kJ/kg

The net energy input of fuel oil per year is:

$$Energy_{fuel\ oil} = 4\,315.7 \times 10^3 \frac{litres}{yr} \times \frac{1m^3}{1000 litres} \times \frac{825.1kg}{m^3} \times \frac{40.19MJ}{kg} = 143.1 \frac{TJ}{yr}$$

$$Energy_{fuel\ oil} = 143.1 \frac{TJ}{yr}$$

Many fibreboard plants in Africa would use coal in their boilers and therefore it is preferable to calculate the equivalent mass of coal and use that value for emission calculations.

The equivalent mass of coal to generate the energy required per year is:

$$Coal_{equivalent} = \frac{143.1 \times 10^{12} J}{27.32 \times 10^6 J} = 5\,237.9 \times 10^3 kg$$

$$Coal_{equivalent} = 5\,237.9 \frac{tons}{yr}$$

Coal required per kg of fibreboard produced is:

$$Coal_{reqd} = \frac{Coal_{equivalent} \frac{kg}{yr}}{Fibreboard produced \frac{kg}{yr}} = \frac{5\,237.9 \times 10^3}{56 \times 10^6} = 0.094$$

$$Coal_{reqd} = 0.094 \frac{kg_{coal}}{kg_{fibreboard}}$$

Energy transferred to steam by 80% efficient coal boiler is:

$$Energy_{steam} = 143.1 \frac{TJ}{yr} \times 0.8 = 114.48 \frac{TJ}{yr}$$

The mass of steam produced by the 80% efficient boiler is:

$$Mass_{steam} = \frac{Energy_{steam}\ \frac{kJ}{yr}}{Energy_{gain}\ \frac{kJ}{kg}} = \frac{114.48 \times 10^{9}\ \frac{kJ}{yr}}{\left(2\ 777\ \frac{kJ}{kg} - 293\ \frac{kJ}{kg}\right)} = 46.09 \times 10^{6}\ \frac{kg_{steam}}{yr}$$

The mass of steam required per kg of fibreboard is:

$$Mass_{\frac{steam}{fibreboard}} = \frac{Mass_{steam}}{Mass_{fibreboard}} = \frac{46.09 \times 10^{6}}{56.00 \times 10^{6}} = 0.823\ \frac{kg_{steam}}{kg_{fibreboard}}$$

The fibreboard manufacturing capacities achievable using the proposed CHP process steam are:

- Current capacity using 7.2 tons of saturated steam per hour, at 10 bar: 5.93 tons of fibreboard per hour; 1.215 tons per ton of steam
- Maximum capacity using 10 tons of saturated steam per hour, at 10 bar: 12.15 tons of fibreboard; 1.215 tons per ton of steam
- Maximum capacity using 78 840 tons of saturated steam per year, at 10 bar: 95 791 tons of fibreboard per year

Appendix 6.7) Water-heating

Appendix 6.7.1) Water-heating; capacity achievable

The energy from the available CHP process steam can be transferred through a heat exchanger to heat water at atmospheric pressure from a minimum of 1°C to 90°. This range of temperatures is considered to be extreme and thus the water-heating capacity is considered conservative if not accurate.

Calculation set 17: Water-heating capacity achievable

hg_1:	specific enthalpy of dry saturated steam at 10 bar	2 777 kJ/kg
hf_2:	specific enthalpy of water at 1 bar, 90°C	377 kJ/kg
$hf_{1°C}$:	specific enthalpy of water at 1 bar, 1°C	4.187 kJ/kg

Energy transferred through a heat exchanger of 95% efficiency:

$$Energy_{transfer} = \left(hg_1 - hf2\right) \times 0.95$$

$$Energy_{transfer} = \left(2\ 777\ \frac{kJ}{kg} - 377\ \frac{kJ}{kg}\right) \times 0.95 = 2\ 280\ \frac{kJ}{kg}$$

Heating capacity of saturated steam at 10 bar:

$$Hot\ water_{90C} = \frac{Energy_{transfer}}{Energy_{gain}}$$

$$Hot\ water_{90C} = \frac{2\,280\,\frac{kJ}{kg_{steam}}}{\left(377\,\frac{kJ}{kg_{water}} - 4.187\,\frac{kJ}{kg_{water}}\right)} = 6.12\,\frac{kg_{water}}{kg_{steam}}$$

The water-heating capacities achievable using the proposed CHP process steam are:

- Hot water capacity at 90°C using 10 tons of saturated steam per hour, at 10 bar: 61.16 kilolitres per hour; 6.12 kilolitres of hot water per ton of steam
- Hot water capacity at 90°C using 78 840 tons of saturated steam per year, at 10 bar: 482.16 megalitres per year

Appendix 7) Cost of steam from old and new coal-fired boilers

The distillery currently uses a 25 year old coal-fired boiler to provide the required 12 480 tons of process steam per year. [61]

Table 35: Annual chemical costs for the distillery boiler

	Chemicals (Total)		
	Amount	cost/kg	monthly
Month	kg	R/kg	Cost (R)
Feb-03	0.00	58.25	0.00
Mar-03	0.00	58.25	0.00
Apr-03	0.00	58.25	0.00
May-03	7220.00	58.25	20245.83
Jun-03	0.00	60.33	0.00
Jul-03	250.00	60.33	7743.45
Aug-03	0.00	60.33	0.00
Sep-03	7430.00	60.33	27573.32
Oct-03	100.00	60.33	1332.60
Nov-03	225.00	60.33	5158.13
Dec-03	175.00	60.33	4491.83
Jan-04	0.00	61.33	0.00
Total	**15400.00**	**R 59.72**	**R 66,545.16**

[61]

Table 36: Annual water costs for the distillery boiler

	Water		
	Amount	cost/kl	monthly
Month	kilolitres	R/kl	Cost (R)
Feb-03	1040	R 1.96	R 2,323.78
Mar-03	1040	R 1.96	R 2,323.78
Apr-03	1040	R 1.96	R 2,323.78
May-03	1040	R 1.96	R 2,323.78
Jun-03	1040	R 1.96	R 2,323.78
Jul-03	1040	R 1.96	R 2,323.78
Aug-03	1040	R 1.96	R 2,323.78
Sep-03	1040	R 1.96	R 2,323.78
Oct-03	1040	R 1.96	R 2,323.78
Nov-03	1040	R 1.96	R 2,323.78
Dec-03	1040	R 1.96	R 2,323.78
Jan-04	1040	R 1.96	R 2,323.78
Total	12.480.00		R 27,885.31

[62]

Appendix 7.1) Cost of steam from distillery's old coal-fired boiler

Table 37: Annual coal costs for the distillery's old boiler

	Coal		
Month	**Amount tons**	**cost/ton R/ton**	**monthly Cost (R)**
Feb-03	58.38	R 530.00	R 35,273.20
Mar-03	113.8	R 530.00	R 68,757.96
Apr-03	101.82	R 530.00	R 61,519.64
May-03	105.72	R 530.00	R 63,876.02
Jun-03	62.34	R 530.00	R 37,665.83
Jul-03	174.6	R 530.00	R 105,493.32
Aug-03	78.34	R 530.00	R 47,333.03
Sep-03	62.52	R 530.00	R 37,774.58
Oct-03	61.86	R 530.00	R 37,375.81
Nov-03	91.58	R 530.00	R 55,332.64
Dec-03	42.12	R 530.00	R 25,448.90
Jan-04	116.06	R 530.00	R 70,123.45
Total	1069.14		R 645,974.39

[61]

Calculation set 18: Cost of steam from distillery's old coal-fired boiler

Annual cost of existing steam system:

$$Cost\ of\ steam\ system = \left(\frac{coal\ cost}{yr} + \frac{water\ cost}{yr} + \frac{chemical\ cost}{yr}\right)$$

$$Cost\ of\ steam\ system = \frac{R645\,974.39}{yr} + \frac{R27\,885.31}{yr} + \frac{R66\,545.16}{yr}) = R740\,404.86$$

Minimum current cost of steam:

$$Cost\ of\ steam = \frac{Cost\ of\ steam\ system}{\frac{Tons\ of\ steam}{year}}$$

$$Cost\ of\ steam = \frac{R740\,404.86}{12\,480} = \frac{R59.33}{ton}$$

These costs are based on the:

- Coal and chemical costs; February 2003 to the end of January 2004
- Current cost of water on Cape Town's bulk water consumption tariff
- Approximate annual steam requirement of 12 480 tons
- Excluding boiler operator cost
- Excluding boiler maintenance cost

Appendix 7.2) Efficiency of distillery's old coal-fired boiler

Calculation set 19: Efficiency of distillery's old coal-fired boiler

Annual coal requirement:	1 069 tons
Annual amount of steam produced:	12 480 tons/yr
Gross calorific value of South African coal:	27.32 MJ/kg
Feedwater flow:	5 000 kg/hr
Boiler output steam pressure:	7 bar
Boiler output steam temperature:	170.5°C
Specific enthalpy of saturated steam at 7 bar:	2 047 kJ/kg
Specific enthalpy of feedwater at 7 bar, 70°C:	293 kJ/kg

$$\text{Energy input} = \text{Mass}_{\text{coal}} \times \text{GCV} = 1\,069 \times 10^{3} \times 27.32 \times 10^{6} = 29.2\ \text{TJ}$$

$$\text{Energy output} = \text{Mass}_{\text{steam}} \times \text{enthalpy gain} = 12\,480 \times 10^{3} \times [(2\,047 - 293) \times 10^{3}]$$

$$\text{Energy output} = 21.89\ \text{TJ}$$

$$\text{Efficiency of boiler is} = (21.89\ \text{TJ} \div 29.2\ \text{TJ}) = 0.75 = 75\%$$

Appendix 7.3) Cost of steam from new coal-fired boiler

The existing distillery boiler is relatively old and it has been suggested that a new coal boiler will need to be purchased within the next few years. [63] The budget cost of a new 10 ton coal-fired boiler with grit-collection and ash conveyor is approximately R3 million. A new boiler will have an efficiency of approximately 80%. [60]

Assuming that a bank loan would be taken out over a 20 year period in order to cover the cost of the installation.

Current prime interest rate:	10.5% [42]
Total cost for 20 year period:	R10.05 million
Annual levelised cost of boiler:	R502 500.00

It is assumed that the total annual steam requirement remains the same at approximately 12 480 tons/year.
The cost of coal for the new higher efficiency distillery coal boiler in producing 12 480 tons of steam will be reduced, the new annual coal cost is:

$$Coal\ cost_{80\%eff} = \frac{R645\,974}{yr} \times \frac{75\%\ efficiency}{80\%\ efficiency} = \frac{R605\,600.00}{yr}$$

Calculation set 20: Cost of steam from new coal-fired boiler

Annual cost of existing steam system:

$$Cost\ of\ steam\ system = \frac{coal\ cost}{yr} + \frac{water\ cost}{yr} + \frac{chemical\ cost}{yr} + \frac{levelised\ boiler\ cost}{yr}$$

$$Cost\ of\ steam\ system = \frac{R605\,600.00}{yr} + \frac{R27\,885.31}{yr} + \frac{R66\,545.16}{yr} + \frac{R502\,500.00}{yr}$$

$$Cost\ of\ steam\ system = \frac{R1\,202\,531.00}{yr}$$

Minimum current cost of steam:

$$Cost\ of\ steam = \frac{Cost\ of\ steam\ system}{\frac{Tons\ of\ steam}{year}}$$

$$Cost\ of\ steam = \frac{R1\,202\,531.00}{12\,480} = \frac{R96.36}{ton}$$

These costs are based on:

- Annual levelised cost of new boiler
- The reduced coal cost; February 2003 to the end of January 2004
- The cost of chemicals; February 2003 to the end of January 2004
- The current cost of water on Cape Town's bulk water consumption tariff
- Approximate annual steam requirement 12 480 tons
- Excluding boiler operator cost
- Excluding boiler maintenance cost

Appendix 8) Emissions resulting from CHP intervention

Only additional emissions resulting from the intervention of the CHP plant are considered in this section as these are the emissions of prime concern with regard to CDM requirements.

GHGs affect global warming with varying intensities; the intensity of each GHG is measured by its Global Warming Potential (GWP). The GWP of nitrous oxide (N_2O) for example is 310 and the GWP of carbon dioxide (CO_2) is 1. [1] Therefore, one ton of N_2O has 310 times more greenhouse affect than carbon dioxide does. CERs are awarded based on the global warming potential of the gas.
tCO_2eq = Tons of GHG reduced × GWP of the gas

Carbon monoxide (CO) is not considered a greenhouse gas, however it is considered a precursor to greenhouse gasesas it elevates the concentrations of methane and ozone in the atmosphere before it eventually oxidises into carbon dioxide.[64]

Table 38: Additional emissions resulting from CHP processes per year

Emissions	**tCO2eq**
Transport (pinus)	+4.70
Chipper (pinus)	+16.93
Transport (WFW)	+0.11
Chipper (WFW)	+1.07
Total	+22.81

Appendix 8.1) Emissions from transport of residues

The transport of residues can be divided into three stages.
The first stage is when the tree has been felled and requires transport to the main access roads (roadside or landing). This is typically achieved using off-road-terrain going vehicles such as 4×4 tractors and off-road terrain loaders. [38] However, this stage is required for current forestry operations and the emissions cannot be attributed to CHP intervention. Any excess emissions, associated with this process, resulting from CHP intervention can only be accurately determined once the plant is running.

The second stage is the transport of the residues and timber to the sawmill site; typically performed by road hauling trucks. [38] The emissions from this stage have been calculated and included in the overall emissions resulting from CHP intervention.

The third and final stage is the transport of residues on the sawmill site. There are many unknowns regarding the transport of these residues and the excess emissions associated with this process can only be determined once the plant is running.

According to Mercedes-Benz the fuel consumption of a new technology 30 ton payload. Mercedes-Benz Actros diesel truck is approximately 55 litres per 100 kilometres. The vehicle travels at 78 km/hr in 14th gear. engine speed 1 800 rpm, engine power output 230 kW. [65]
The 1996 IPCC guidelines for GHG inventories states that for a heavy-duty diesel vehicle with a fuel consumption of 29.9 litres per 100 kilometres the GHG emissions are:

NO_x	10 g/km
CH_4	0.06 g/km
NMVOC	1.9 g/km
CO	9 g/km
N_2O	0.03 g/km
CO_2	770 g/km

Thus. the emissions of a vehicle with a fuel consumption of 55 litres per 100 kilometres will be approximately 1.839 times greater.
(55 litres/100 km ÷ 29.9 litres/100 km = 1.839)
Therefore the emissions of a typical 30 ton payload transport vehicle are:

NO_x	18.390 g/km
CH_4	0.110 g/km
NMVOC	3.494 g/km
CO	16.551 g/km
N_2O	0.055 g/km
CO_2	1 416.030 g/km

Appendix 8.1.1)Emissions from transport: plantation to sawmill

The tops of trees, branches and foliage from freshly cut trees are sent through a chipper on site before being sent to the sawmill.
5 408.451 m^3 of the above-mentioned residues are harvested each year. At the time of transport the density of the freshly cut material is approximately 1 000 kg/m^3 [66], at 83% moisture content[11]. Thus the weight of residues requiring transport to the sawmill is approximately 5 408.451 tons
(5 408.451 m^3 × 1 000 kg/m^3 = 5 408.51 × 10^3 kg)

Each truck can only transport 30 tons of residues per trip. Thus, 181 trips are required to transport these residues to the sawmill.
(5 408.451 tons ÷ 30 tons/trip = 180.28 trips)

The average transport distance from plantation to saw mill is 70 km, return trip being 140 km. [38] Therefore, the emissions associated with the overall transport of residues from the plantations to sawmill are 253.4 times that given by the IPCC for a typical 30 ton payload residue transport vehicle over 100 km.
(140 km/trip ÷ 100 km ×181 trips per year = 253.4)

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[11] The roundwood from the plantations typically air-dries to approximately 47% moisture content, 800 kg/m^3, before being processed by the sawmill

Therefore the total emissions associated purely with the transport of these residues are:

NO_x	4 660.026 g/yr	= 4.660 kg/yr	
CH_4	27.874 g/yr	= 0.028 kg/yr	or 0.001 tCO2eq
NMVOC	885.380 g/yr	= 0.885 kg/yr	
CO	4 194.023 g/yr	= 4.194 kg/yr	
N_2O	13.937 g/yr	= 0.014 kg/yr	or 4.340 tCO2eq
CO_2	358 822.002 g/yr	= 358.822 kg/yr	or 0.359 tCO2eq

Therefore, the total equated GHG emissions resulting from transport of residues from the plantation to the sawmill is 4.70 tCO2eq/yr

Appendix 8.1.2)Emissions from transport: WFW plains to sawmill

The total mass of residues transported from the west coast WFW programme per year is 68.313 tons.
Each truck can only transport 30 tons of residues per trip. Thus, 3 trips are required to transport these residues to the sawmill.
(68.313 tons ÷ 30 tons/trip = 2.277 trips ≈ 3 trips)

The total mass of residues transported from the Agulhas plains WFW programme per year is 237.69 tons.
Each truck can only transport 30 tons of residues per trip. Thus, 8 trips are required to transport these residues to the sawmill.
(237.69 tons ÷ 30 tons/trip = 7.92 trips ≈ 8 trips)

The average transport distance from both the west coast and Agulhas plains to the sawmill is 350 km, return trip being 700 km [38]

Therefore the emissions associated with the overall transport of residues from the plantations to the saw mill are 77 times that given by the IPCC for a typical 30 ton payload residue transport vehicle over 100 km.
(700 km/trip ÷ 100 km × 11 trips = 77)

The total emissions associated purely with the transport of these residues are:

NO_x	1 416.030 g/yr	= 1.42 kg/yr	
CH_4	8.470 g/yr	= 0.008 kg/yr	or 0.000 tCO2eq
NMVOC	269.038 g/yr	= 0.269 kg/yr	
CO	1 274.43 g/yr	= 1.274 kg/yr	
N_2O	4.235 g/yr	= 0.004 kg/yr	or 0.001 tCO2eq
CO_2	109 034.310 g/yr	= 109.034 kg/yr	or 0.109 tCO2eq

Therefore, the total equated GHG emissions resulting from transport of residues from the WFW plains to the sawmill is 0.11 tCO2eq/yr

Appendix 8.2) Emissions from chipping of residues

Chippers are currently and will be used to reduce the size of waste biomass. The sawmill currently sends all residues from the wetmill and drymill processes through a chipper before they are sold or used in the sawmill's boiler. Since these processes are part of the current sawmill operation they cannot be attributed to CHP intervention.

Chippers will need to be introduced for residues collected in the plantations and WFW programme, the emissions from these chippers have been calculated and included in the overall emissions resulting from CHP intervention.

Appendix 8.2.1)Emissions from chipper: plantation residues

The Cape forestry company was unable to provide details of the chipper of their choice and therefore there was no data on the chippers fuel consumption. Research was conducted to find out a suitable chipper to handle both materials in the plantations and plains as well as the sawmill.
Morbark manufacture forestry equipment; they produce chippers suitable for various applications. [67]
The Morbark model 20/36 whole tree chipper is a mobile unit suitable for use both in the field and at the sawmill. The chipper can process 30 tons of material per hour. The unit has a 196 kW caterpillar motor this is similar to the power output of the Mercedes-Benz Actros diesel heavy-duty truck engine used for residue transport. [67]

Whereas the trucks emissions are given in g/km the chippers emissions are required in g/hr of operation. In order to determine an accurate emissions multiplication factor so as to convert the trucks emissions to those applicable to the chipper it is necessary to determine the ratio of chipper engine power output to truck engine power output and then multiply this ratio by the trucks emissions, given in g/km, as well as the distance covered by the truck over an hour.

Thus the emissions, in g/hr, associated with the chipping of 30 tons of material per hour are 66.47 times that of the emissions of the 30 ton payload transport vehicle, in g/km.
(196 (kW) ÷ 230 (kW) × 78 (km/hr) × GHG (g/km) = 66.47 × GHG (g/hr))

NO_x	1 222.383 g/hr
CH_4	7.312 g/hr
NMVOC	232.246 g/hr
CO	1 100.145 g/hr
N_2O	3.656 g/hr
CO_2	94 123.514 g/hr

The weight of residues transported to the sawmill from the plantations is approximately 5 408.451 tons.
Thus, the chipper would be required to operate for a minimum of 180.28 hours
(5 408.451 tons ÷ 30 tons/hr = 180.28 hrs)
Running for 8 hours per day it would take 22.5 days to chip these residues.

Therefore, the total emissions attributed to the chipping of plantation residues prior to arrival at the sawmill are:

NO_x	220 373.652 g/yr	= 220.374 kg/yr	
CH_4	1 318.222 g/yr	= 1.318 kg/yr	or 0.028 tCO2eq
NMVOC	41 869.773 g/yr	= 41.870 kg/yr	
CO	198 336.34 g/yr	= 198.336 kg/yr	
N_2O	659.111 g/yr	= 0.659 kg/yr	or 0.204 tCO2eq
CO_2	16 968 775.35 g/yr	= 16 968.775 kg/yr	or 16.699 tCO2eq

Therefore, the total equated GHG emissions resulting from chipping of residues in the plantations is 16.93 tCO2eq/yr

Appendix 8.2.2)Emissions from chipper: WFW residues

The total mass of residues that is required to be processed from residues originating from the WFW programme is 306 tons per year.
The Morbark model 20/36 mobile chipper is able to process 30 tons an hour thus it would take the chipper a minimum of 11 hours to process all the WFW residues. (306 tons ÷ 30 tons/hr = 10.2 hrs)

The emissions associated with processing 30 tons of material per hour are as calculated under the section titled "Emissions from chipper: plantation residues". The emissions are:

NO_x	1 222.383 g/hr
CH_4	7.312 g/hr
NMVOC	232.246 g/hr
CO	1 100.145 g/hr
N_2O	3.656 g/hr
CO_2	94 123.514 g/hr

Therefore, the total emissions attributed to the chipping of the WFW residues for 11 hours are:

NO_x	13 446.18 g/yr	= 13.446 kg/yr	
CH_4	80.432 g/yr	= 0.080 kg/yr	or 0.002 tCO2eq
NMVOC	2 554.706 g/yr	= 2.554 kg/yr	
CO	12 101.595 g/yr	= 12.101 kg/yr	
N_2O	40.216 g/yr	= 0.040 kg/yr	or 0.012 tCO2eq
CO_2	1 035 358.654 g/yr	= 1 035.359 kg/yr	or 1.035 tCO2eq

Therefore, the total equated GHG emissions resulting from chipping of residues in the WFW plains is 1.07 tCO2eq/yr

Appendix 8.3) Emissions from construction and decommission of CHP plant

The emissions from these stages will be significant but are unknown at this stage.

Appendix 9) Emission reduction potential of CHP plant

GHGs affect global warming with varying intensities: the intensity of each GHG is measured by its Global Warming Potential (GWP). The GWP of nitrous oxide (N_2O) for example is 310 and the GWP of carbon dioxide (CO_2) is 1. [1] Therefore, one ton of N_2O has 310 times more greenhouse affect than carbon dioxide does. CERs are awarded based on the global warming potential of the gas.
tCO_2eq = Tons of GHG reduced × GWP of the gas

Carbon monoxide (CO) is not considered a greenhouse gas, however it is considered a precursor to greenhouse gasesas it elevates the concentrations of methane and ozone in the atmosphere before it eventually oxidises into carbon dioxide.[64]

Appendix 9.1) Offset of GHG through use of CHP electricity

If the CHP plant generates 6 MW of electricity with a yearly availability factor of 0.9 then the plant would produce 47.3 GWh of electricity per year.
(6×10^6 W × 24 hrs/day × 365 days/yr × 0.9 = 47.3×10^9 Wh/yr)
The CHP plant could use as much as 10% of the electricity produced. Therefore, the amount of fossil-fuelled electricity the CHP plant could replace is 42.57 GWh/yr.

The environmental implications of using one kilowatt-hour of Eskom generated electricity are:

Water usage	1.29	litres *1	
Coal usage	0.5	kg	
Ash produced	0.14201	kg	
Ash emitted	0.28×10^{-3}	kg	
SO_2 emissions	8.22×10^{-3}	kg *2	
NO_x emissions	3.62×10^{-3}	kg *2	
CO_2 emissions	0.9	kg *2	[68]

The environmental implications of using 42.57 GWh of fossil-fuelled electricity per year are:

Water usage	54.915×10^6	litres *1	
Coal usage	21.285×10^6	kg	
Ash produced	6.045×10^6	kg	
Ash emitted	11.920×10^3	kg	
SO_2 emissions	349.925×10^3	kg *2	
NO_x emissions	154.103×10^3	kg *2	
CO_2 emissions	38.313×10^6	kg *2	or 38 313.00 tCO_2eq

*1 Volume of water consumed per unit of generated power sent out, excluding rain and mine water used.
*2 Calculated annual figures based on coal characteristics and power station design parameters.

Summary

The CHP plant could export 42.57 GWh of 'green' electricity per year.
The GHG emissions offset through the use of 42.57 GWh of 'green' electricity, as opposed to fossil-fuelled electricity, would be:

Electricity (GWh)	42.57
tCO_2eq	38 313
tSO_2	350
tNOx	154

Appendix 9.2) Offset of GHG through use of CHP process steam

Appendix 9.2.1) Offset of GHG: steam from coal-fired boilers

The environmental implications of burning one kilogram of coal in an industrial boiler are:

Coal usage	1.0	kg
Ash produced	0.2840	kg
SO_2 emissions	16.44×10^{-3}	kg
NO_x emissions	7.24×10^{-3}	kg
CO_2 emissions	1.8	kg

[68]

The old coal boiler at the distillery, which was calculated to have an efficiency of 75%, requires 85.66 kg of coal to produce 1 ton of steam. [See appendix 7]
A new coal boiler, with an efficiency of approximately 80%, would require 80.30 kg of coal to produce 1 ton of steam. (85.66 kg × 75% ÷ 80% = 80.30 kg)

Therefore, the environmental implications of producing 1 ton of steam from the 75% and 80% efficient boilers are:

Boiler efficiency	75%	80%	
Coal usage	85.66	80.30	kg
Ash produced	24.33	22.81	kg
SO_2 emissions	1.41	1.32	kg
NO_x emissions	0.62	0.58	kg
CO_2 emissions	154.19	144.54	kg

Therefore, the environmental implications of producing the same amount of steam from a coal boiler as that obtained from the maximum annual use of CHP process steam, 78 840 tons, are:

Boiler efficiency	75%	80%	
Coal usage	6 753.43	6 330.85	tons
Ash produced	1918.18	1 798.34	tons
SO_2 emissions	111.16	104.07	tons
NO_x emissions	48.88	45.73	tons
CO_2 emissions	12 156.34	11 395.53	tons

The graphs below illustrate the emissions offset through the use of the 'green' CHP steam as opposed to steam from coal-fired boilers of 75% and 80% efficiency.

Figure 21: tCO2eq offset by the use of steam from the CHP plant

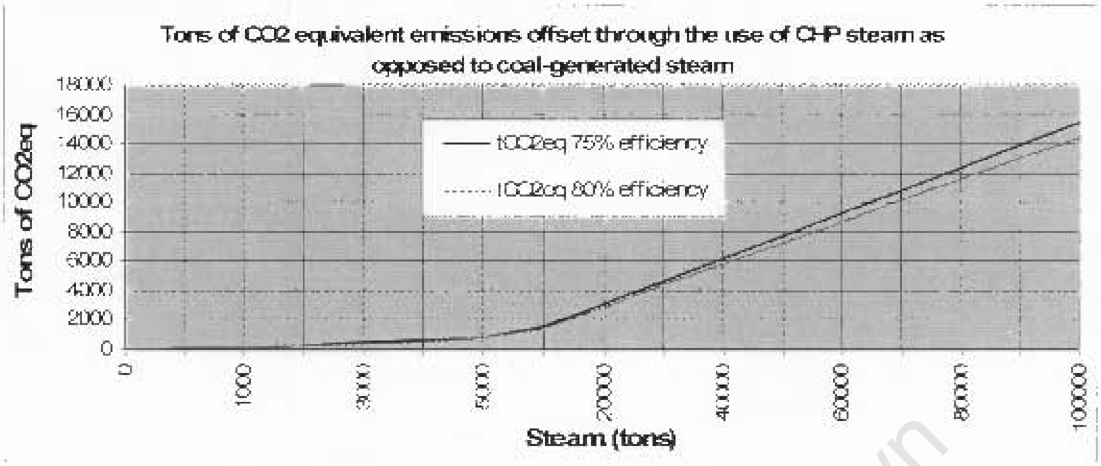
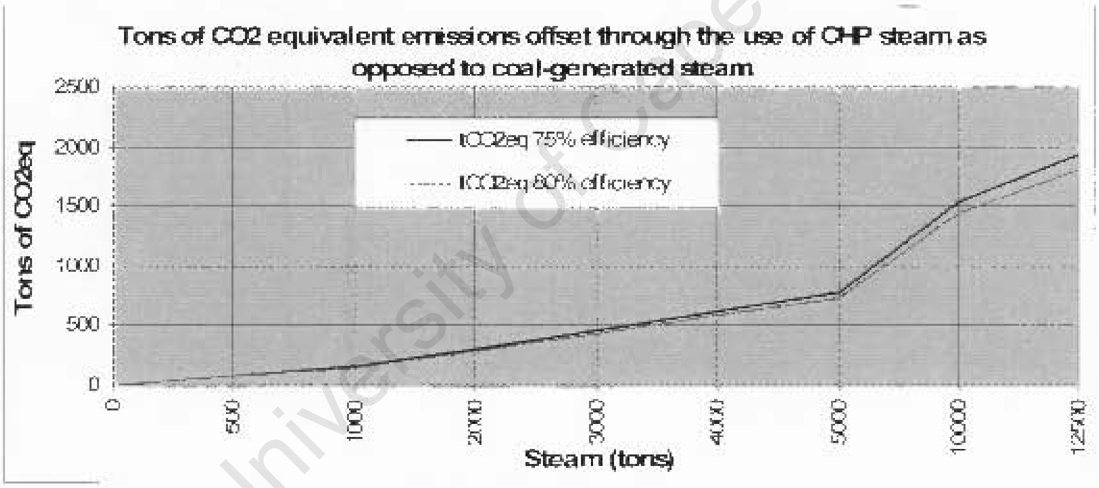


Figure 22: tCO2eq offset by the use of steam from the CHP plant



Appendix 9.2.1.1) Offset of GHG: wood-drying kilns

Typically, wood-drying kilns in Africa are steam heated. Steam is generated through the combustion of some fuel; typically coal, oil or biomass. [32]

The Stellenbosch sawmill currently uses the by-products of the sawmill to provide the 10 tons per hour of saturated steam, at 8 bar, required for the 72 m^3 of wood-drying kiln capacity currently installed; the current kiln is approximately 8.6% thermally efficient. An efficient design could provide a thermal efficiency of 95% and a kiln capacity of $800m^3$.

Kilns of 800 m^3 capacity, 95% efficient, would require approximately 10 tons of steam an hour during operation.
Due to the logistics of kiln operation the maximum amount of CHP steam that could be used per year would be approximately 52 592 tons of saturated steam at 10 bar.
The GHG emissions offset through the use of this steam as opposed to steam generated from an 80% efficient coal boiler would be:

➢ tCO_2eq	7 602
➢ tSO_2	69
➢ tNOx	31

Appendix 9.2.1.2) Offset of GHG: distillation and sanitation

The distillery uses an old coal boiler, efficiency 75%, to generate the steam required for distillation and sanitation. The distillery currently uses 1 069 tons of coal to generate 12 480 tons of steam; pressure 7 bar.
The GHG emissions resulting from the production of this steam are:

➢ tCO_2eq	1 924
➢ tSO_2	18
➢ tNOx	8

If the distillery capacity could be increased to use all 78 840 tons of the available CHP process steam, then the GHG emissions offset through the use of this steam as opposed to steam generated from an 80% efficient coal boiler would be:

➢ tCO_2eq	11 396
➢ tSO_2	104
➢ tNOx	46

Appendix 9.2.1.3) Offset of GHG: pasteurisation

The milk and fruit-juice pasteurisation plant is assumed to use all 78 840 tons of the available CHP process steam, the GHG emissions offset through the use of this steam as opposed to steam generated from an 80% efficient coal boiler would be:

➢ tCO_2eq	11 396
➢ tSO_2	104
➢ tNOx	46

Appendix 9.2.1.4) Offset of GHG: fibreboard production

The fibreboard plant uses a fuel-oil boiler, maximum efficiency 80%, to generate the steam required. The plant currently uses 4 316 kilolitres of fuel-oil, the equivalent of 5 238 tons of coal, to generate 46 090 tons of steam at 10 bar. [55]
The GHG emissions resulting from the production of this steam are:

➢ tCO_2eq	6 662
➢ tSO_2	61
➢ tNOx	27

If the plant capacity could be increased to use all 78 840 tons of the available CHP process steam, then the GHG emissions offset through the use of this steam as opposed to steam generated from an 80% efficient coal boiler would be:

➢ tCO_2eq	11 396
➢ tSO_2	104
➢ tNOx	46

Appendix 9.2.2) Offset of GHG: absorption-cooling

Mechanical chillers generally require electricity as the energy input to the system.
The environmental implications of using one kWh of Eskom generated electricity are:

Water usage	1.29	litres [*1]
Coal usage	0.5	kg
Ash produced	0.14201	kg
Ash emitted	0.28×10^{-3}	kg
SO_2 emissions	8.22×10^{-3}	kg [*2]
NO_x emissions	3.62×10^{-3}	kg [*2]
CO_2 emissions	0.9	kg [*2]

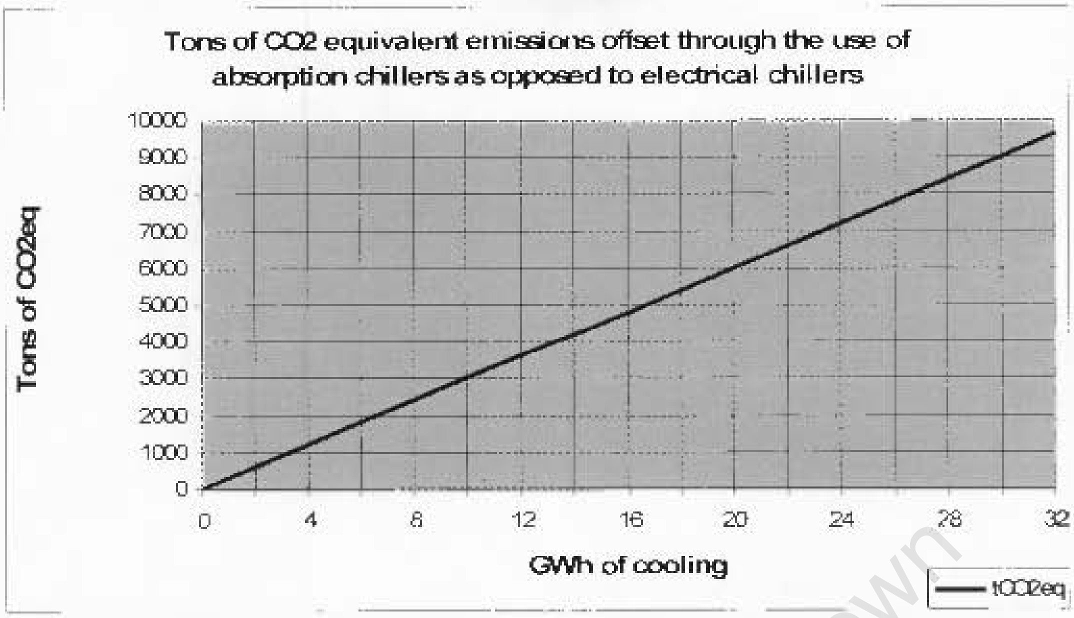
[68]

The CHP plant could provide 78 840 tons of saturated steam at 10 bar to an absorption-cooling plant which could provide 31.37 GWh of cooling capacity.
Mechanical-chillers typically have a COP of approximately 3; 0.333 kWh of electricity is required to produce 1 kWh of cooling.
Therefore, the absorption-cooling plant will replace 10.46 GWh/yr of electricity.
(31.37 GWh/yr ÷ 3 = 10.46 GWh/yr)

The environmental implications of using 10.46 GWh of Eskom generated electricity to produce 31.37 GWh of cooling capacity are:

Water usage	13 493	kilolitres [*1]
Coal usage	5 230	tons
Ash produced	1 485	tons
Ash emitted	3	tons
SO_2 emissions	86	tons [*2]
NO_x emissions	38	tons [*2]
CO_2 emissions	9 414	tons [*2]

Figure 23: tCO2eq offset through the use of absorption-cooling



Appendix 9.2.3) Offset of GHG: water-heating

Electricity is very often used for heating water.
The use of CHP process steam to heat water could supply hot water without the emissions associated with electrical heating. The 78 840 tons of saturated steam at 10 bar from the CHP plant could provide enough energy to heat 482.16 megalitres water from 1°C to 90°C

Energy required to heat water from 1°C to 90°C:

$$Energy_{reqd} = (90 - 1)\ Kelvin \times 4.19\ \frac{kJ}{kgKelvin} = 372.91\ \frac{kJ}{kg}$$

Energy required to heat 482.16 megalitres of water from 1°C to 90°C:

$$Energy_{reqd} = 482.16 \times 10^{6}\ kg \times 372.91\ \frac{kJ}{kg} = 179.80 \times 10^{9}\ kJ$$

$$Energy_{reqd} = \frac{179.80 \times 10^{9}\ \frac{kJ}{yr}}{3\,600\ \frac{kJ}{kWh}} = 49\,945\,079\ \frac{kWh}{yr} \approx 49.95\ \frac{GWh}{yr}$$

The environmental implications of using one kWh of Eskom generated electricity are:

Water usage	1.29	litres ^{*1}	
Coal usage	0.5	kg	
Ash produced	0.14201	kg	
Ash emitted	0.28×10^{-3}	kg	
SO_2 emissions	8.22×10^{-3}	kg^{*2}	
NO_x emissions	3.62×10^{-3}	kg^{*2}	
CO_2 emissions	0.9	kg^{*2}	[68]

The environmental implications of using 49.95 GWh of Eskom generated electricity to heat water are:

Water usage	64.44	megalitres [*1]
Coal usage	24 975	tons
Ash produced	7 093	tons
Ash emitted	13.99	tons
SO_2 emissions	411	tons[*2]
NO_x emissions	181	tons[*2]
CO_2 emissions	44 968	tons[*2]

Appendix 9.2.4) Offset of GHG by avoiding residue disposal and decay

All white chips. off-cuts and shavings are presently sold to the fibreboard plant. presently all sawdust and 50% of bark from timber is used in the sawmill's two boilers to generate process steam. the other 50% of the bark is sold to nurseries and gardening services. [38]
If the residues. currently utilised by the fibreboard. had to be disposed of elsewhere. the two most likely and globally utilised options would be disposal in a landfill or on the forest floor. In addition to the cost incurred by this procedure there would be significant GHG emissions from residue decay.

The total mass of residues requiring disposal would be 31 358 tons. approximately one third of the plant's roundwood intake.
These residues would need to be trucked either to the landfill or forest for disposal resulting in transport emissions. these emissions have been calculated and included in the respective emission amounts. The distance from the sawmill to the landfill site is half that of the average distance to the forest disposal sites. [38]
The varying moisture content of these residues affects the amount of emissions released and this was taken into consideration when calculating the emission amounts.

Table 39: Emission offsets through avoidance of residue disposal (tCO_2eq)

Scenario	Emissions	Reductions
- Landfill disposal	NA	-6 652
- Forest disposal	NA	-3 344

Appendix 9.2.4.1) Mass of residues for disposal

The total mass of residues sold to the fibreboard plant is:

- *Logyard*
  - Offcuts 2 688 tons
- *Wetmill*
  - Slabs: 10 913.28 tons
  - White chips: 15 590.401 tons
- *Drymill*
  - Offcuts: 2 166.091 tons

Total mass of residues otherwise requiring disposal 31 357.772 tons

Appendix 9.2.4.2) Emissions released during decay in landfill/forest

The density of pinus residues at the various moisture contents relevant are:

- 0% moisture content: 545.5 kg/m^3
- 12% moisture content: 611kg/m^3
- 47% moisture content: 800 kg/m^3
- 83% moisture content: 1 000 kg/m^3 (see appendix 2)

The carbon content of wood at 15% moisture content is approximately 46.5% by mass. [69]

$Mass_{carbon} = 0.465 \text{ B } Mass_{wet\ wood}$

$Mass_{wet\ wood} = Mass_{dry\ wood} + 0.15 \text{ B } Mass_{dry\ wood}$

Therefore the mass of carbon in the wood is:

$Mass_{carbon} = 0.465 \text{ B } 1.15 \text{ B } Mass_{dry\ wood} = 0.535 \text{ B } Mass_{dry\ wood}$

Therefore, the approximate carbon content of wood at 0% moisture content is 53.5%

Calculation set 21: Landfill/Forest decay equations

MC = moisture content
Cc = carbon content of wood
Ce = carbon emitted from wood
Ncb = nitrogen content of bark
Ncs = nitrogen content of stem
Ne = nitrogen emitted from wood
Gf = Gas fraction of element
Conversion of carbon to CO_2 = 44/12
Conversion of carbon to CH_4 = 16/12
Conversion of nitrogen to N_2O = 44/14
GWP CH_4 = 21
GWP N_2O =310

$Mass_{dry\ wood} = Mass_{wet\ wood} \div (1 + MC)$ (see appendix 2)

Carbon emitted through carbon dioxide (CO_2)

$Mass_{carbon\ emitted} = Mass_{dry\ wood} \times Cc \times Ce$

$Mass_{carbon\ emitted} = Mass_{wet\ wood} \div (1 + MC) \times Cc \times Ce$

$Mass_{CO2\ emitted} = Mass_{carbon\ emitted} \times Gf_{CO2} \times 44/12$

$Mass_{CO2\ emitted} = Mass_{wet\ wood} \div (1 + MC) \times Cc \times Ce \times Gf_{CO2} \times 44/12$

Carbon emitted through methane (CH_4)

$Mass_{CH4\ emitted} = Mass_{carbon\ emitted} \times Gf_{CH4} \times 16/12$

$Mass_{CH4\ emitted} = Mass_{wet\ wood} \div (1 + MC) \times Cc \times Ce \times Gf_{CH4} \times 16/12$

Nitrous oxide emitted (N_2O)
Mass_{N2O} emitted= $\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Nc \times GF_{N2O} \times 44/14$

Change in carbon stock
Change in carbon stock = $\text{Mass}_{\text{carbon}}$ - $\text{Mass}_{\text{carbon emitted}}$
Change in carbon stock (C) = $(1\text{-}Ce) \times [\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc]$
Change in carbon stock (CO_2) = $(1\text{-}Ce) \times [\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc] \times 44/12$

Landfill decay

A study into forestry landfill emissions concluded that as much as 3% of the carbon contained within the wood products would be emitted into the atmosphere. The gas released can be split into equal volumetric amounts of CO_2 and CH_4. [69]
Carbon contained within carbon dioxide (CO_2) is reabsorbed by the growth of plantation trees however, the carbon contained within methane is not. (CH_4)
In addition the nitrogen content of the bark and stem wood of pinus radiata is estimated at 0.39% and 0.06% respectively [70] and as much as 1.2% of this nitrogen will be emitted as N_2O during residue decay in the landfill.
The carbon not emitted into the atmosphere is stored in the landfill as carbon stock.

Calculation set 22: Emissions released in landfill

Fraction of carbon released as gas	= 3%
Fraction of nitrogen released as gas	= 1.2%
Proportion landfill gas that is CO_2	= 50%
Proportion landfill gas that is CH_4	= 50%

Landfill emissions and carbon stock calculations
Logyard and wetmill residues
Total mass of logyard and wetmill residues = 29 191.68 tons/yr, density 800 kg/m3
Mass_{CO2} emitted = $\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc \times Ce \times Gf_{CO2} \times 44/12$
Mass_{CO2} emitted (tCO_2/yr) = $29\,191.68 \div 1.466 \times 0.535 \times 0.03 \times 0.5 \times 44/12$
Mass_{CO2} emitted (tCO_2/yr) = 585.92

Mass_{CH4} emitted = $\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc \times Ce \times Gf_{CH4} \times 16/12$
Mass_{CH4} emitted (tCH_4/yr) = $29\,191.68 \div 1.466 \times 0.535 \times 0.03 \times 0.5 \times 16/12$
Mass_{CH4} emitted (tCH_4/yr) = 213.06

Mass_{N2O} emitted = $\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Nc \times GF_{N2O} \times 44/14$
Mass_{N2O} emitted (tN_2O/yr) = $29\,191.68 \div 1.466 \times 0.0039 \times 0.012 \times 44/14$
Mass_{N2O} emitted (tN_2O/yr) = 2.93

Change in carbon stock (CO_2) = $(1\text{-}Ce) \times [\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc] \times 44/12$
Change in carbon stock (tCO_2/yr) = $0.97 \times 29\,191.68 \div 1.466 \times 0.535 \times 44/12$
Change in carbon stock (tCO_2/yr) = 3 7889.78

Drymill residues
Total mass of drymill residues = 2 166.091 tons/yr, density 611 kg/m3

Mass_{CO_2} emitted = $\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc \times Ce \times Gf_{CO_2} \times 44/12$
Mass_{CO_2} emitted (tCO_2/yr) = $2\ 166.091 \div 1.12 \times 0.535 \times 0.03 \times 0.5 \times 44/12$
Mass_{CO_2} emitted (tCO_2/yr) = 56.91

Mass_{CH_4} emitted = $\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc \times Ce \times Gf_{CH_4} \times 16/12$
Mass_{CH_4} emitted (tCH_4/yr) = $2\ 166.091 \div 1.12 \times 0.535 \times 0.03 \times 0.5 \times 16/12$
Mass_{CH_4} emitted (tCH_4/yr) = 20.69

Mass_{N_2O} emitted = $\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Nc \times GF_{N_2O} \times 44/14$
Mass_{N_2O} emitted (tN_2O/yr) = $2\ 166.091 \div 1.12 \times 0.0039 \times 0.012 \times 44/14$
Mass_{N_2O} emitted (tN_2O/yr) = 0.28

Change in carbon stock (CO_2) = $(1\text{-}Ce) \times [\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc] \times 44/12$
Change in carbon stock (tCO_2/yr) = $0.97 \times 2\ 166.091 \div 1.12 \times 0.535 \times 44/12$
Change in carbon stock (tCO_2/yr) = 3 680.10

Total GHG emissions associated with landfill decay is 6 546.73 tCO2eq/yr
Mass_{CO_2} emitted (tCO_2/yr) = 642.83
Mass_{CH_4} emitted (tCH_4/yr) = 233.75 or 4 908.8 tCO_2eq
Mass_{N_2O} emitted (tN_2O/yr) = 3.21 or 995.1 tCO_2eq

Change in carbon stock (tCO_2/yr) = 41 569.85

Forest decay

Residues disposed of in the forest are assumed to completely decompose within a year, with all carbon emitted. The carbon gas emissions are 90% CO_2 and 10% CH_4 [69]

As in the case of landfill disposal nitrogen contained within the tree will be emitted as N_2O during residue decay.

Calculation set 23: Emissions released in forest

Fraction of carbon released as gas = 100%
Fraction of nitrogen released as gas = 1.2%
Proportion forest gas that is CO_2 = 90%
Proportion forest gas that is CH_4 = 10%

Logyard and wetmill residues

Total mass of logyard and wetmill residues = 29 191.68 tons/yr
Mass_{CO_2} emitted = $\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc \times Ce \times Gf_{CO_2} \times 44/12$
Mass_{CO_2} emitted (tCO_2/yr) = $29\ 191.68 \div 1.466 \times 0.535 \times 0.03 \times 0.9 \times 44/12$
Mass_{CO_2} emitted (tCO_2/yr) = 1 054.66

Mass_{CH_4} emitted = $\text{Mass}_{\text{wet wood}} \div (1 + MC) \times Cc \times Ce \times Gf_{CH_4} \times 16/12$
Mass_{CH_4} emitted (tCH_4/yr) = $29\ 191.68 \div 1.466 \times 0.535 \times 0.03 \times 0.1 \times 16/12$
Mass_{CH_4} emitted (tCH_4/yr) = 42.61

N_2O emissions (tN_2O/yr) = R ÷ (1 + MC) × N × GF × 44/14
N_2O emissions (tN_2O/yr) = 29 191.68 ÷ 1.466 × 0.0039 × 0.012 × 44/14
N_2O emissions (tN_2O/yr) = 2.93

Drymill residues
Total mass of drymill residues = 2 166.091 tons/yr. density 611 kg/m3
$Mass_{CO2}$ emitted = $Mass_{wet\ wood}$ ÷ (1 + MC) × Cc × Ce × Gf_{CO2} × 44/12
$Mass_{CO2}$ emitted (tCO_2/yr) = 2 166.091 ÷ 1.12 × 0.535 × 0.03 × 0.9 × 44/12
$Mass_{CO2}$ emitted (tCO_2/yr) = 102.43

$Mass_{CH4}$ emitted = $Mass_{wet\ wood}$ ÷ (1 + MC) × Cc × Ce × Gf_{CH4} ×16/12
$Mass_{CH4}$ emitted (tCH_4/yr) = 2 166.091 ÷ 1.12 × 0.535 × 0.03 × 0.1 × 16/12
$Mass_{CH4}$ emitted (tCH_4/yr) = 4.14

$Mass_{N2O}$ emitted = $Mass_{wet\ wood}$ ÷ (1 + MC) × Nc × GF_{N2O} × 44/14
$Mass_{N2O}$ emitted (tN_2O/yr) = 2 166.091 ÷ 1.12 × 0.0039 × 0.012 × 44/14
$Mass_{N2O}$ emitted (tN_2O/yr) = 0.28

Total GHG emissions associated with forest decay is 3 133.95 tCO_2eq/yr
$Mass_{CO2}$ emitted (tCO_2/yr) = 1 157.1
$Mass_{CH4}$ emitted (tCH_4/yr) = 46.75 or 981.75 tCO_2eq
$Mass_{N2O}$ emitted (tN_2O/yr) = 3.21 or 995.1 tCO_2eq

Appendix 9.2.4.3) Emissions released during transport to landfill/forest

The average distance to the forest plantations is 70 km [38], it is assumed that the distance to a suitable landfill disposal site is half that of the distance to the forest. The total mass of residues requiring disposal is equal to the sum of the wetmill and drymill residues currently purchased by the fibreboard plant.
This amounts to 31 357.771 tons/yr.

It is assumed that a 30-ton payload truck would be used to transport the excess residues to either the forest or landfill. This would require a minimum of 1 046 return trips.
(31 357.771 tons/yr ÷ 30 tons/trip = 1 045.3 trips/yr)

The emissions of a typical 30-ton payload transport vehicle are:

NO_x	18.390 g/km
CH_4	0.110 g/km
NMVOC	3.494 g/km
CO	16.551 g/km
N_2O	0.055 g/km
CO_2	1 416.030 g/km

(see appendix 8)

Emissions released during transport to landfill

The assumed return distance to a suitable landfill is 70 km, number of trips 1 046. Therefore the emissions associated with transport of the excess residues to the landfill are:

NO_x	1 346 515.8 g/yr	= 1 346.516 kg/yr	
CH_4	8 054.2 g/yr	= 8.054 kg/yr	or 0.17 tCO_2eq
NMVOC	255 830.68 g/yr	= 255.831 kg/yr	
CO	1 211 864.220 g/yr	= 1 211.864 kg/yr	
N_2O	4 027.1 g/yr	= 4.027 kg/yr	or 1.24 tCO_2eq
CO_2	103 681 716.6 g/yr	= 103 681.716 kg/yr	or 103.68 tCO_2eq

Total GHG emissions from transport of residues to landfill is 105.09 tCO_2eq/yr

Emissions released during transport to forest

The average return distance to the forest plantations is 140 km [38], number of trips required is 1 046.

Therefore, the emissions associated with transport of the excess residues to the forest are double that of those attributed to transport of excess residues to the landfill.

The emissions attributed to transport of excess residues to the forest are:

NO_x	2 693.032 kg/yr	
CH_4	16.108 kg/yr	or 0.34 tCO2eq
NMVOC	511.662 kg/yr	
CO	2 423.728 kg/yr	
N_2O	8.054 kg/yr	or 2.50 tCO2eq
CO_2	207 363.432 kg/yr	or 207.36 tCO_2eq

Total GHG emissions from transport to forest is 210.20 tCO_2eq/yr

Appendix 10) Expected revenues

Appendix 10.1) Expected revenue from current residue markets sales

The average price obtained from the sawmill waste residues is R70/m^3. [71]

Calculation set 24: Revenue from residue sales to current markets

$$Cost_{residues}\left(\frac{R}{m^3}\right)=\frac{R70}{m^3}\times\left(1+\left(years\ from\ original\ value\times annual\ percentage\ increase\right)\right)$$

or

$$Cost_{residues}\left(\frac{R}{m^3}\right)=2.87X+70$$

Where:

X = years from original value; 2006 value

$$Revenue_{residues}\left(\frac{R}{yr}\right)=Cost_{residues}\left(\frac{R}{m^3}\right)\times\frac{m^3}{yr}$$

Table 40 : Revenue from residue sales to current markets

Revenue from Sawmill residues					
Year	Cost/m3	Annual % increase	Years from original value	Available (m3)	Revenue
2006	R 70.00	4.10%	0	35838	R 2,508,660.00
2007	R 72.87	4.10%	1	35838	R 2,611,515.06
2008	R 75.74	4.10%	2	35838	R 2,714,370.12
2009	R 78.61	4.10%	3	35838	R 2,817,225.18
2010	R 81.48	4.10%	4	35838	R 2,920,080.24
2011	R 84.35	4.10%	5	35838	R 3,022,935.30
2012	R 87.22	4.10%	6	35838	R 3,125,790.36
2013	R 90.09	4.10%	7	35838	R 3,228,645.42
2014	R 92.96	4.10%	8	35838	R 3,331,500.48
2015	R 95.83	4.10%	9	35838	R 3,434,355.54
2015	R 98.70	4.10%	10	35838	R 3,537,210.60
2017	R 101.57	4.10%	11	35838	R 3,640,065.66
2018	R 104.44	4.10%	12	35838	R 3,742,920.72
2019	R 107.31	4.10%	13	35838	R 3,845,775.78
2020	R 110.18	4.10%	14	35838	R 3,948,630.84
2021	R 113.05	4.10%	15	35838	R 4,051,485.90
2022	R 115.92	4.10%	16	35838	R 4,154,340.96
2023	R 118.79	4.10%	17	35838	R 4,257,196.02
2024	R 121.66	4.10%	18	35838	R 4,360,051.08
2025	R 124.53	4.10%	19	35838	R 4,462,906.14
2026	R 127.40	4.10%	20	35838	R 4,565,761.20

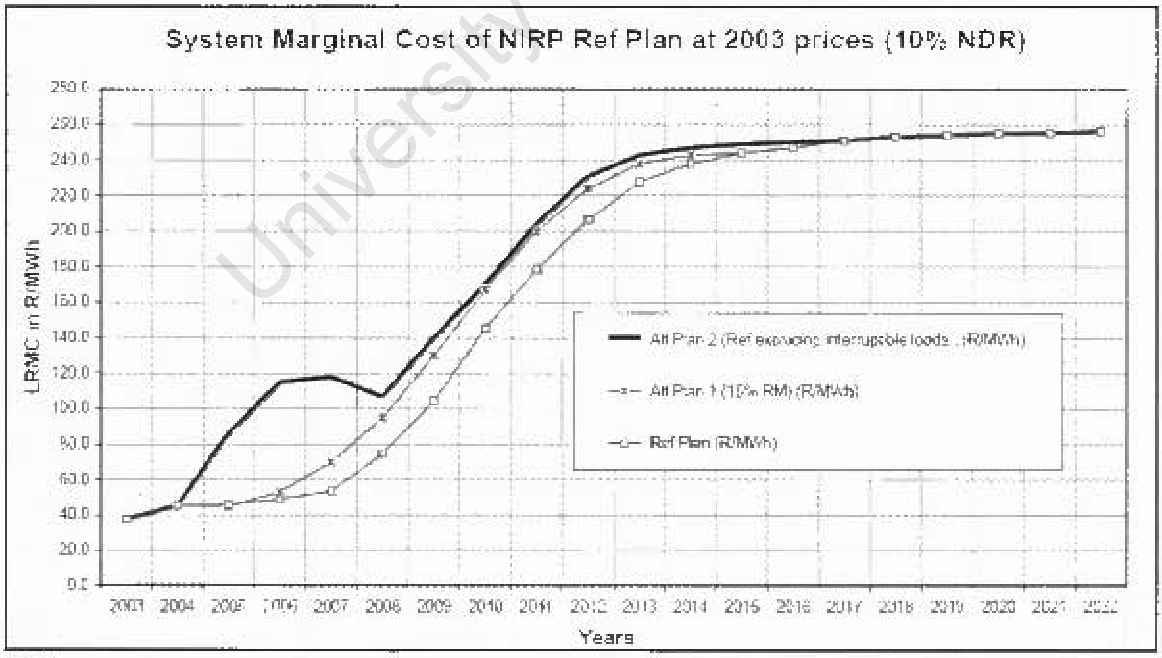
2027	R 130.27	4.10%	21	35838	R 4,668,616.26
2028	R 133.14	4.10%	22	35838	R 4,771,471.32
2029	R 136.01	4.10%	23	35838	R 4,874,326.38
2010-2029	Average R 106.75			Total 716760	Total R 77,944,066.20

Appendix 10.2) Expected revenue from electricity sales

Year 2006				
Tariff used. Ruraflex				
High-demand Season		Low demand season		
June to August		September to May		
86,32c + VAT = 98,40c/kWh	Peak	23.91c + VAT = 27.26c/kWh		
22.32c + VAT = 25.44c/kWh	Standard	14.59c + VAT = 16.63c/kWh		
11.86c + VAT = 13.52c/kWh	Off-peak	10.15c + VAT = 11.57c/kWh		
Average high season price for constant demand		29.84	c/kWh	
Average low season price for constant demand		15.47	c/kWh	
Average annual price for constant demand		19.09	c/kWh	

Defined time periods			
	Weekdays	Saterday	Sunday
Peak:	07 00-10:00	N/A	N/A
	18 00-20:00		
Standard:	06 00-07:00	07:00-12:00	N/A
	10 00-18:00	18:00-20:00	
	20:00 22:00		
Off-peak:	22 00-06:00	12:00-18:00	Whole day
	20 00-07:00		

Figure 24: Eskom's long run marginal electricity expansion costs



[46]

Calculation set 25: Revenue from electricity sales

$$Cost_{green\ elec}\left(\frac{R}{kWh}\right) = Previous\ years\ cost + Eskom\ annual\ production\ cost\ increase$$

$$Revenue_{green\ electricity}\left(\frac{R}{yr}\right) = Cost_{green\ electricity}\left(\frac{R}{kWh}\right) \times 42.5 \times 10^{6}\left(\frac{kWh}{yr}\right)$$

Table 41: Revenue from electricity sales based on present value of 19c/kWh

Revenue from sale of 'green' electricity 2010-2029					
Eskom's annual average long run marginal cost of electricity production from NIRP2 (Ref plan)			Price of green electricity based on increase in marginal cost of Eskom electricity		
Year	Cost (R/MWh)	Cost (R/kWh)	Cost (R/kWh)	Revenue from 42.5 GWh/yr	% price increase
2003	R 40.00	R 0.04			
2004	R 45.00	R 0.05			
2005	R 48.00	R 0.05			
2006	R 50.00	R 0.05	R 0.19	R 8,075,000.00	
2007	R 55.00	R 0.06	R 0.20	R 8,287,500.00	2.63%
2008	R 70.00	R 0.07	R 0.21	R 8,925,000.00	7.69%
2009	R 105.00	R 0.11	R 0.25	R 10,412,500.00	16.67%
2010	R 145.00	R 0.15	R 0.29	R 12,112,500.00	16.33%
2011	R 180.00	R 0.18	R 0.32	R 13,600,000.00	12.28%
2012	R 210.00	R 0.21	R 0.35	R 14,875,000.00	9.38%
2013	R 230.00	R 0.23	R 0.37	R 15,725,000.00	5.71%
2014	R 240.00	R 0.24	R 0.38	R 16,150,000.00	2.70%
2015	R 245.00	R 0.25	R 0.39	R 16,362,500.00	1.32%
2016	R 250.00	R 0.25	R 0.39	R 16,575,000.00	1.30%
2017	R 252.00	R 0.25	R 0.39	R 16,660,000.00	0.51%
2018	R 253.00	R 0.25	R 0.39	R 16,702,500.00	0.26%
2019	R 254.00	R 0.25	R 0.39	R 16,745,000.00	0.25%
2020	R 255.00	R 0.26	R 0.40	R 16,787,500.00	0.25%
2021	R 256.00	R 0.26	R 0.40	R 16,830,000.00	0.25%
2022	R 257.00	R 0.26	R 0.40	R 16,872,500.00	0.25%
2023	R 258.00	R 0.26	R 0.40	R 16,915,000.00	0.25%
2024	R 259.00	R 0.26	R 0.40	R 16,957,500.00	0.25%
2025	R 260.00	R 0.26	R 0.40	R 17,000,000.00	0.25%
2026	R 261.00	R 0.26	R 0.40	R 17,042,500.00	0.25%
2027	R 262.00	R 0.26	R 0.40	R 17,085,000.00	0.25%
2028	R 263.00	R 0.26	R 0.40	R 17,127,500.00	0.25%
2029	R 264.00	R 0.26	R 0.40	R 17,170,000.00	0.25%
		Sum total 2010-2029		R 325,295,000.00	3.46%

Table 42: Revenue from electricity sales based on present value of 36c/kWh

Revenue from sale of 'green' electricity 2010-2029					
Eskom's annual average long run marginal cost of electricity production			Price of green electricity based on increase in marginal cost of Eskom electricity		
Year	Cost (R/MWh)	Cost (R/kWh)	Cost (R/kWh)	Revenue from 42.5 GWh/yr	% price increase
2003	R 40.00	R 0.04			
2004	R 45.00	R 0.05			
2005	R 48.00	R 0.05			
2006	R 50.00	R 0.05	R 0.36	R 15,368,000.00	
2007	R 55.00	R 0.06	R 0.37	R 15,580,500.00	1.38%
2008	R 70.00	R 0.07	R 0.38	R 16,218,000.00	4.09%
2009	R 105.00	R 0.11	R 0.42	R 17,705,500.00	9.17%
2010	R 145.00	R 0.15	R 0.46	R 19,405,500.00	9.60%
2011	R 180.00	R 0.18	R 0.49	R 20,893,000.00	7.67%
2012	R 210.00	R 0.21	R 0.52	R 22,168,000.00	6.10%
2013	R 230.00	R 0.23	R 0.54	R 23,018,000.00	3.83%
2014	R 240.00	R 0.24	R 0.55	R 23,443,000.00	1.85%
2015	R 245.00	R 0.25	R 0.56	R 23,655,500.00	0.91%
2016	R 250.00	R 0.25	R 0.56	R 23,868,000.00	0.90%
2017	R 252.00	R 0.25	R 0.56	R 23,953,000.00	0.36%
2018	R 253.00	R 0.25	R 0.56	R 23,995,500.00	0.18%
2019	R 254.00	R 0.25	R 0.57	R 24,038,000.00	0.18%
2020	R 255.00	R 0.26	R 0.57	R 24,080,500.00	0.18%
2021	R 256.00	R 0.26	R 0.57	R 24,123,000.00	0.18%
2022	R 257.00	R 0.26	R 0.57	R 24,165,500.00	0.18%
2023	R 258.00	R 0.26	R 0.57	R 24,208,000.00	0.18%
2024	R 259.00	R 0.26	R 0.57	R 24,250,500.00	0.18%
2025	R 260.00	R 0.25	R 0.57	R 24,293,000.00	0.18%
2026	R 251.00	R 0.26	R 0.57	R 24,335,500.00	0.17%
2027	R 252.00	R 0.26	R 0.57	R 24,378,000.00	0.17%
2028	R 253.00	R 0.26	R 0.57	R 24,420,500.00	0.17%
2029	R 264.00	R 0.26	R 0.58	R 24,463,000.00	0.17%
		Sum total 2010-2029		R 471,155,000.00	2.09%

Appendix 10.3) Expected revenue from process steam sales

Calculation set 26: Revenue from process steam sales: present value of R60/ton

$$Cost_{steam}\left(\frac{R}{ton}\right)=\frac{R60}{ton}\times\left(1+\left(years\ from\ original\ value\times annual\ percentage\ increase\right)\right)$$

or

$$Cost_{steam}\left(\frac{R}{ton}\right)=3X+60$$

Where:

X = years from original value; 2006 value

$$Revenue_{residues}\left(\frac{R}{yr}\right)=Cost\left(\frac{R}{m^3}\right)\times\frac{m^3}{yr}$$

Table 43: Revenue from process steam sales based on present value of R60/ton

Revenue from CHP steam					
Year	Cost/ton	Annual % increase	Years from original value	Available (tons)	Revenue
2006	R 60.00	5.00%	0	78840	R 4,730,400.00
2007	R 63.00	5.00%	1	78840	R 4,966,920.00
2008	R 66.00	5.00%	2	78840	R 5,203,440.00
2009	R 69.00	5.00%	3	78840	R 5,439,960.00
2010	R 72.00	5.00%	4	78840	R 5,676,480.00
2011	R 75.00	5.00%	5	78840	R 5,913,000.00
2012	R 78.00	5.00%	6	78840	R 6,149,520.00
2013	R 81.00	5.00%	7	78840	R 6,386,040.00
2014	R 84.00	5.00%	8	78840	R 6,622,560.00
2015	R 87.00	5.00%	9	78840	R 6,859,080.00
2016	R 90.00	5.00%	10	78840	R 7,095,600.00
2017	R 93.00	5.00%	11	78840	R 7,332,120.00
2018	R 96.00	5.00%	12	78840	R 7,568,640.00
2019	R 99.00	5.00%	13	78840	R 7,805,160.00
2020	R 102.00	5.00%	14	78840	R 8,041,680.00
2021	R 105.00	5.00%	15	78840	R 8,278,200.00
2022	R 108.00	5.00%	16	78840	R 8,514,720.00
2023	R 111.00	5.00%	17	78840	R 8,751,240.00
2024	R 114.00	5.00%	18	78840	R 8,987,760.00
2025	R 117.00	5.00%	19	78840	R 9,224,280.00
2026	R 120.00	5.00%	20	78840	R 9,460,800.00
2027	R 123.00	5.00%	21	78840	R 9,697,320.00
2028	R 126.00	5.00%	22	78840	R 9,933,840.00
2029	R 129.00	5.00%	23	78840	R 10,170,360.00
2010-2029	Average R 100.50			Total 1576800	Total R158,468,400.00

Calculation set 27: Revenue from process steam sales; present value of R100/ton

$$Cost_{steam}\left(\frac{R}{ton}\right)=\frac{R100}{ton}\times\left(1+\left(years\ from\ original\ value\times annual\ percentage\ increase\right)\right)$$

or

$$Cost_{steam}\left(\frac{R}{ton}\right)=5X+100$$

Where:

X = years from original value: 2006 value

$$Revenue_{residues}\left(\frac{R}{yr}\right)=Cost\left(\frac{R}{m^3}\right)\times\frac{m^3}{yr}$$

Table 44: Revenue from process steam sales based on present value of R100/ton

Revenue from CHP steam					
Year	Cost/ton	Annual % increase	Years from original value	Available (tons)	Revenue
2006	R 100.00	5.00%	0	78840	R 7,884,000.00
2007	R 105.00	5.00%	1	78840	R 8,278,200.00
2008	R 110.00	5.00%	2	78840	R 8,672,400.00
2009	R 115.00	5.00%	3	78840	R 9,066,600.00
2010	R 120.00	5.00%	4	78840	R 9,460,800.00
2011	R 125.00	5.00%	5	78840	R 9,855,000.00
2012	R 130.00	5.00%	6	78840	R 10,249,200.00
2013	R 135.00	5.00%	7	78840	R 10,643,400.00
2014	R 140.00	5.00%	8	78840	R 11,037,600.00
2015	R 145.00	5.00%	9	78840	R 11,431,800.00
2016	R 150.00	5.00%	10	78840	R 11,826,000.00
2017	R 155.00	5.00%	11	78840	R 12,220,200.00
2018	R 160.00	5.00%	12	78840	R 12,614,400.00
2019	R 165.00	5.00%	13	78840	R 13,008,600.00
2020	R 170.00	5.00%	14	78840	R 13,402,800.00
2021	R 175.00	5.00%	15	78840	R 13,797,000.00
2022	R 180.00	5.00%	16	78840	R 14,191,200.00
2023	R 185.00	5.00%	17	78840	R 14,585,400.00
2024	R 190.00	5.00%	18	78840	R 14,979,600.00
2025	R 195.00	5.00%	19	78840	R 15,373,800.00
2026	R 200.00	5.00%	20	78840	R 15,768,000.00
2027	R 205.00	5.00%	21	78840	R 16,162,200.00
2028	R 210.00	5.00%	22	78840	R 16,556,400.00
2029	R 215.00	5.00%	23	78840	R 16,950,600.00
2010-2029	Average R167.50			Total 1576800	Total R264,114,000.00

Appendix 10.4) Expected revenue from water-heating sales

Calculation set 28: Revenue from water-heating sales

$$Cost_{Eskom\,elec} = Previous\,years\,cost\left(\frac{R}{kWh}\right) + Eskom\,annual\,production\,cost\,increase\left(\frac{R}{kWh}\right)$$

$$Revenue_{water-heating}\left(\frac{R}{yr}\right) = Cost_{Eskom\,electricity}\left(\frac{R}{kWh}\right) \times 49.95 \times 10^{6}\left(\frac{kWh}{yr}\right)$$

Table 45: Revenue from water-heating sales; present electricity value of 19c/kWh

Revenue from water- heating 2010-2029					
Eskom's annual average long run marginal cost of electricity production			Price of Eskom electricity based on increase in marginal cost of Eskom electricity		
Year	Cost (R/MWh)	Cost (R/kWh)	Cost (R/kWh)	Revenue from 49.95 GWh/yr	% price increase
2003	R 40.00	R 0.04			
2004	R 45.00	R 0.05			
2005	R 48.00	R 0.05			
2006	R 50.00	R 0.06	R 0.19	R 9 490 500.00	
2007	R 55.00	R 0.06	R 0.20	R 9 990 000.00	2.63%
2008	R 70.00	R 0.07	R 0.21	R 10 489 500.00	7.69%
2009	R 105.00	R 0.11	R 0.25	R 12 487 500.00	16.67%
2010	R 145.00	R 0.15	R 0.29	R 14 485 500.00	16.33%
2011	R 180.00	R 0.18	R 0.32	R 15 984 000.00	12.28%
2012	R 210.00	R 0.21	R 0.35	R 17 482 500.00	9.38%
2013	R 230.00	R 0.23	R 0.37	R 18 481 500.00	5.71%
2014	R 240.00	R 0.24	R 0.38	R 18 981 000.00	2.70%
2015	R 245.00	R 0.25	R 0.39	R 19 480 500.00	1.32%
2016	R 250.00	R 0.25	R 0.39	R 19 480 500.00	1.30%
2017	R 252.00	R 0.25	R 0.39	R 19 480 500.00	0.51%
2018	R 253.00	R 0.25	R 0.39	R 19 480 500.00	0.26%
2019	R 254.00	R 0.25	R 0.39	R 19 480 500.00	0.25%
2020	R 255.00	R 0.26	R 0.40	R 19 980 000.00	0.25%
2021	R 256.00	R 0.26	R 0.40	R 19,980 000.00	0.25%
2022	R 257.00	R 0.26	R 0.40	R 19,980,000.00	0.25%
2023	R 258.00	R 0.26	R 0.40	R 19,980,000.00	0.25%
2024	R 259.00	R 0.26	R 0.40	R 19,980 000.00	0.25%
2025	R 260.00	R 0.26	R 0.40	R 19,980 000.00	0.25%
2026	R 261.00	R 0.26	R 0.40	R 19,980 000.00	0.25%
2027	R 262.00	R 0.26	R 0.40	R 19,980,000.00	0.25%
2028	R 263.00	R 0.26	R 0.40	R 19,980,000.00	0.25%
2029	R 264.00	R 0.26	R 0.40	R 19,980,000.00	0.25%
		Sum total 2010-2029		R 382,617,000.00	3.46%

Table 46: Revenue from water-heating sales; present electricity value of 36c/kWh

Revenue from water-heating 2010-2029					
Eskom's annual average long run marginal cost of electricity production			Price of green electricity based on increase in marginal cost of Eskom electricity		
Year	Cost (R/MWh)	Cost (R/kWh)	Cost (R/kWh)	Revenue from 49.95 GWh/yr	% price increase
2003	R 40.00	R 0.04			
2004	R 45.00	R 0.05			
2005	R 48.00	R 0.05			
2006	R 50.00	R 0.05	R 0.36	R 17,982,000.00	
2007	R 55.00	R 0.06	R 0.37	R 18,481,500.00	1.38%
2008	R 70.00	R 0.07	R 0.38	R 18,981,000.00	4.09%
2009	R 105.00	R 0.11	R 0.42	R 20,979,000.00	9.17%
2010	R 145.00	R 0.15	R 0.46	R 22,977,000.00	9.60%
2011	R 180.00	R 0.18	R 0.49	R 24,475,500.00	7.67%
2012	R 210.00	R 0.21	R 0.52	R 25,974,000.00	6.10%
2013	R 230.00	R 0.23	R 0.54	R 26,973,000.00	3.83%
2014	R 240.00	R 0.24	R 0.55	R 27,472,500.00	1.85%
2015	R 245.00	R 0.25	R 0.56	R 27,972,000.00	0.91%
2016	R 250.00	R 0.25	R 0.56	R 27,972,000.00	0.90%
2017	R 252.00	R 0.25	R 0.56	R 27,972,000.00	0.36%
2018	R 253.00	R 0.25	R 0.56	R 27,972,000.00	0.18%
2019	R 254.00	R 0.25	R 0.57	R 28,471,500.00	0.18%
2020	R 255.00	R 0.26	R 0.57	R 28,471,500.00	0.18%
2021	R 256.00	R 0.26	R 0.57	R 28,471,500.00	0.18%
2022	R 257.00	R 0.26	R 0.57	R 28,471,500.00	0.18%
2023	R 258.00	R 0.26	R 0.57	R 28,471,500.00	0.18%
2024	R 259.00	R 0.26	R 0.57	R 28,471,500.00	0.18%
2025	R 260.00	R 0.26	R 0.57	R 28,471,500.00	0.18%
2026	R 261.00	R 0.26	R 0.57	R 28,471,500.00	0.17%
2027	R 262.00	R 0.26	R 0.57	R 28,471,500.00	0.17%
2028	R 263.00	R 0.26	R 0.57	R 28,471,500.00	0.17%
2029	R 254.00	R 0.25	R 0.58	R 28,971,000.00	0.17%
		Sum total 2010-2029		R 553,446,000.00	2.09%