A GATE-TO-GATE LIFE CYCLE ASSESSMENT OF A PULP AND PAPER MILL IN SOUTH AFRICA

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ABSTRACT

Life Cycle Assessment (LCA) is a tool for the evaluation of environmental impacts of a product, service or activity. It implies taking a life cycle perspective as lead principle, as opposed to traditional environmental legislation that looks at specific environmental impacts or industrial activities.

Firms in many industrial sectors face both regulatory and market pressure to consider and modify resource commitments and environmental impacts of products as well as being forced to consider environmental consequences of product systems outside their direct control. Thus adoption of LCA by industry is an indicator of the importance firms attach to environmental issues. By encouraging lower material and energy intensities and encouraging greater recycling, life cycle approaches provide long term benefits.

The two-year project jointly undertaken by the Pollution Research Group, Mondi Kraft and the Water Research Commission entails a *gate-to-gate* analysis of Mondi Kraft, Richards Bay, based on LCA methodology. The aim being, to depict in as much detail as necessary, the interaction of individual products (Baywhite and Baycel) and activities (cooking, chemical production, energy usage etc.) on the environment, and to supply decision-makers with information on the possibilities for improvement.

The boundary for the LCA study has been set as *gate-to-gate*, thus a Life Cycle Inventory (LCI) of all inputs and outputs into and out off the mill has been compiled. In compilation of the LCI, the guidelines as set out by the Nordic Pulp and Paper Institute have been followed. This has been conducted with a view to maintaining a developed methodology for the collection; processing and reporting of data, in such a way that LCA of forest products can be performed and combined in a more consistent way.

Significant LCA activities are now being conducted in all sectors of South African Industry, which include activities within firms, and between firms and academia. Export regulation in some cases, and market competition in others have driven LCA approaches in industry. LCA has not yet had a marked influence on environmental performance of product systems in South Africa, but with further learning and standardisation of life cycle thinking, significant and radical environmentally based innovations will be generated.

‘You can not control what you can not measure’ – Tom DeMarco

And

‘Nothing in Life is to be feared. It is to be Understood’ – Madam Marie Curie;

It is for these reasons that scientific environmental tools such as Environmental Impact Assessments, Environmental Management Systems and Life Cycle Assessments and Analysis have been developed.

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This dissertation is dedicated to all my family elders who have the Wisdom of Solomon.

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LIST OF ABBREVIATIONS

ACLCA	American Centre for Life Cycle Assessment
ADt	Air-dry Metric Ton
ALCANET	African Life Cycle Assessment Network
ALCAS	Australian Life Cycle Assessment Society
AOX	Absorbable Organic Halogen
BAT	Best available technology
BOD	Biological Oxygen Demand
ECA	Environmental Conservation Act
EIA	Environmental Impact Assessment
ESP	Electrostatic Precipitation
FAO-UN	Food and Agriculture organisation of the United Nations
GHG	Green House Gas
HFO	Heavy Fuel Oil
HVLC	High Volume, Low Concentration
IPPC	Intergovernmental Panel on Climate Change
ISO	International Organisation of Standardisation
JLCA	Life Cycle Assessment Society of Japan
KCL	Finnish Pulp and Paper Institute
KSLCA	Korean Society for Life Cycle Assessment
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LVHC	Low Volume, High Concentration
MKRB	Mondi Kraft Richards Bay
NEMA	National Environmental Management Act
NordPap	Nordic Research and Development Programme
OBA	Optical Brightening Agent
PAMSA	Paper Manufacturers Association of South Africa
PM1	Paper Machine 1
PM2	Paper Machine 2
SA	South Africa
SANAS	South African National Association of Standards
SETAC	Society of Environmental and Toxicological Chemistry

STFI	Swedish Pulp and Paper Institute
TAPPSA	Technical Association of Pulp and Paper South Africa
UNEP	United Nations Environmental Programme
US-EPA	United States Environmental Protection Agency
WBCSD	World Business Council for Sustainable Development
WMO	World Meteorological Organisation
VOC	Volatile Organic Compound

GLOSSARY

A

Absorbable Organic Halogen (AOX)

A measure of the amount of chlorine that is chemically bound to the soluble organic matter in the effluent.

Accepts

Accepted portion of pulp after cleaning and or screening operation.

Activated Sludge

The biomass produced by rapid oxygenation of effluent.

Active Alkali (AA)

Caustic (NaOH) and Sodium sulphide (Na_2S) expressed as Na_2O in alkaline pulping liquor.

Additives

Clay, fillers, dyes, sizing and other chemicals added to pulp to give the paper greater smoothness, colour, and fibred appearance of other desirable attributes.

Air Dry (AD)

Refers to the weight of dry pulp/paper in equilibrium with the atmosphere. Though the amount of moisture in dry pulp/paper will depend on the atmospheric condition of humidity and temperature but as a convention 10% moisture is assumed in air-dry pulp/paper.

Air Drying

Using hot air to dry pulp or paper sheets.

Alum

The paper maker alum is hydrated Aluminium Sulphate $\{A1_2(SO_4)_3\}$. It is used to adjust the pH of the mill water or as a sizing chemical in combination with rosin size.

Approach Flow System

The stock flow system from Fan pump to headbox slice.

B

Bagasse

Sugar cane residue left after extracting the juice

Bark

The outer protective layer of a tree outside the cambium comprising the inner bark and the outer bark. The inner bark is a layer of living bark that separates the outer bark from the cambium and in a living tree is generally soft and moist. The outer bark is a layer of dead bark that forms the exterior surface of the tree stem. The outer bark is frequently dry and corky.

Barker or Debarker

The equipment used to remove bark from wood.

Batch Cooking

A chemical pulping process in which a discrete quantity of fibrous raw material is individually processed.

Beating and Refining

The mechanical treatment of the fibres in water to increase surface area, flexibility and promote bonding when dried.

Biocide

A biological control chemical such as fungicide or bactericide used in papermaking.

Biochemical Oxygen Demand (BOD)

When effluent containing biodegradable organic matter is released into receiving water, the biodegradation of the organic matter consumes dissolved oxygen from the water. The BOD of an effluent is an estimate of the amount of oxygen that will be consumed in five days following its release into a receiving water, assuming a temperature of 20°C.

Black Liquor

The liquor that exits the digester with the cooked chips at the end of the Kraft cook is called “black” liquor.

Bleach Plant

Section of a pulp mill where pulp is bleached.

Bleaching

A chemical process used to whiten and purify the pulp. Bleaching also adds to the sheet's strength and durability.

Blow

It is the discharging of pressure and contents of the digester in to blow tank.

Blow Tank

The tank in which cooked chips and spent liquor is blown from digester at the end of the cooking cycle.

Board

Thick and stiff paper, often consisting of several plies, widely used for packaging or box making purposes. Its grammage normally is higher than 150g/m^2 or thickness is more than 9 point (thousandth of an inch).

Bone Dry

Moisture free or zero moisture.

Brightness

The reflectance or brilliance of the paper when measured under a specially calibrated blue light. Not necessarily related to colour or whiteness. Brightness is expressed in %.

Broke

Paper that is unusable because of damage or non-conformity to the specifications. It is put back into the pulping system.

Brown Stock

The unbleached chemical pulp.

C

Causticising

It is the process in which Green Liquor is converted into “white” liquor. Technically speaking it is the process of converting sodium carbonate into sodium hydroxide.

Cellulose

It is a high molecular weight, stereoregular and linear polymer of repeating beta-D-glucopyranose units. Simply speaking it is the chief structural element and major constituents of the cell wall of trees and plants.

Chemical Oxygen Demand (COD)

The amount of oxygen consumed in complete chemical oxidation of matter present in wastewater indicates the content of slowly degradable organic matter present. COD is easier to measure compared to BOD (Biological Oxygen Demand).

Chemical Recovery

It is the process in which cooking chemicals are recovered.

Chip

Wood chips produced by a chipper, used to produce pulp, fibreboard and particleboard and also as fuel.

Consistency

The percentage of bone dry solids by weight in pulp or stock.

Contraries

Improper drying of ink. Ink vehicle has been absorbed too rapidly into the paper leaving a dry, weak pigment layer which dusts easily.

Cooking

Reacting fibrous raw material with chemical under pressure and temperature to soften and remove lignin to separate fibres.

Cooking Liquor

Liquor made up of selected chemicals and used for cooking pulp e.g. cooking liquor in kraft pulping mainly consist of NaOH and Na_2S.

D

Deckle

The width of the wet sheet as it comes off the wire of a paper machine. Also defined as the wood frame resting on or hinged to the edges of the mould that defines the edges of the sheet in handmade papermaking or strap or board on the wet end of a paper machine that determines the width of the paper web.

Delignification

The removal of lignin, the material that binds wood fibres together, during the chemical pulping process.

Digester

The reaction vessel in which wood chips or other plant materials are cooked with chemicals to separate fibre by dissolving lignin.

Dioxin

A group of 75 chlorinated compounds. Dioxins are formed in a complex process where chlorine combines with other additives during bleaching.

Dirt Count

The average amount of dirt specks in a specific size of paper area. Both virgin sheets and recycled sheets have “dirt” although recycled paper usually has a slightly higher dirt count than virgin paper. However, it rarely affects recycled papers quality and use.

Dispersants

Substances such as phosphates or acrylates that cause finely divided particles to come apart and remain separate from each other in suspension.

Dregs

The solids which settle down in the clarifiers in the Causticising process.

Dry End

That part of the paper machine where the paper is dried, surface sized, calendered and reeled.

Drying

This is the final stage of water removal from wet web of the paper formed on wire. After pressing the moisture content of the web is approximately 40-45%. The remaining water (up to 95% dryness) is removed by evaporation. This is done by moving the web around a series of steam heated iron drums in the dry end of the paper machine.

E

Effective Alkali

Caustic (NaOH) and one half of Sodium sulphide (05*Na_2S) expressed as Na_2O in alkaline pulping liquor.

Electrostatic Precipitator (ESP)

Used to clean up flue and process gases. Removes 99.5-99.8% of dust particles emitted from recovery boilers, limekilns and bark-fired boilers.

Elemental Chlorine Free (ECF)

ECF papers are made exclusively with pulp that uses chlorine dioxide rather than elemental chlorine gas as a bleaching agent. This virtually eliminates the discharge of detectable dioxins in the effluent of pulp manufacturing facilities.

F

Fibre or Fibre

The slender, thread like cellulose structures that forms the main part of tree trunk and from separated suitably treated, cohere to form a sheet of paper.

Filler

Any inorganic substance added to the pulp during manufacturing of paper.

Fourdrinier

Names after its inventor, the Fourdrinier papermaking machine is structured on a continuously moving wire belt onto which a watery slurry or pulp is spread. As the wire moves the water is drained off and pressed out and the paper is then dried.

G

Grade

Papers are differentiated from each other by their grade. Different grades are distinguished from each other on the basis of their content, appearance, manufacturing history, and/or their end use.

Grammage

Weight in grams of one square meter of paper or board (g/m^2); also basis weight.

Green Liquor

The liquor that results when the inorganic smelt from the recovery furnace is dissolved in water is called “green” liquor.

H

Hardwood

Wood from trees of angiosperms class, usually with broad leaves. Trees grown in tropical climates are generally hardwood. Hardwood grows faster than softwood but have shorter fibres compared to softwood.

Head Box

The part of the paper machine whose primary function is to deliver a uniform dispersion of fibres in water at the proper speed through the slice opening to the paper machine wire.

Hydropulper

Equipment used to slush broke/paper into pulp

Integrated Mill

A mill which starts with logs or wood chips and first produces wood pulp which is then processed to make paper or board.

I

ISO Brightness

The brightness of paper and board measured at a wavelength of 457 nanometres under standard conditions.

K

Kappa Number

A term used to define the degree of delignification. Modified permanganate test value of pulp which has been corrected to 50 percent consumption of the chemical. Kappa number has the advantage of a linear relationship with lignin content over a wide range. Kappa Number x 0.15% = % lignin in pulp

Kraft Pulp

Chemical wood pulp produced by digesting wood by the sulphate process (q.v.). Originally a strong, unbleached, coniferous pulp for packaging papers, kraft pulp has now spread into the realms of bleached pulps from both coniferous and deciduous woods for printing papers.

Kraftliner

Paperboard of grammages of 120g and more, generally made from bleached or unbleached sulphate pulp and used as an outer ply in corrugated board.

L

Lignin

A complex constituent of the wood that cements the cellulose fibres together. Lignin is brown in colour. Lignin is largely responsible for the strength and rigidity of plants, but its presence in paper is believed to contribute to chemical degradation. To a large extent, lignin can be removed during manufacturing.

Lime Sludge or Sludge

Sludge of calcium carbonate ($CaCO_3$) formed during preparation of white liquor in the chemical recovery process.

Linerboard

The inner and outer layers of paper that form the wall of a corrugated board

M

Machine Chest

Usually the last large chest or tank that contains thick-stock pulp before it is made into paper.

Market Pulp

Pulp which is made to be used elsewhere for the production of paper, dried to reduce freight costs.

Mill

The physical site where paper is manufactured; also refers to the company that manufactures paper.

Moisture Content

The amount of moisture or water in a sheet of paper, expressed in percent . 6-7% is desirable.

O

Optical Brightener

Fluorescent dyes added to paper to enhance the visual brightness; the dye absorbs ultraviolet light and re-emits it in the visual spectrum.

P

Particulate

Airborne solid impurities such as those present in gaseous emissions (sodium sulphate, lime, calcium carbonate, soot).

Press

A combination of two or more rolls used to press out water from wet paper web.

Pulp

A suspension of cellulose fibres in water.

Pulper

Unit for defibrating (slushing) pulps and paper machine broke, usually at the wet end of the paper machine.

R

Retention Aid

Chemical additives, especially high molecular weight copolymers of acrylamide, designed to increase the retention efficiency of fine materials during paper formation.

Rosin

Rosin, a natural resin from pine trees in combination with alum, is used for internal sizing of paper in acidic paper making. The chemical formula of rosin is $C_{19}H_{29}COOH$.

Rosin Size

Partially or completely saponified (neutralized) rosin. The chemical formula of rosin is $C_{19}H_{29}CONa$.

S

Salt Cake

Or sodium sulphate added to the black liquor to compensate for the soda loss.

Screen

Device used to remove large solids particles such as fibre bundles and flakes from stock. In earlier years screens used were open type and could deal with thin stock only. Modern screens are closed (pressurized) and can handle low, medium and even high consistency stock. Perforations in the screen basket can be circular, counter shrink or slotted. The screen used before the headbox not only removes large particles but also aligns fibres in the direction of stock flow.

Shives

Small bundles of fibres that have not been separated completely during pulping.

Sizing

The treatment of paper which gives it resistance to the penetration of liquids (particularly water) or vapours. Sizing improves ink holdout.

Smelt

Inorganic chemicals obtained in molten form from the recovery furnace.

Softwood

Woods obtained from coniferous trees. Generally grown in cold climates. Softwood grows slower than hardwood but has longer fibres compared to hardwood.

Spent Liquor

Liquor recovered from cooked pulp.

Starch

A natural product from corn, potatoes, tapioca, etc., and used for dry strength. Cationic starch is added at the paper machine wet end.

Stock

A term used to define pulp after mechanical (refining or beating) and /or chemical treatment (sizing, loading, dying etc.) in the paper making process. A pulp ready to make paper.

Stock Preparation

Collective term for all treatment necessary for the preparation of the stock before it reaches the paper machine.

T

Talc

Mineral used in papermaking as a filler and coating pigment.

Testliner

Mainly produced from waste paper used as even facing for corrugated board or as liner of solid board.

Total Alkali

NaOH + Na2S + Na2CO3 + 0.5*Na2SO3 all expressed as Na2O in alkaline pulping liquor.

Totally Chlorine Free (TCF)

Totally chlorine free applies to virgin fibre papers that are unbleached or processed with a sequence that includes no chlorine or chlorine derivatives. (Also see ECF).

W

White Liquor

White liquor is the aqueous solution of sodium hydroxide & sodium sulphide used as the cooking liquor in Kraft pulping.

White Top Liner

A two-ply sheet comprised of one bleached and one unbleached layer.

Wrapper

The materials, consisting usually of paper or paperboard, sometimes with treatment for moisture barrier properties, which are used to protect the roll or pile from damage.

CHAPTER ONE: An introduction

This chapter introduces the mill under investigation, the requirements of the mill with regards to this study and an introduction into the life cycle assessment (LCA) methodology used to fulfil these requirements.

1.1 Introduction

Papermaking has always been considered an art form and only recently (since the late 60's) has the industry at large begun initiating and implementing scientific reasoning into the manufacturing process. Along with this revolution has come the added burden of acknowledging that the industry does have a significant environmental burden due its use of non-renewable resources and its emissions to water and air.

The isolation of South Africa (SA) saw local mills operate from an economic perspective only. With the abolishment of sanctions, the export market for SA paper and board grew. With this newfound freedom came the increased demand for improvement of standards, not just economical, but social and environmental accountability as well.

The Mondi mill at Richards Bay is South Africa's largest exporter of bleached pulp. The mill produces two products, Baycel, bleached hardwood pulp sheets which are supplied to the local pulp and paper market in South Africa and Baywhite, a white top linerboard consisting of a bleached hardwood top liner and unbleached softwood underliner which is exported. The mill is fully integrated and the process begins with pine and eucalyptus as the raw input material.

The tool, Life Cycle Assessment, is based on scientific methodology and is used to determine the burdens associated with a product, service or activity from inception to disposal (i.e. cradle-to-grave). These burdens are classified into impact categories that enable the user to determine specific hotspots within a process. These categories can be weighted and adjusted to suit the geological, social and economical situation encountered by that particular study. Where global set standards and weightings are used, the comparison between different studies resulting in the same product, activity or service can be facilitated.

This study scientifically compares the environmental burdens of manufacturing the products produced at Mondi Kraft Richards Bay Mill (MKRB), Baycel and Baywhite.

MKRB commissioned this study to determine the scientific environmental accountability of its two products and to pinpoint the mill processes that required immediate focus due to its contribution to the overall burden. The results of this study will also be used for eco-labelling purposes in the export market.

The scope of the study has been set as *gate-to-gate* and therefore excludes transport, forestry, chemical and product development by service providers, usage, disposal and or recycling of the products.

This study can be used in future studies that require the manufacturing of bleached kraft market pulp as input or output. The results of producing 1 BDton of Baycel has been compared to that of a similar process LCA conducted in Finland and gives the South African industry a benchmarking standard towards which to aim.

The impact categories are enumerated as follows: climate change, ozone depletion, acidification, eutrophication, summer smog, winter smog, pesticides and carcinogenic substances. An inventory of all input and outputs required and produced by the production of either 1 BDton of Baycel off paper machine one (PM1) or 1 BDton of Baywhite off paper machine two (PM2) have been tabulated and the contributions of these inventories have been assigned to the related impact category. The impacts have been 'scored' on the basis of manufacturing 1 BDton of saleable quality Baycel or 1 BDton of saleable quality Baywhite, which have been assigned as the functional units of the two products under study.

This study was guided by research conducted by the Nordic Research and Development Programme (NordPap) and the LCA work done by the Finnish Pulp and Paper Research Institute (KCL). The impact assessment has been accomplished using the *Eco-Indicator* 95 methodology that uses the distance to target method in determining characterisation and weighting factors.

1.2 The Aim and Objectives of the study

The general aim of this study is to compile and document local information relating to the production of pulp and paper in South Africa. The industry has been reliant on international data that does not necessarily reflect the emissions and resource usage factors that impact on local industry and has to a certain extent seen the industry being pressurised by opinion and external drivers without sound scientific backup.

The *Kraft process* of producing pulp and paper is used worldwide and has economical benefits due to the reclamation; regeneration and re-use of cooking chemicals and the specific benefits or pit-falls require identification and attention.

Questions that could be answered by further studies incorporating this study are: Is it environmentally beneficial to regenerate cooking chemicals, or should it be used as a secondary input to a different process and should new cooking chemicals be manufactured from scratch? Does the energy generated by the process have a greater environmental impact if coal is burnt on-site to generate power or if total power requirements are supplied from the national grid?

These questions have not been dealt with in this study, as the main objective has been to fulfil the needs of MKRB who are the project sponsors and to obtain a masters degree for the author.

The specific objectives of the study are therefore:

- To conduct a *gate-to-gate* study on the production of 1 bone-dry metric tonne (BDt) of Baycel off PM1 using LCA methodology.
- To conduct a *gate-to-gate* study on the production of 1 BDt of Baywhite off PM2 using LCA methodology
- To determine the environmental impact category that is most impacted on and by which process.
- To determine whether the processes incurred to produce 1 BDt of Baywhite have a greater or lesser impact on the environment compared to the processes incurred in the generation of 1 BDt of Baycel
- To pinpoint specific processes that contributes significantly to the total environmental burden of either product such that improvement alternatives can be investigated.
- To develop South African pulp and paper industry data that can be used for further LCA studies and as an industry benchmark.

1.3 Structure and Presentation of the Dissertation

Two standards were adhered to in the structuring of this dissertation. The first was the reporting requirements as per the Nordic guidelines for pulp and paper LCA [Lindfors L., 1995]. This is to facilitate comparison between LCA studies relating to pulp and paper and for future studies. The second relates to the academic requirements of a dissertation in fulfilment of the authors degree.

The introduction gave a brief insight into the study and the proceeding chapters elaborate on details of LCA and the pulp and paper industry.

Chapter two gives a history of LCA, describes its development, methodology and applications. It investigates the necessity for tools such as LCA, and its development over the years. It also introduces the software tools available and the development thereof for LCA. The chapter aims to provide the reader with information on the methodology and nature of LCA's and the relevance to industry.

The proceeding chapter, **Chapter Three**, introduces the pulp and paper industry and gives a brief history of the industry and its economic importance to South Africa. This aims to impart to the reader the importance of developing a **sustainable** local pulp and paper industry and the role of the company under study, Mondi, in this quest. The history of Mondi and specifically Richards Bay Mill is discussed to ascertain its role in the SA pulp and paper industry and hence conclude the relevance and importance of the results of this study to the SA industry.

An overview of the Richards Bay Mill process, the kraft process, is discussed as well as an overview of each of the processes that occur at the different plants or modules. This aims to give the reader a general description and knowledge of paper and pulp manufacturing.

Chapter Four links the LCA tool and the pulp and paper industry by highlighting previous research done in this regard. The aim of this chapter is to enlighten the reader on the relevance and importance of this study and its applicability to future SA research in this field based on the foundations established by this study. Important conclusions are drawn from the literature reviewed.

Chapter Five highlights the different stages of the study (as discussed in chapter two) prior to the Life Cycle Inventory (LCI) stage and presents the boundary, scope, functional units and objectives of this study.

In **Chapter Six**, the LCI data is presented for each module of the mill under study and the description, assumptions and methodology of each is discussed. The problems experienced during the collection of data are also discussed. The results of the impact assessment phase and the methodology applied to this study are also presented.

Chapter Seven is the final phase of the LCA where the results and data presented in the previous chapter are interpreted. A comparison between an international manufacturing process and that of this study is compared as a benchmarking exercise.

Chapter Eight is the concluding chapter of this study and summarises the results of producing Baycel and Baywhite. It also attempts to provide recommendations to improve the environmental performance of Mondi Kraft Richards Bay.

CHAPTER TWO: Life Cycle Assessment

This chapter introduces Life Cycle Assessment, as a tool to measure environmental impacts. Its history, development, methodology and applications are discussed.

2.1 The Need

Industry is considered the greatest culprit towards the exacerbation of environmental degradation by its large-scale consumption of natural resources and emission of pollutants [Park, 1998]. These affects have resulted since the early 60's in global initiatives towards improvement or at least continuing decline of negative impacts on the environment.

Spear heading this global struggle is the concept of sustainable development, which can be defined as:

> *...the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs...*
>
> (Brundtland Report, 1987)

The definition quoted is simple yet profound when one investigates the means of accomplishing this. How does civilisation ensure that its need for escalating levels of comfort, convenience and progress, through industrialisation and globalisation, is controlled and contained such that our children can enjoy the pleasures of the earth and all its resources?

Bjorn Stigson, the president of the World Business Council for Sustainable Development (WBCSD) is quoted as saying:

> *…Nowadays, burying a few well-worn platitudes about "a profound concern for the environment" and "an unshakeable commitment to behaving in a socially responsible manner" deep within a company's annual report no longer cuts the mustard. Stakeholders want chapter and verse. They want data. They want transparency. In short, they want greater corporate accountability…'*

Public pressure regarding matters of environmental concern, have driven organisations with strong environmental affiliations and opinions, such as *Green Peace* to investigate and tackle industry regarding their impacts.

In 2000, the then Minister of Environmental Affairs and Tourism is quoted as saying:

> *...In South Africa we are faced with the realisation that we can no longer rely on what was once considered a limitless supply of natural resources. This is evident in the country's natural mineral wealth, fauna, flora, fisheries and fresh water. We see emerging signs of land degradation (exacerbated by apartheid policy of the past), negative consequences of energy generation, and inappropriate waste disposal practices. The poorer sectors of society in particular have often had to bear a disproportionate burden of the negative consequences of the economic exploitation of our resources…The Bill of Rights includes an environmental right which acknowledges a right to an environment conducive to health and well being and exhorts the government to secure sustainable development…*
>
> (Glazewski J., 2005)

National legislation such as the *National Environmental Management Act of 1998* (NEMA) and the *Environmental Conservation Act of 1989* (ECA) are aimed at preventing the exploitation of South Africa's natural resources and promote *cleaner production* and *waste minimisation* efforts.

In responsive to the drivers above, there have been several tools created to assist in reaching a global solution.

2.2 Introduction to Life Cycle Thinking

A products *life cycle* begins when raw materials and natural resources are extracted from the environment. It is then manufactured, transported, used and finally either recycled or disposed. At every stage of the life cycle there are emissions and consumption of resources, which require quantification and impact evaluation. LCA systematically describes and assesses all flows to and from nature, from a cradle to grave perspective (earth to earth).

The *Life Cycle Initiative* is a response to the call from governments for a life cycle economy in the Malmo Declaration (2000). It contributes to the 10-year framework of programmes to promote sustainable consumption and production patterns, and is a joint *United Nations Environment Programme* (UNEP) and *Society of Environmental Toxicology* *and Chemistry* (SETAC) partnership to foster life-cycle thinking around the world through the development of an international *life-cycle management* (LCM) framework, project-specific activities and databases of best available LCA methods and data.

The WSSD plan of implementation states:

> *'…We must develop production and consumption policies to improve the products and services provided, while reducing environmental and health impacts, using, where appropriate, science based approaches, such as Life Cycle Analysis...'*

(UNEP Life Cycle Initiative Background Information)

2.3 The Evolution of Life Cycle Analysis

In the early years (mid 1960's), LCA studies were generally commissioned by clients who were interested primarily in the solid waste aspects of total manufacturing and use systems, especially for packaging products. The energy and other environmental information was just a "bonus". In about 1975, the interest turned to energy. In 1988, the primary interest returned to solid waste, but was quickly replaced by a more balanced concern about the broad areas of resource use and environmental emissions. [Ecobilan, 2004]

In 1969, Teastley carried out the first multi-criteria LCA for The Coca-Cola Company [Weidema, 1997]. The study took into account raw material extraction to waste disposal. The goal of the study was to determine the following:

- Choice between glass and plastic for the product bottling
- Choice between internal or external bottle production,
- End of life options (recycling or one way) for the chosen bottle.

The study revealed the plastic bottle as the best choice, contrary to all expectations. The complete results of this study were never published, but a summary of the study was published in a 1976 science magazine.

With the evolution of LCA, coupled with the growing number of practitioners, a rapid diversification of the methodology and studies of the same product giving vastly different results prompted discussions on the validity of comparisons, which lead the scientific community to go into a standardisation process. A brief history of these landmarks is presented on the following page.

- 1984: the Swiss Federal laboratories for Materials Testing and Research published a report titled *'The Ecological Report of Packaging Material'*
- 1991: The SETAC began an advisory group to advance the science, practice and applications of LCA.
- March 1992: First European Scheme on Eco-labels
- June 1992: Creation of SPOLD, creation of data exchange standard between 1995 and 1996. (SPOLD is an association of industries interested in accelerating the development of LCA as an accepted management tool for the necessary restructuring of company policies towards sustainable development.)
- 1996: NF X30-300, first standard in France for LCA
- 1997 to 2000: ISO 14040, 14041, 14042, 14043 international series of standard defining the different stages of the LCA methodology
- 1999 to 2001: ISO 14020, 14025, 14048, 14049 series of standard and technical documents concerning communication, environmental declaration directions and working methods.

Today, LCA is driven by external forces such as the European Eco-labels, SPOLD, SETAC and various global LCA organisations (e.g. African LCA Network (ALCANET), American Centre for LCA (ACLCA), Australian LCA Society (ALCAS), LCA Society of Japan (JLCA), Korean Society for LCA (KSLCA), etc.), and is integrated into environmental management programmes motivated by market awareness, public perceptions, export requirements and cost savings.

The rapid growth of LCA is evident by the number of journals devoted to it. *'The International Journal of Life Cycle Assessment'* was the first published and is a forum for:

- Scientists developing LCA
- LCA practitioners
- Managers concerned with environmental aspects of products
- Governmental environmental agencies responsible for product quality
- Scientific and industrial societies involved in LCA development
- Ecological institutions and bodies.

The US-EPA website provides a list of publications, books, standards and web sites that contain information on both managing and conducting LCA.

As part of a Tufts University study (1994) requested by the US Department of Energy, the team focused on evaluating the current trend and issues that are driving LCA internationally. The consensus reached is that LCA is driven by external forces such as eco-labels and the International Organisation of Standards (ISO) and is integrated into environmental management programs, motivated by market awareness, public perception, and cost savings [Breville et al., 1994].

2.4 Why Perform LCA?

Of the tools developed such as, *Environmental Impact Assessment* (EIA), *Eco-labelling* etc., LCA is the only one that studies a product, process or service from *earth to earth*. A collection of processes that together perform a specific function forms a system, and LCA is the only environmental tool, which is capable of considering all the components of this system from an environmental point of view [Curran, 1996].

LCA is used for identification of product improvement hotspots, to support sound decision-making and to market products. Companies use it as an internal decision making tool to incorporate environmental improvements into the design and development of its products and packaging. Due to legislative pressure and public interest, companies are using EIA and LCA to make environmentally sound business choices. Government has used LCA to compare the impacts of alternative products for legislative decision-making and the development of strategic policies [Ross and Evans, 2002]. The World Bank is seeking to adopt many of the principles behind LCA for assessing the worthiness of projects under consideration for financing.

A study conducted by Parker and Haydock states:

> *…SmithKline Beecham sees LCA as a management tool to aid integrity, as well as to help gain a competitive edge. After all, market research surveys suggest that green consumers are still alive and well and they want environmentally responsible products and packaging. Few of these consumers are willing to pay extra for such environmental responsibility, of course, but SmithKline Beecham's experience of LCA suggests that this is not necessarily unrealistic: saving energy and raw materials leads to cost benefit just as much as it leads to environmental benefit…*

Similarly, the identification of process hotspots in this study and the payback from optimisation of the identified processes could lead to cost savings.

Without looking at the holistic picture regarding processes, products and services, companies are at risk of misdirecting a great deal of time and effort at processes or products that contribute relatively little to the overall problem. Without comparing operations in a systematic way, the environmental applications of options such as product substitution remain unknown and the danger of **trading** environmental impacts rather than an overall reduction of impacts exists [Usman and Valiant, 1995].

All products have some impact on the environment and some use more resources, cause more pollution or generate more waste than others. The aim is to identify those, which are most harmful.

LCA is applied to industry to identify areas where improvements can be made, in environmental terms. Alternatively, it may be intended to provide environmental data for the public or for government.

Even for those products whose environmental burdens are relatively low, the LCA should help to identify those stages in production processes and in use, which cause or have the potential to cause pollution and those, which have a heavy material or energy demand.

Breaking down the manufacturing process into detail can be an aid to identifying the use of scarce resources, showing where a more sustainable product could be substituted [World Resource Foundation, 1995].

2.5 What is LCA?

LCA is described as [modified from Consoli et al, 1993]:

> '*A process to evaluate the environmental burdens associated with a product system, or activity by identifying and quantitatively or qualitatively describing the energy and materials used, and wastes released to the environment, and to assess the impacts of those energy and material uses and releases into the environment. The assessment includes the entire life cycle of the product or activity, encompassing extracting and processing raw material; manufacturing, distribution; use, re-use, maintenance: recycling and final disposal: and all transportations involved. LCA addresses environmental impacts of the system under study in the areas of ecological systems, human health and resource depletion. It does not address economic or social effects*'

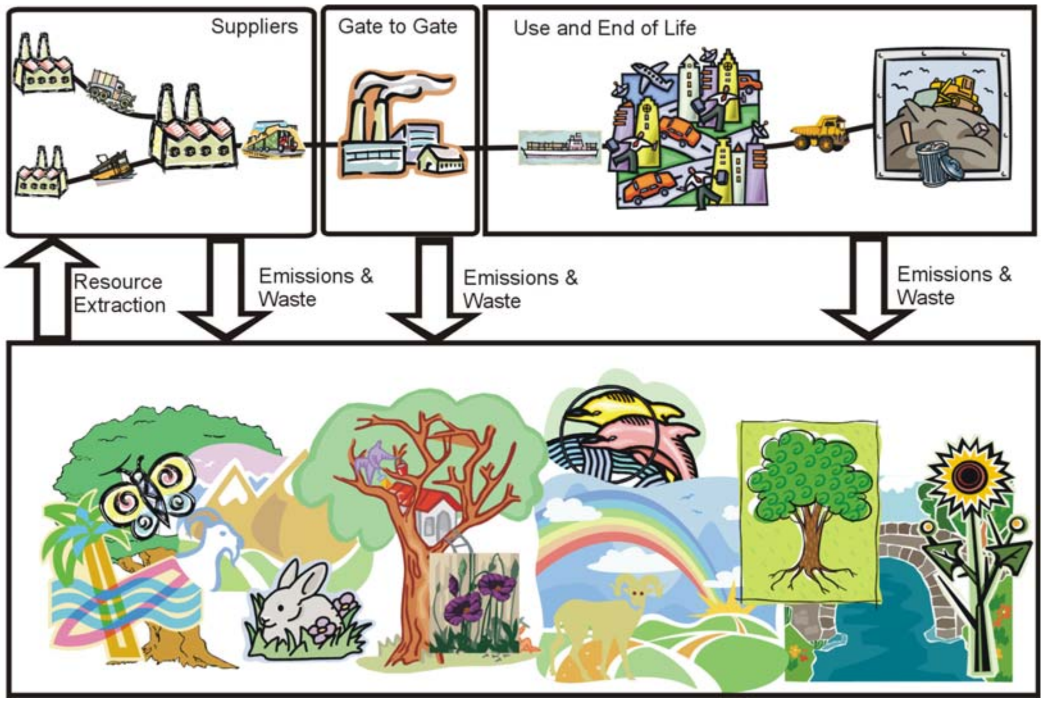


Figure 2.1: Illustration of the life cycle stages and their interactions with the environment

(Adopted from Carlson, CPM, Chalmers University of Technology, 1996)

It is a qualitative and quantitative evaluation of the impacts of a product or service on the environment from the conception of the product or service, to final disposal (cradle to grave) and is achieved by a scientific method-based inventory of all environmental aspects. Figure 2.1 above diagrammatically depicts the life cycle stages and the resulting interactions with the environment at each stage.

It is considered the only environmental tool which avoids positive ratings for measurements which only consists in the shifting of burdens [Kloepfer, 1997]. The system is unique in that it reports all results in terms of a functional unit. In this way it directly links the market for goods and services and is therefore a good yardstick for environmental improvement.

In the South African National Association of Standards (SANAS) and the International Standardisation Organisation (ISO) 14040 standard (1997), the following definition is presented for LCA:

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by

- *Compiling an inventory of relevant inputs and outputs of a system,*
- *Evaluating the potential impacts associated with those impacts and outputs,*

- *Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.*

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resources use, human health and ecological consequences

2.6 LCA Methodology

The steps to LCA are as follows [ISO 14040]:

- Scope and Goal Definition
- Life Cycle Inventory (LCI)
- Impact Assessment
- Improvement Assessment

A schematic overview of the LCA methodology is presented in figure 2.2 below,

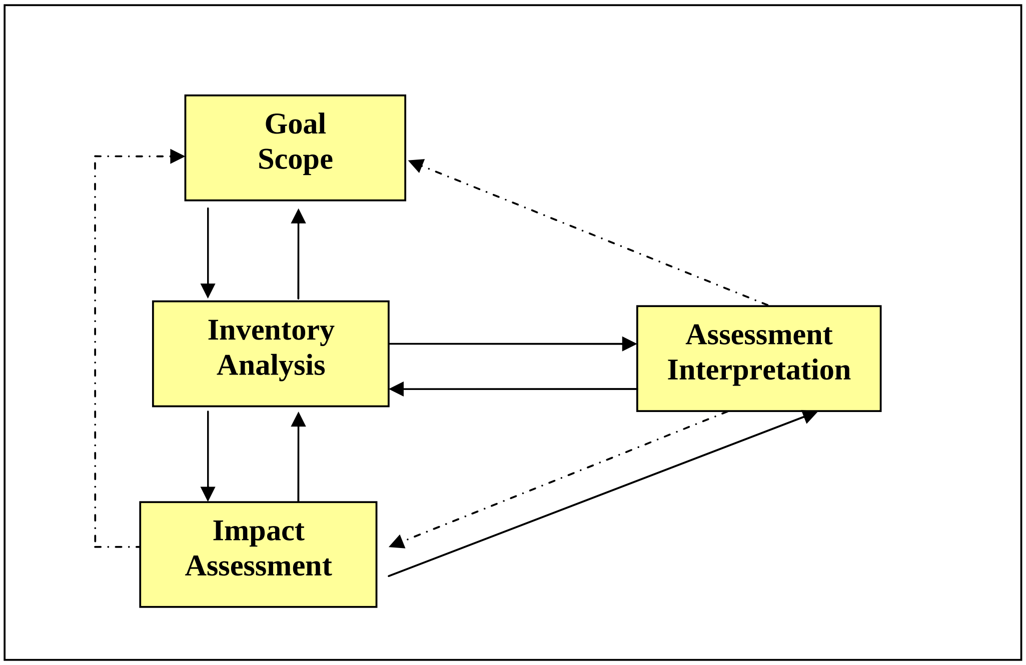


Figure 2.2: The Phases of Life Cycle Assessment (according to ISO 14040)

2.6.1 Scope and Goal Definition

At the first SETAC sponsored LCA workshop the following definition was provided [Consoli F. et al., 1991]:

> *'The goal definition element of an LCA identifies the purpose for the study and its intended application(s). This step will present reasons why the study is being conducted and how the results will be used.*
> *Scoping defines the boundaries, assumptions, and limitations of a particular LCA.*

An LCA stands or falls based on its scoping and the following decisions are made [Schenck, 2002]:

- The system boundary that determines which processes are included and which are excluded,
- The selection of impact categories that determine which of the environmental concerns are considered or excluded,
- The system function and functional unit that describes the economic or social good provided by the goods or services in question,
- Technical issues such as engineering conventions and impact assessment models are introduced and,
- The target audience of the LCA must be taken into account to determine if the study should be a peer-reviewed document.

The *functional unit* is a key element of LCA and has to be clearly defined. It is a measure of the function of the studied system and it provides a reference to which the inputs and outputs can be related.

When comparisons are performed it is important that the products to be compared fulfil the same function. The unit of comparison for a study to determine whether packaged made of polyethylene or paper is an environmentally better option, the functional unit would be *1 000 uses of check-out carrier bags* [Nedlac study, 2000]. A comparison of the environmental impact of two different systems or products with the same functional unit is therefore possible.

In this study, two different products produced via parallel and interconnected manufacturing processes are assessed. The two products have been individually assessed and no comparison on the basis of product use can be made. A comparison on the environmental burden attributed to the manufacturing process by these products has been however been made.
The functional units defined for either product is *1000 kg bone-dry saleable quality bleached market pulp off PM1,* and *1 000kg bone-dry saleable quality white top lined board produced off PM2.*

2.6.2 Life Cycle Inventory (LCI)

An inventory of all extractions and emissions are compiled. The energy carriers and raw materials used, the emissions to atmosphere, water and soil are quantified for each process, then combined in the process flow chart and related to the functional basis.

Conducting an LCA is an iterative process and the following steps (figure 2.3) are as per the ISO 14041 guidelines.

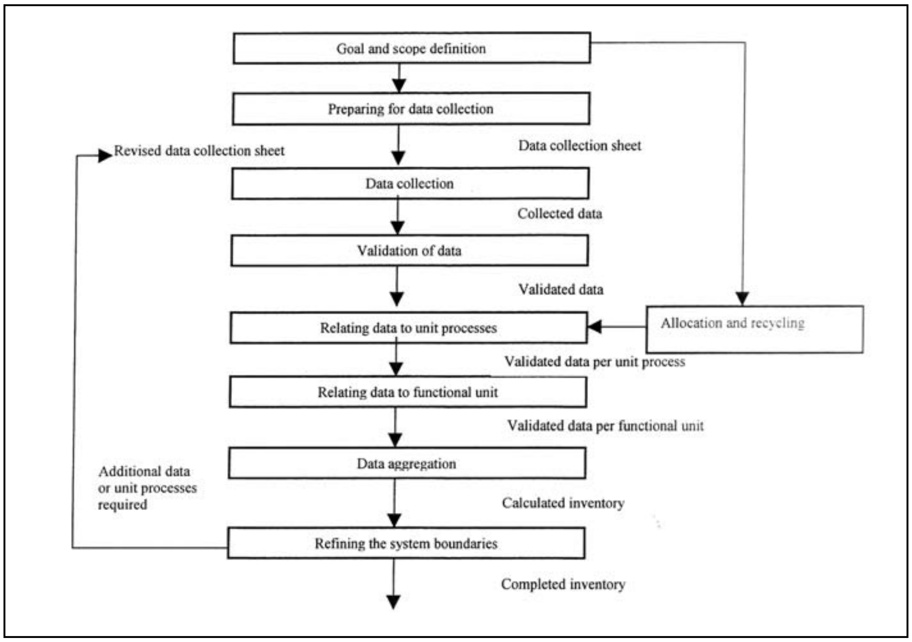


Figure 2.3: Simplified Procedures for Inventory Analysis

(Source: ISO 14041 and Friedrich E., 2001)

For each of the processes included in the system as represented by the diagram above and based on the goal and boundaries of the study, (*cradle-to-grave* or *gate-to-gate*, etc.) data are collected as inputs and outputs to key unit processes. The data are then validated and related to the functional unit in order to allow for aggregation of results.

Data collection is the most resource consuming part of an LCA. Reuse of data from other studies can simplify the work but the quality of data and applicability of data to the defined scope and goal should be considered. For very detailed studies site specific data are sought, however, in most cases regional or country specific data are considered good enough [Freidrich E., 2001].

During this phase of the LCA, software programmes are used to facilitate the management of data, which can at times be very large and cumbersome to manipulate. For this project the *KCL-Eco 95* software was used. It was the only software available at the time of the study designed specifically for the pulp and paper industry. A generic module was purchased from the Finnish database to be used as a comparison to the production of bleached market pulp at the mill under study.

2.6.2.1 Allocation

Allocation refers to the partitioning of the input and output flows of a unit process to the product system under study. When unit processes yield more than one product, resources consumed, emissions generated and material and energy flows from the whole process must be allocated to the different products produced.

2.6.3 Life Cycle Impact Assessment (LCIA)

This third stage of the study is more difficult as it requires interpretation of the data, and value judgments to be made.

The effects of the resources used and the emissions generated are grouped and quantified into a limited number of impact categories, which may then be weighted for importance.

A typical list of global impact indicators include:

- Global climate change
- Stratospheric ozone depletion

- Smog
- Acidification
- Eutrophication
- Natural Resources (habitat, water, fossil fuels, minerals, biological resources) depletion
- Human toxicity
- Eco-toxicity

When selecting these environmental impact categories, a few issues to consider are [Lindfors et al., 1995]:

- Completeness; problems relevant to the system under investigation should be considered.
- Practicality; It is pointless selecting a criteria such as human toxicity for a human food product etc.
- Independence; to avoid double counting of impacts, mutually exclusive impact categories should be selected.
- Relation to the characterization step; ensure that characterisation models related to the selected impact categories are available.

In this study, the impact categories selected were based on those available with the software used.

These indicators are further divided by *classification* (used to classify the load data by its environmental impact, such as acid rain, ozone depletion etc.); *characterisation* (analyses the impact of the load classified to each category) and *valuation* which enables the consolidation of the degree of impacts of each category obtained by the qualitative analysis into simple figures.

Optional elements of an LCIA are [ISO 14042], *normalisation*, *weighting*, *grouping* and *data quality analysis*.

Normalisation occurs when the magnitude of the category indicator results is calculated relative to reference information (e.g. the comparison of products).

Weighting occurs when indicator results from different impact categories are converted to a common unit by using factors based on value-choices. If the impact categories are required to be assigned to one or more groups sorted after geographic relevance, company priorities etc., then *grouping* should be carried out.

Data quality analysis or *sensitivity analysis,* determines the appropriateness of the data inventory and its applicability to the study (especially when generic or database information is used). In this study, the no generic data was used and data verification has been performed by the environmental officer, at MKRB.

2.6.4 Assessment Interpretation

The aim of this phase is to reach conclusions and recommendations in accordance with the defined goal and scope of the study. Results of the LCI and LCIA are combined and reported to give a complete and unbiased account of the study.

The life cycle interpretation of an LCA or an LCI comprises three main elements [ISO 14043]:

- Identification of the significant issues based on the results of the LCI and LCIA phases of an LCA.
- Evaluation of results, which considers completeness, sensitivity and consistency checks.
- Conclusions and recommendations.

2.7 Limitations of LCA

A continued concern has been the time and cost required for full LCA studies. Practitioners have questioned whether the LCA community has established a methodology that is beyond the reach of most potential users. Others have questioned the relevance of LCA to the actual decisions that the potential users must make.

These concerns encouraged practitioners to investigate the possibility of *streamlining* LCA to make it more feasible and more immediately relevant without losing the key features of a life-cycle approach.

SETAC together with the United States Environmental Protection Agency (USEPA) initiated a workgroup in 1994 to define and document a process for a shortened form of LCA. At the time, because of the large amount of data needed to do a cradle to grave evaluation, it was believed that in addition to such a *full* LCA approach there was a possibility to conduct a simplified process called *streamlined LCA*. However, it was recognised by the workshop that streamlining is an inherent part of any LCA. The key is to link the streamlining process with the goal and scope definition process. That is, streamlining is a routine element of defining the boundaries and data needs of a study and is not in itself a different approach or methodology for LCA. [Todd et al., 1999]

LCA cannot provide a truly comprehensive and all-encompassing assessment. Industrial processes are very extensive and globally interconnected that complete assessment of all these inter dependencies is prohibitive. The results of an LCA are approximations and simplifications of aggregated loadings to the environment and resources used. Therefore, the process does not directly measure actual environmental impact or predict effects.

Another problem affecting the application of LCA-based tools concerns the data on resource use and emissions that are used in the LCI [Fava et al., 1994, Weida and Wesnaes 1996]. Actual monitoring of resources and emissions is historically not common practice and many producers do not provide data necessary for LCA.

A tendency for LCA’s to be used to ‘prove’ the superiority of a product over another has brought the concept into disrepute in some areas. It is therefore not surprising that many of the studies that are published, and not simply used internally, endorse the views of the sponsors.

In recent years, a number of major companies have cited having carried out LCA in their marketing and advertising, to support claims that their products are 'environmentally friendly' or even 'environmentally superior' to those of their rivals. Environmental groups have successfully challenged many of these claims which in turn have diminished the power of LCA.

Overall, LCA has a number of limitations relating to data assimilation, quality and subjective choices by the persons conducting the study. In spite of these, LCA is the only tool that encompasses a cradle-to-grave approach.

Specific to South Africa is the lack of data and the poor quality of data. This is largely due to the reluctance by South African companies to provide data towards the study. Companies who are willing to supply information, generally do not have the information in the format that can be used in the LCA and further time and effort is required to compile this data [Friedrich E., 2001]. This reluctance to release data can also be attributed to the seclusion of SA as discussed in chapter one.

In this study, the data required was internal to the business as the scope of the study is *gate-to-gate*. The main problem was convincing employees at MKRB that the information was not going to be used as a stick to beat them, but rather as a tool to assist them.

A drawback to the application of LCA in South Africa is that the software tools and databases available have been developed overseas and present the researcher with the problem of applying the data collected elsewhere to the South African situation. In this study, site-specific data is used as available and no generic data from databases were used.

A downfall of this study as well as others conducted in South Africa is the applicability of the *impact assessment* phase to this country. The impact categories in this study have been developed for European situations and impacts considered as irrelevant there, are important to our continent. Water for example is not considered an important resource in the northern hemisphere and therefore water as a non-renewable resource, salination and soil erosion have not been identified as environmental impact categories. As a solution, national research and studies are being conducted to determine factors and categories applicable to South Africa.

Further, the equivalency factors used within impact categories are derived from industrial processes operating in Europe and America, and therefore do not relate directly to the South African situation.

Over the last five years since the beginning of this study, the number of LCA practitioners and studies relevant to the continent has grown. The introduction of an LCA network for Africa has facilitated the progress towards an LCA methodology that is applicable to South Africa and has increased the capacity for peer review previously found lacking [Friedrich E., 2001].

2.8 LCA Tools and Software

The evolving availability of hardware and software technologies is facilitating the use of LCA methodologies. The intent of these tools is to assist LCA practitioners with the data intensive nature of LCA and provide relational database management. In addition many software packages provide models for impact assessments of various methodologies. Most of these tools are designed to be user-friendly and flexible in a developing and changing environment, with the goal of being comprehensive and consistent with all the elements of a LCA methodology [Breville M., (1994)].

A powerful way of reducing time and data problems within the Inventory Analysis stage is to develop large generic databases to provide readily accessible information about the processes outside the control of the individual manufacturer. At present, there are a number of specific products and processes, mainly in the chemical and packaging industries. Though the range of information is constantly growing, they do not yet include the necessary information to make them applicable to all industrial processes.

2.9 Cradle-to-Grave or Gate-to-Gate?

Currently LCA can be regarded as generally expensive, time and labour intensive and requiring significant investment in measurement equipment for data acquisition.

Despite continued methodology frameworks and debate, a number of traditional manufacturing companies are now attempting to apply LCA within their existing businesses and culture. Most are beginning work in this field by avoiding the complexities of a full LCA. Instead, they are attempting to complete restricted studies, with clearly defined limits and boundaries. Thus much work is being carried out at a variety of levels of completeness, commitment of resources and levels of detail.

Hook points out in her review of progress towards full LCA [Hook E., 1996] that there is nothing wrong with restricted approaches to LCA as long as their limitations are clearly stated and they are not represented as full studies.

The Chalmers Institute points out that full LCA is (currently) beyond the budget and /or time constraints of many potential users and that at this stage of LCA development, restricted studies provide business with realistic targets for initial entry into this complex field. If applied with care they provide additional useful information about the impacts of the current and future products, processes or services under study and enable the development of structured improvement programmes. In addition they serve to demonstrate the usefulness of a life cycle approach and to prepare a company for the use of full LCA techniques as they become more fully defined and accessible.

2.10 Conclusion

Life Cycle Assessment is a unique tool developed over the last 40 years to enable the environmental impacts of a product, service or activity to be scientifically evaluated. It has been developed in response to a global need for the detrimental impacts of industrialisation to be identified, evaluated and controlled such that development can be sustained, economically, socially and environmentally.

LCA facilitates the qualitative and quantitative environmental impact of processes by collation of all inputs and outputs associated with the product. The proceeding steps of the LCA process classify these inputs into relevant environmental categories and systematically score them according to their effects on a particular impact category. Internationally and within South Africa, LCA is used as a tool to facilitate information reconciliation and process improvement. It is used in varying degrees as applicable, and in this study, the methodology of LCA is applied to the process of manufacturing Baycel and Baywhite at MKRB.

When this study was initiated in 2000, it was the first LCA study in South Africa related to the forest and pulp and paper industry, the results of which, are an example of the added knowledge and value that the tool provides to users.

CHAPTER THREE: The pulp and paper industry

This chapter gives a brief overview of the Pulp and Paper Industry in South Africa. It introduces Mondi Kraft Richards Bay (the mill of study), and presents a general overview of the kraft pulping process. The process specific to MKRB is discussed in greater detail in chapter six.

3.1 Pulp and Paper through the decades in South Africa

1920s South Africa's first paper mill established near Johannesburg with an annual capacity of 1 000 tons of wrapping and baling paper.

1930s The first board mill at Umgeni in Durban.
The first integrated pulp and paper mill, producing paper from straw.

1940s The first toilet tissue production facility.
The country's first binding and suitcase production plant.

1950s Fibreboard and vulcanized paper produced for the first time.
First mill producing bagasse from sugar cane residue.
Africa's biggest Kraft Pulp and Paper Mill, producing linerboard, fluting, bag and wrapping paper established.

1960s First production of newsprint.

1970s First mill producing Testliner.
Installation of world's first full scale oxygen bleaching production unit.
First production of coated papers using bagasse as raw material.

1980s This decade was characterised by the establishment of new, modern facilities and significant increases in production capabilities through expansion projects and efficiency improvement. Significant technological developments included:

- The development of superior quality test liner produced from waste paper.
- The commission of the first fully automatic hydropulper installation.
- Production for the first time in South Africa of supercalendered mechanical papers for magazines and catalogues.

1990s South Africa becomes the world's largest producer of dissolving/market pulp.
Re-establishment of trade with the rest of the world, accompanied by reductions in protective tariffs.
The country's major pulp and paper producers expand into international activities through the acquisition of mills in Europe and America.

2000s The country's major pulp and paper producers expand into international activities.

3.2 The Economics of Pulp and Paper

The industry is a significant player in the South African economy, contributing 14.4% to manufacturing GDP and 2.7% to national GDP. South Africa is ranked as the 16th largest producer of pulp in the world and 24th (2000 figures) of paper and board production. Since 1970, the industry growth rate has been consistently higher than the international average. [PAMSA, 2004]

The industry provides a comprehensive range of pulp, paper and board products and supplies the bulk of local demand. Numerous grades of paper are produced and the three major groups are: printing and writing grades, packaging grades and tissue grades.

The five largest manufacturers of pulp and paper are Sappi, Mondi, Nampak, Kimberly-Clark and Unicell. These five groups combined produce almost 99% of national pulp, paper and board production.

The industry now produces in excess of 2,5 million tons of product each year, which is somewhat less than 1% of international capacity. However, a significant portion of the product is exported which generates foreign capital and the manufacturing part of the paper industry contributes significantly to the wealth of the eastern part of South Africa. [McDonald C., 2004]

3.3 Mondi

Mondi (a subsidiary of Anglo American plc.) is a paper and packaging company producing market pulp and linerboard. It has expanded globally in the last decade and has become a significant international producer ranked 39th by turnover on the list of the largest pulp and paper companies of the world. [PAMSA, 2002]

The company was incorporated on 11 December 1967, initially as *Main Paper Company Limited*, with a name change to *Mondi Valley Paper Company Limited* a year later.

3.4 Mondi Kraft-Richard Bay Mill

Figure 3.1: Plant Overview – Mondi Richards Bay

A major building block in achieving Mondi's objective of a world class, fully integrated forest products enterprise was the investment of R1-billion in 1982 to develop a mill at Richards Bay. Figure 3.1 above is a plan view of MKRB.

Completed in just two years and at the time one of the largest single greenfields pulp projects in the world, the mill produced pulp for Mondi Mills and for export, as well as kraftliner board for local and overseas packaging markets. Commissioned in 1984, this mill was one of the largest single line operations of its kind in the world and had a rated capacity of 450 000 tonnes/year.

In 1989 a R10-million hydropulping plant, the first automatic installation in South Africa was commissioned and a R50-million debottle-necking and expansion programme was implemented to raise annual production of bleached pulp to 420 000 tons by 1991.

In 1992 the Mondi fluting operations at Felixton and Piet Retief Board Mills were rationalised and incorporated into the Richards Bay division.

In 1994, a R 62-million plant to produce elemental chlorine-free (ECF) bleached eucalyptus pulp was commissioned in line with global pressure to reduce elemental chlorine usage and inherent dioxin generation.

3.4.1 Geographical Location

Mondi Kraft Mill is situated in Northern KwaZulu-Natal, near the Richards Bay deep-water port on the east coast. The area flourished as an industrial town but is also neighbour to nature reserves and world heritage sites.

3.4.2 Products

Richards Bay produces two key products: ***Baycel***, a bleached hardwood market pulp, which is made from 100% eucalyptus fibres, and ***Baywhite***, a virgin white top kraft twin ply-linerboard, which is used for printed packaging. The topliner is 100% bleached eucalyptus pulp and the underliner is unbleached softwood pulp.
Baycel is sold locally to fine paper makers and approximately 150 000 tons of Baywhite is exported and 50 000 tons are sold in South Africa.

3.4.3 Operation

MKRB employees 1 570 full time employees and operates 24 h/d, 7 d/week, 365 d/yr. Down time for maintenance is planned and ongoing.

3.4.4 Environmental Policy

ISO 14001 certification was obtained in 2000 by BVQI. The mill therefore has an auditable environmental management system in place and can prove continuous improvement with regard to pollution abatement and renewable resource consumption.

Due to its eco-sensitive location, the odorous emissions and fresh water consumption that is typically associated with the kraft and bleaching processes, draw much attention to MKRB. An environmental pressure group [Groundwork, 2004] has been formed and the mill is consistently in open communication with interested and affected parties.

3.5 The Kraft Process

The Kraft (which means strength, in German) process was developed in Germany about 100 years ago and is commonly referred to as the alkaline or sulphate process. The diagram below is a schematic representation of the general Kraft process used world-wide.

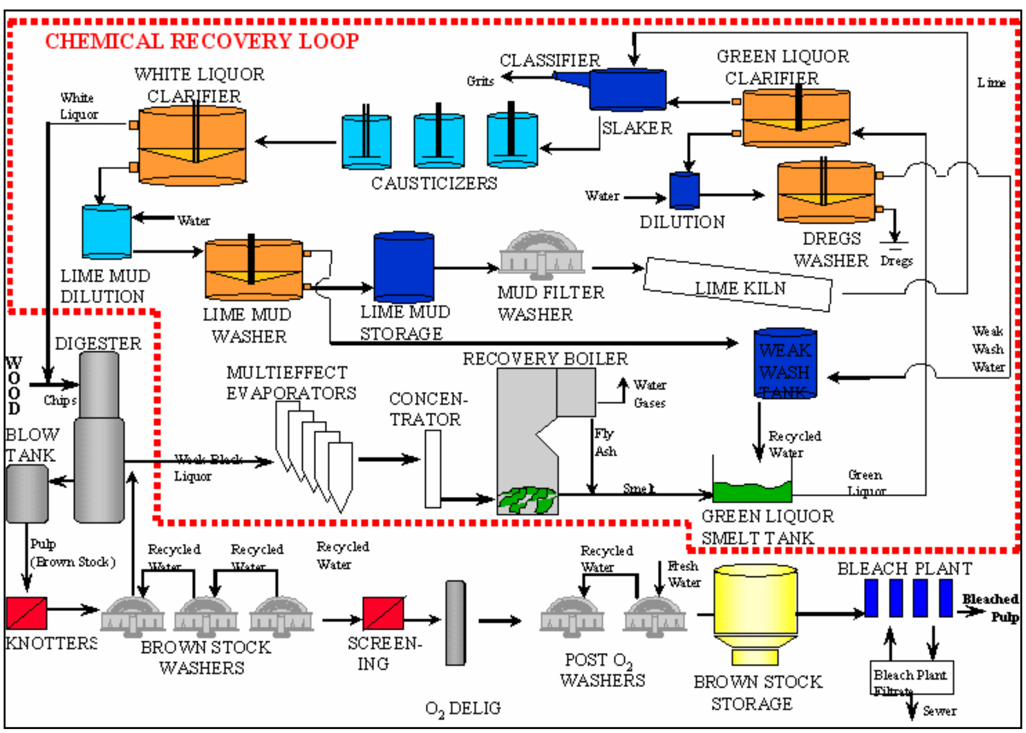


Figure 3.2: A process overview of The Kraft Process

The process involves the cooking of wood chips in a solution of sodium hydroxide and sodium sulphide (called liquor). The alkaline attack causes the lignin molecules (the molecules in the wood which bond the fibres) to fragment into smaller segments. These smaller fragments are then soluble in an alkali liquor and can be removed from the wood, thus leaving the wood fibres (pulp). The liquor and dissolved lignin is burnt in the recovery boilers and the expensive alkaline chemicals can be recovered for reuse. The specific processes involved are discussed in greater detail below [Martin, 1995].

3.5.1 Wood Yard

Hard wood (HW) and softwood (SW) logs are transported from the forest to the wood yard. In South Africa, hardwoods used are either eucalyptus (gum) or wattle, while the softwood is pine.

One of the major advantages of the South African pulp and paper industry is that it is supplied exclusively from plantation forests and, unlike many other countries, does not make use of natural or indigenous forest. The wood as raw material into the mill under study is therefore regarded as a renewable material and is classified as a *material* input rather than a *resource*.

Softwood logs are conveyed to debarking devices (typically a drum debarker) for bark removal. The logs are fed into a large revolving perforated cylindrical drum. The tumbling action knocks off the bark. The bark is transported to the power plant to be used as a fuel. Hardwood logs are debarked in the forest before delivery to the mill.

The debarked logs are fed through a chipper, which has a rotating plate with knives set into it. The logs are fed down a chute and the revolving knives cut the logs into chips. The chips are stored in large piles prior to being fed into the digester as illustrated in figure 3.3 below. The logs are chipped to facilitate the absorption of the cooking chemicals by increasing the exposed surface area.

Figure 3.3 Wood Yard chip pile at Richard Bay

3.5.2 Digester/Cooking Plant

There are two basic types of digester operation in the cooking process:

- Batch digesters,
- Continuous digesters.

At the MKRB, batch cooking occurs in 14 digesters and is included in the *cook* process module. Digesters are cylindrical pressure vessels in which the wood chips and cooking liquor are fed. A system of heat exchangers heat the cooking liquor or *white liquor* as it is referred to, to the required cooking temperature. The cooking time and temperature relates to the *kappa* number required (i.e. the quality of pulp required). During the cooking phase, vapours are continuously relieved. Once the set time has elapsed, the blow valve is opened and the content of the digester is blown into the blow-tank.

3.5.3 Pulp Washing

The wood chips once cooked and blown into the blow-tank, is referred to as *brown stock*. This stock is washed to remove any residual cooking liquor, which is referred to as *black liquor* and contains the cooking chemicals that can be recovered and re-used.

Five to six banks of rotary drum washers are used to reclaim the black liquor with as little dilution as possible. The recovered liquor is referred to as *weak black liquor*.

The pulp washing process is included in the *cook* process module in this study.

3.5.4 Pulp Bleaching

Pulp bleaching is the process of purifying or whitening pulp by chemically treating it to alter the coloured matter and to impart a higher brightness to the pulp.
There are a number of chemicals used in this process: chlorine gas, chlorine dioxide gas, liquid hydrogen peroxide and oxygen gas. Sodium hydroxide (i.e. caustic soda) is used to extract the bleaching chemicals from the pulp. Each stage of the process is given a symbolic name according to the chemicals used in that stage:

C = Chlorine
E = Extraction phase using caustic soda
D = Chlorine dioxide
CD = Chlorine and chlorine dioxide mixed together in one stage.

A bleaching phase, either C, D or CD is followed directly by an extraction phase (E).
Over the last 10 years, the issue of dioxin production due to the use of elemental chlorine has shifted the industry to elemental free chlorine bleaching only with the addition of an oxygen delignification stage. At the Richards Bay Mill, *classic* bleaching using elemental chlorine and *Elemental Chlorine Free (ECF)* bleaching using chlorine dioxide are in use.

At the time of the study the construction of the oxygen delignification plant was in progress but had not been commissioned. The oxygen delignification process has therefore been excluded from this study.

In this study the effects of the bleaching process have been captured in the *bleach* module.

3.5.5 Stock Preparation

After cooking and washing, brown stock contains contaminants such as uncooked chips, wood knots, shives or fibre bundles, stones, wire etc., which must be removed before it can be sent to the paper machine.

The brown stock is pumped through the stock preparation plant where it is refined, screened and cleaned.

The purpose of *refining* is to separate individual fibres in the pulp to develop strength properties of the final product. The cell wall of a fibre is made up of strands or fibrils of cellulose. Refining partially loosens or breaks off *fibrils* from the main body of the fibre. The resulting *fibrillation* determines the strength of the final paper product such that strength properties increase as fibrillation increases.

Refiners are arranged in banks and the pulp passes from one to another until the required degree of fibrillation is achieved (which is determined by the quality requirements of the product). *Conical* and *disc* are two types of refiners, both of which are used at the Richards Bay mill. Once refined, the pulp is stored in storage chests prior to further treatment and is referred to as *stock*.

A pressure-screen facilitates screening of the pulp. The screen consists of a perforated cylinder or basket in a housing. Stock is pumped into the housing in the centre of the basket. Under pressure, pulp of acceptable fibre length is forced through the slots in the basket and is referred to as *accepts*. The *rejects* are retained in the centre of the basket and is sent back to the refiners and then rescreened.

Stock cleaning removes heavier particles from the stock by centrifugal force. Banks of centrifugal cleaners are used to separate the particles and contaminates from the acceptable stock by their differences in density. Heavier contaminants are flung outward and downward whilst the *accepts* are passed forward. The rejects are passed backward to the previous cleaner.

Additives are added to the stock during the stock preparation phase to obtain the required quality of the final product.

Rosin size (partially or completely saponified, neutralised rosin) the chemical formula of which is $C_{19}H_{29}CONa$ is a wet strength additive that when added to paper and board improves its resistance to water and hence increases its wet-strength properties. No wet strength additive is required at PM1, as the market pulp produced (Baycel) must to be readily pulpable.

Alum $(Al_2(SO_4)_3$ and is added to the product to *fix* the size to the fibres.

Clay or *starch* is added to the stock to make the final product less transparent, increase bulk (which leads to fibre savings) and to improve the surface texture (i.e. smoothness) of the product surface for printing.
Dye or *Optical brightening agents (OBA)* is sometimes added to the stock to improve the shade of the final product (i.e. when coloured sheets of paper are required, or bright white paper).

The inputs and outputs to the stock preparation process have been incorporated into the *cook* module in this study.

3.5.6 Chemical Preparation

Preparation of bleaching chemicals, chlorine, chlorine dioxide, sodium hydroxide and the by-products of the electrolysis of brine are produced on site. Chlorine and sodium hydroxide are produced directly from the electrolysis reaction and chlorine dioxide is produced using either of the processes tabled below:

Process	**Reducing Agent**	**Diluents for Generated Gas**
Solvay	Methanol	Air
Mathieson	SO2	Air
R-2	NaCl	Air
R-3/SVP	NaCl	Water vapour

Table 3.1: Seminal Processes for chlorine dioxide generation

At the mill under study, the R-2 process is used.

3.5.7 Chemical Recovery

Weak black liquor recovered from the brown stock washing process, is sent to the liquor *recovery plant.*

Black liquor is inorganic chemical contaminated with dissolved organic materials extracted from the wood chips during cooking (i.e. lignin and soaps etc.). The weak black liquor is first concentrated and the dissolved organic portion is then burnt off in a furnace.

Typically weak black liquor has a 16% solids content. This is increased to 60% to support combustion in the furnace. The concentrated black liquor is referred to as *strong black liquor*. Evaporation occurs in multi-effect evaporators, which use steam and hot vapour from the previous evaporator to drive the water vapour out of the liquor.

Once the black liquor has been sufficiently concentrated it is sprayed into a chemical recovery unit. This is essentially a very big boiler capable of burning both fuel and/or black liquor and is called a *recovery boiler*.

The recovery boilers are fired by fuel oil. Once the desired temperature is reached, black liquor is introduced into the boiler by atomising the liquor into a fine spray. The organic portion of the liquor burns off and the inorganic portion settles to the bottom of the furnace. The temperatures are such that the inorganic portion turns into a smelt, which is tapped off from the boiler bed into a smelt tank. The smelt is continuously fed with weak wash water from the clarifiers and is referred to as *green liquor* because of the small traces of iron in the solution, which give it a green tinge.

Green liquor is pumped to a clarifier where any insoluble matter is settled out. The dreg or rejects from the clarifiers are washed and the wash water is pumped into the smelt tank to form the green liquor.

The clean green liquor is then pumped into a slaker where burnt lime is fed at a controlled rate. The undissolved lime is removed from the slaker and is sent for landfilling along with the dregs from the green liquor clarifier.

The liquor is now called *raw white liquor*, which is gravity fed to a series of causticising tanks. Here, the causticising reaction continues until complete and produces sodium hydroxide (caustic soda) and lime mud. The lime mud is removed from the white liquor in a white liquor clarifier by settling. The clean white liquor is now ready for re-use in the digesters.

The lime mud is washed and white liquor carry-over is removed. Again, the wash water is re-used with the green liquor dregs wash water in the smelt tank.

Clean, partially dry lime mud is fed into a limekiln. Gas is burnt to generate a long flame that is introduced at one end of the kiln. The lime mud (and some make-up lime stone) is continuously added at the other end of the kiln. As the kiln rotates, the lime mud and limestone form little balls. These balls are burnt to form burnt lime. The burnt lime is added to the slaker (to convert green liquor to raw white liquor).

Diagrammatic representation of the Kraft liquor cycle is as per figure 3.4 below:

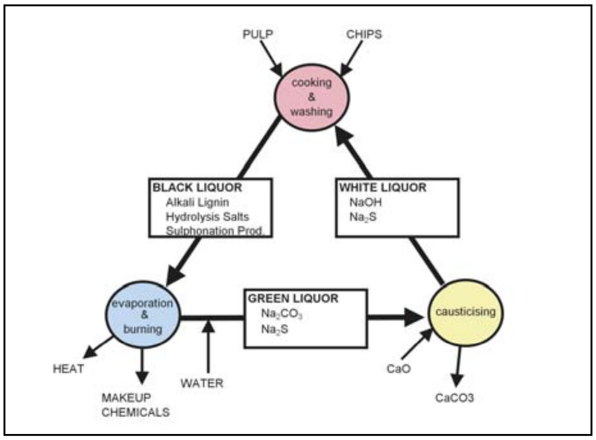


Figure 3.4: Kraft liquor cycle

(Source: Smook, Kraft Pulping, 74)

3.5.8 The Paper Machine

The paper machine consists of the following sections:

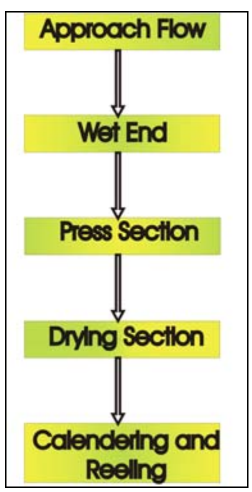


Figure 3.5: Sections of a Paper Machine

The *approach flow* is the mechanism by which the stock is transferred to the paper machine.

The chest is split into two sections, the machine chest and the blend chest, both having agitators. The machine chest receives the stock from the refiners at a consistency between 2.8% and 3%. The stock is diluted with water to approximately 2% in the blend chest and the non-fibrous additives are added (i.e. size and dyes etc.)

A fan pump/s delivers the stock to the pressure screens. The accepts from the pressure screens are sent directly to the headbox, while the rejects from the pressure screens are sent to the centrifugal cleaners. The final stock (the accepts from the pressure screens and the centrifugal cleaners) is diluted before entering the headbox.

The water used for stock dilution in the approach flows is referred to as *white water* or *backwater* and is the water recovered from stock when on the machine wire.

The *wet-end* is generally a *Fourdrinier table* on which the objective is to distribute the stock in the headbox uniformly onto a moving wire mesh table. The water in the stock is drained through the wire using vacuum boxes, foils and table rolls.

The purpose of the *press section* is to remove additional water and consolidate the sheet. Physical water removal be pressing is a lot more economical in terms of energy costs than heat energy.

The *drying section* refers to the removal of water in the sheet by, evaporation, convection or radiant heat.

Evaporative drying occurs on PM2 at Mondi Richards Bay when the sheet is brought into contact with the hot surface of the drying cylinders, alternating the contact side of the sheet as per figure 3.5 below. Temperatures of the drying cylinders vary from the first section to the last section and are controlled by steam injection into the cylinders.

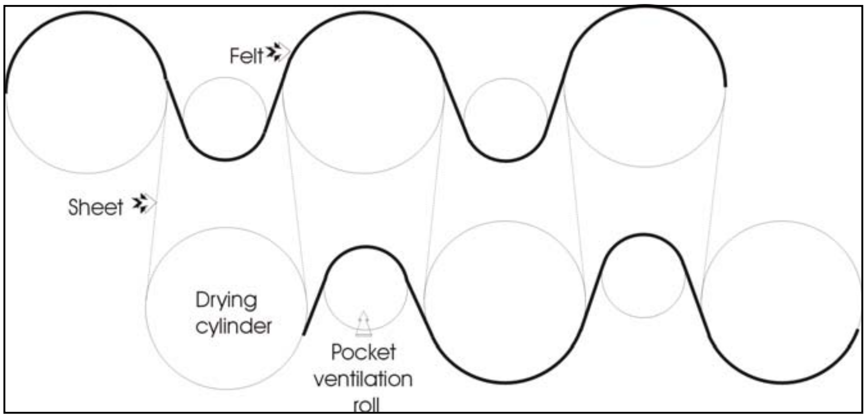


Figure 3.6: Evaporative Drying Section as on PM2

On PM1, convective drying occurs where air serves as the medium for both heat and mass transfer. The heat for evaporation is supplied to the sheet by convection heat from the air surrounding the sheet. The evaporation moisture diffuses into this air and is carried away.

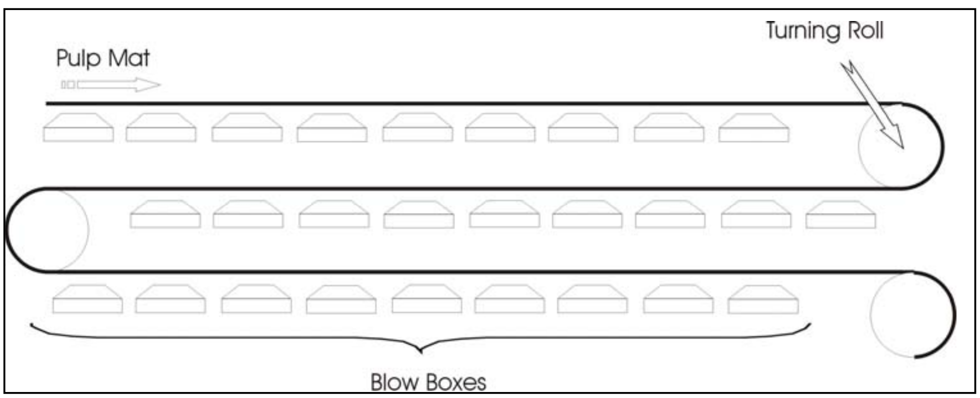


Figure 3.7: Convective Drying Section as on PM1

The process impacts of PM1 have been captured in the *PM1* module and the PM2 process has been captured in the *PM2* module for this study.

3.6 Conclusion

The pulp and paper industry in South Africa is less than 100 years old and its growth has been largely between 1920 and 1985. Post 1985, new developments were of a small nature and mostly related to expansion of existing mills.

The industry is an important part of the economy in South Africa and since 1970, the industry growth has been higher than the international average. In 2003 the forest products industry contributed 9.8% of the countries manufacturing GDP and 2.5% of the national GDP [PAMSA, 2004].

The sustainability of the industry is of paramount importance to the South African economy. The three tiers of sustainability, economic, social and environmental concerns should all be invested in. The latter has only recently been identified as a concern to the industry due to the growing awareness of the importance of the earth's natural resources, the increasing size of the industry and, in particular, the increase in the size of individual production plants and the consequent larger impact on the immediate environment [McDonald C.J.M., 2004].

Mondi Richards Bay has been identified as a major player and stakeholder in the local industry and is at the forefront of implementation of sustainable practices. The mill at Richards Bay is seen in the public eye as a *polluter* due to the odorous emissions and the consumption of large volumes of fresh water resulting from the process.

The process of manufacturing pulp and paper has been described to give the reader insight into the manufacturing process as it occurs at Mondi Richards Bay. The kraft process has developed over years and is generic to mills worldwide and is not exclusive to Mondi Richards Bay.

CHAPTER FOUR: LCA in pulp and paper

This chapter links the tool, Life Cycle Assessment, and the pulp and paper industry by a literature survey. It begins with a brief discussion of the past work done in this specific field, and the tools available to tackle an LCA specific to the pulp and paper industry.

4.1 LCA in Pulp and Paper

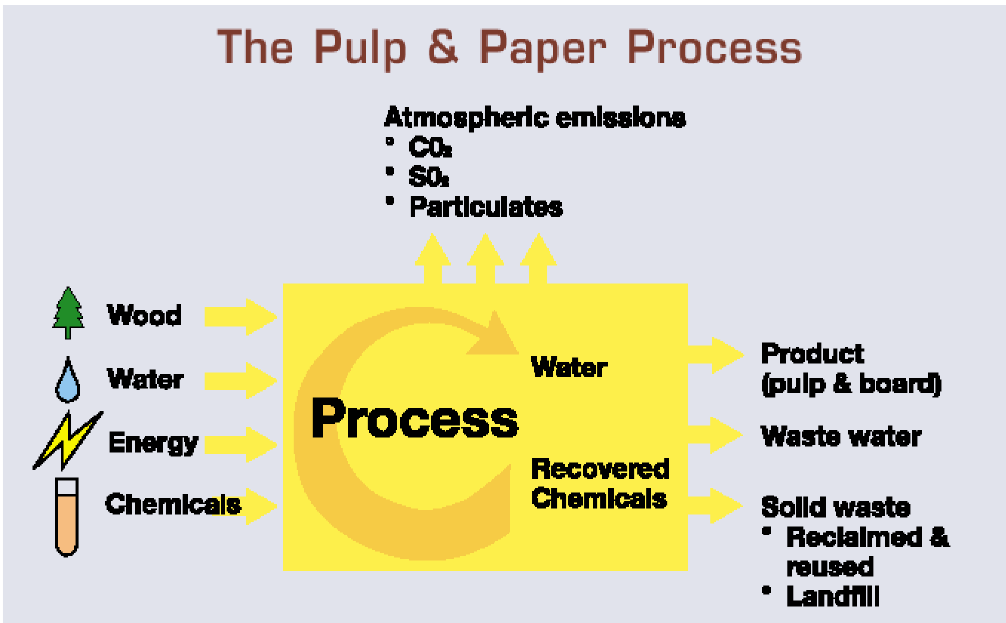


Figure 4.1: Environmental Interactions related to Pulp and Paper Manufacturing

(Adapted: Mondi Kraft 2002 Sustainability Report)

LCA studies related to paper and board began in America and Europe as a method to investigate disposable containers in the early 1980's. In USA, LCA has been conducted at *International Paper* and *Georgia Pacific* since the early 1990's.
The manufacturing sector of the pulp and paper industry has been an onlooker for LCA studies conducted and reported by colleges and universities, research institutions and competing converting industries, rather than being an active participant.

In recent years the industry and its products have been subject to close scrutiny by the authorities, the media, environmental organisations, consumer groups, etc. Although the environmental effects have on occasion been discussed objectively, in many cases they have been treated in a somewhat incompetent manner. Public outcry regarding the pollution supposedly attributed to the Mondi operation in Merebank has received international exposure and in many respects has been exploited by the emotional and social factors involved rather than the scientific.

Internationally, LCA's are becoming frequent in attempts to scientifically judge the effects of different pulp and paper processes, products and recycling. Studies have been carried out not only with a view to comparing different materials and products, but also to get a general impression of the material and energy flows involved in the forest industry. The main application of LCA has been the investigation of alternative packaging.

4.2 LCA in the Nordic Pulp and Paper Industry

LCI practices have been inconsistent in the majority of LCA studies conducted internationally in the pulp and paper field. There has been no commonly accepted guideline, even with regard to the basic issues such as nomenclature and units for parameters related to the products proper, their raw materials, chemicals, energy and transport [Karna et al., 1997].

In view of the above, a joint Nordic Project has been conducted with a view to developing a methodology for the collection, processing and reporting of data, in such a way that life cycle assessments of forest industry products can be performed and combined in a more consistent way.

The Nordic region has been among the leaders in LCA application and method development. The Nordic Council of Ministers started an LCA program in 1991, with a report on the state of the art of LCA activities in 1992 [Lindfors, 1992]. By 1997, 38 LCA studies had been conducted in the packaging-products sector, and 59 in the paper and pulp mass sector. The majority of these studies focused on product development and improvement. [Hanssen O.J., 1999]

LCI work has been conducted in four parts dealing with those items considered to be most important in setting up a life cycle assessment; parameters and units, data quality, system boundaries and allocation.

In line with the above objectives and to make the South African LCA study internationally comparable, this study has been based on the guidelines produced by Stromberg et al., (1997). The *NordPap* program is a joint Nordic Research and development programme aimed at producing new basic knowledge with a view to strengthening the long-term competitiveness of the Nordic pulp and paper industry. The contributors come from all Nordic countries, and the program is being carried out principally at research institutions and universities, but also by industry.

The first LCA project ran from 1 October 1992 to 14 September 1994 and was carried out mainly by research groups at *STFI*, the Swedish Pulp and Paper Institute in Stockholm and *Chalmers Industriteknik* in Gothenburg, supported by *KCL*, the Finnish Pulp and Paper Research Institute in Helsinki and *PFI*, the Norwegian Pulp and Paper Institute in Oslo.

4.3 LCA tools for Pulp and Paper Application

In this section, the development of tools to assist the application of LCA in the pulp and paper industry are introduced and the tools used in this study are discussed.

4.3.1 Historical Development

LCA can provide value in research, technology, and design decision-making. But even for large companies, the value gain does not support the prohibitive expense of conducting comprehensive LCA studies. Streamlined screening methodologies have been developed and high quality environmental inventory data for materials, process, and parts are to be more readily accessible if it is to be used more widely.

For the pulp and paper industry KCL, the Finnish Pulp and Paper Institute in Helsinki, which has extensive experience in LCA, have developed international methods in this area.

4.3.2 KCL-Eco 3.01

KCL-Eco 3.01 is a windows-based calculation program, which can handle large systems. Features include a graphical user interface, impact assessment capabilities (using different methods), sensitivity analysis (Monte Carlo), agglomeration function and graphic processing of results.

Previous versions of the software have been successfully used in different branches of industry other than pulp and paper and for educational purposes since 1994.

Two impact assessment methods have been included in the software: *DAIA-98* (A Finnish method created by the Finnish Environment Institute) and *Eco-Indicator 95* for impact assessment. The Eco-Indicator 95 method has been used in this study.

4.3.3 KCL-EcoData

KCL-EcoData is a separate LCI database in a *KCL-Eco* compatible format primarily developed for life-cycle inventory calculations related to forest products. The data has been collected by using experts from various branches of industry together with publications and questionnaires. It includes nearly 250 data modules covering energy production, chemical production, wood growth and harvesting, pulp, paper and board production, transport and other waste management.
For a comparison to this study, the manufacturing module for bleached kraft market pulp has been used.

4.3.4 Eco-Indicator 95

The inventory table is the most objective result of the study. However, a list of substances is difficult to interpret. To make this task easier *life cycle impact assessment* is used for the evaluation of impacts. The assessment phase uses the inventory data to describe various environmental burdens, and translates the mass and energy inventory data set into an environmental profile of the system under investigation.

One of the oldest impact assessment methods is the *Environmental Priority Strategy (EPS)* system as developed by the Swedish Environmental Institute (IVL) in Sweden. In this method, the complete chain of cause and effect from each impact on a human equivalent is calculated.
Another method is the *Ecopoints* method, developed for the Swiss Government. It is based on the *distance-to-target* principle. The distance between the current level of an impact and the target level is seen to be representative of the seriousness of the emission. The latter methodology is the principle adopted by the Eco-Indicator impact assessment tool as used in this study. Figure 4.2 depicts the relationship between the *life cycle inventory* and *life cycle impact assessment* phase of the study using Eco-Indicator 95 methodology.

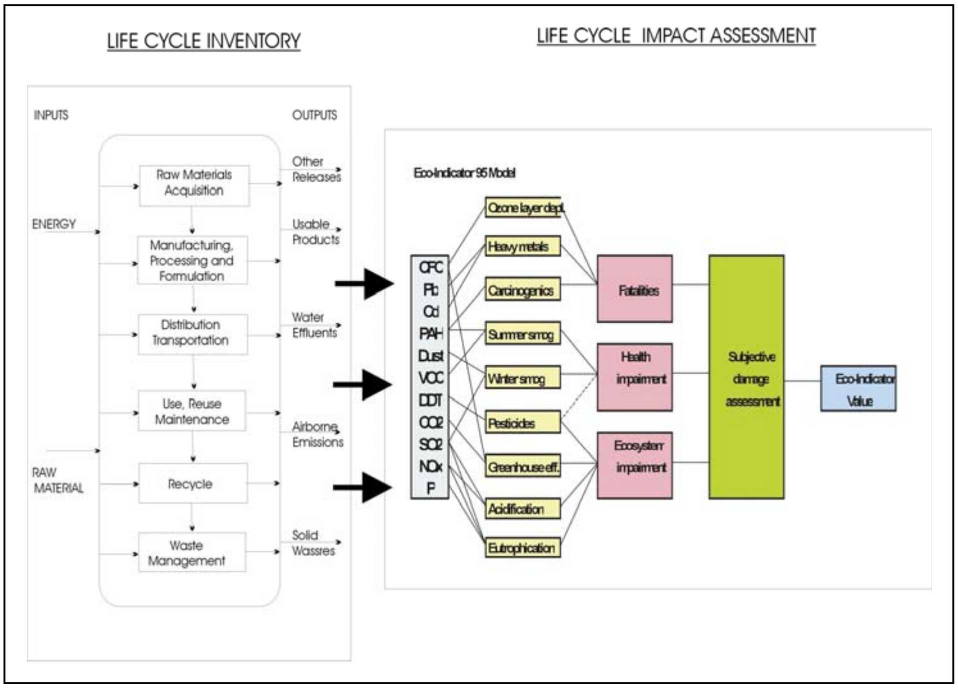


Figure 4.2: A LCA schematic overview

(Adapted from SETAC, 1997; Wenzel et al., 1997 and Friedrich E., 2001)

The following impacts are evaluated by Eco-Indicator 95 software:

- Climate Change
- Ozone layer depletion
- Acidification
- Eutrophication
- Smog
- Toxic substances

4.4 International LCA in Pulp and Paper

A brief overview is presented of LCA studies conducted worldwide in the field of pulp and paper. Conclusions reached if pertinent to the SA case study have been highlighted. This study was the first LCA study to be conducted in South Africa related to pulp and paper or the forest industry when it was initiated in 2000 and since then, further studies in the related fields of packaging have been conducted.

4.4.1 Swedish Pulp and Paper Institute (STFI)

Internationally, STFI has been performing environmental related research and development since mid 1970's and has been engaged in pulp and paper related LCA since 1992.

Studies carried out by STFI include [STFI website, 2005]:

- "LCA of mineral-based coating pigment". A minFo project (the Mineral Processing Research Association).
- "LCA: Land and Geography". An NI project
- Environmental evaluation of model mills in the MISTRA research program "The eco-cyclic pulp mill" http://www.stfi.se/mistra/kamprog.htm
- The administration of an LCA database with Swedish or Scandinavian mean values for several pulp and paper products and data for the production of process chemicals.
- Contract work LCA.

4.4.2 European Union (EU)

OMNIITOX, a EU-project under the 'Competitive and Sustainable Growth' programme, running from 2001-2004, conducted a case study: *LCA of pulp and paper industry projects with a site-specific approach regarding water recipients* [OMNITOX website, 2005]. The project intentions were to develop a scientifically standardised method, which include local and regional (European) environmental conditions in an LCIA. The purpose of the study is to show, at what degree and in what way, a production site affects its water surroundings.

At the time of this study, results of the OMNIITOX study had not been released, and it is doubtful if it would have been applicable to this study due to effluent discharge being directly to sea.

4.4.3 Korean LCA

The author of several papers on LCA in the Korean pulp and paper field, Kwangho Park, was contacted, but all papers have been published in Korean and therefore could not be included in this research [Kwangho P., 2005].

4.4.4 Portuguese LCA

In 2002, a paper on '*The Application of Life Cycle Assessment to the Portuguese Pulp and Paper Industry*' was published in the Journal of Cleaner Production [Lopes E., 2003].

The LCA methodology was applied to Portuguese printing and writing paper in order to evaluate its environmental performance (cradle-to-grave), and to compare the environmental impact of the use of two kinds of fuels (natural gas and heavy fuel oil) in the pulp and paper production process. The functional unit of the study was defined as '*1 tonne of printing and writing paper, with a standard weight of 80gsm, produced from Portuguese eucalyptus globulus kraft pulp and consumed in Portugal.*'

Based on the LCI analysis and LCIA results the following conclusions were made:

- The results of *inventory analysis* and *impact assessment* show that the pulp and paper production/manufacturing process is the most important contributor to non-renewable CO_2 emissions due to on-site energy production, which does not correspond, however, to a major contribution to the overall global warming potential. (This impact category in Portugal is dominated by CH_4 emissions from waste paper landfilling.) On-site energy production in the paper production subsystem is the major source of SO_2 emissions, which makes it the most significant contributor to the acidification impact category. This subsystem is also the main consumer of non-renewable energy and, as a result, it is responsible for the most important share of the global system potential impact concerning non-renewable resource depletion.

- Although the eucalyptus pulp production is the largest consumer of energy throughout the paper life cycle, its contributions to air emissions is not predominant, because almost 90% of the energy consumed in the production process is renewable energy from bark and black liquor combustion. Consequently, this subsection has the highest renewable energy in the system. The production of eucalyptus kraft pulp is an important contributor to acidification due to the emission of SO_2 from the cooking process and furthermore dominates the results for water emissions (COD and AOX), thus being responsible for a great deal of the overall eutrophication potential.

- The final disposal stage plays a major role in global warming and photochemical oxidant formation impact categories as a result of CH_4 emissions in landfilling.

- Transport is the main source of NO_x emissions, resulting in an important contribution to the eutrophication and acidification categories.

- The contribution of the remaining stages of the paper life cycle to the impact categories is not relevant.

The results of this (MKRB) study compare favourably with the results of the Portuguese study when one compares the production of paper and the production of eucalyptus pulp results. The results pertaining to transport and disposal have not been evaluated in this (MKRB) *gate-to-gate* study. The Portuguese study does substantiate the fact that the production or manufacturing phase of a *cradle-to-grave* study is the phase contributing the most to the environmental impact and therefore implies that a *gate-to-gate* study, as is this (MKRB) study, is of significant value to the pulp and paper industry.

4.4.5 ***Visy Industries*** **– Australia**

Visy Industries (Visy), is the largest privately owned paper packaging manufacturing company in the world whose core business is the manufacture of cardboard boxes from recycled paper. Visy proposed the building of a new kraft mill in New South Wales, Australia and used LCA as an environmental decision support tool to quantify the CO_2 and CH_4 emissions across the entire life cycle of the Visy paper recycling and virgin papermaking processes. Commercially defined LCA models were developed for both papermaking processes. Green house gas (GHG) emissions estimated by each model was compared and the effect of different energy sources, technologies and manufacturing processes on CO_2 and CH_4 emissions were assessed. Results were used to propose appropriate GHG reduction strategies and business opportunities.

4.4.6 Europe LCA

Eurosac and *Eurokraft* released a study *'The LCA of Industrial Paper Sacks'* during September 1996 [Eurosac et al., 1996]. The study was divided into four steps and included extraction of raw materials (upstream) to waste treatment (downstream).

The first step, called the paper production step, includes forestry for obtaining wood such as pine and spruce, lopping, clearing wood and the production on site of pulp and paper, including that of related materials (electricity, natural gas, heavy fuel oils, consumables such as $CaCO_3$, CaO, H_2O_2, SO_2, starch etc.).

The production and printing of the paper sacks formed the second step of the system. The third step included the filling of the mass produced industrial products for distribution and palletisation of the full sacks. Finally, the last step comprises waste management, including recycling. The study also includes a comparative section between paper sacks and polyethylene (PE) sacks.

The study originated in 1993 and took four years and research conducted by four different countries (France, Sweden, Germany and the Netherlands) to conclude. The impact assessment investigated contributions to resources depletion (non-renewable, renewable substances water), human health toxicological impacts, global warming; acidification of the atmosphere, eutrophication of water, the formation of antioxidants and eco-toxicological effects.

The different scenarios studied within the framework of the inventory phase for brown paper sacks enabled the study to identify that the paper manufacturing step contributes significantly to the overall environmental impact of the system. It is a particularly heavy consumer of renewable and non-renewable energy.

It also identified and confirmed incineration with energy recovery as being the most environment-friendly end-of-life (grave) option: it enables the environmental impact of the system to be reduced, especially since the energy thus recovered is re-injected into the production processes and replaces average European electricity production.

Results from the comparative study between paper and PE sacks concluded that the overall environmental impact from paper sacks is less than that of PE sacks and the difference seems significant even if for certain parameters, the results are reversed.

An important conclusion highlighted in the study, is that the manufacturing of paper sacks from cultivated forests (as is the case in SA); results in the impact of biomass CO_2 as being nil, thanks to the phenomenon of photosynthesis.

The paper manufacturing phase (the second step) has once again been identified as a major contributor, specifically the energy generation subsection, of this process and is in agreement with the conclusions reached in this (Mondi) study.

4.4.7 Thailand

A published paper [Ongmongkolkul et al., 2001] presents the LCA results obtained by comparing a paperboard box produced from virgin pulp and an old corrugated box in Thailand. All materials and resource use, energy use, and emissions to environment of each process in the life cycle were identified and analysed. In the impact assessment phase, contributions to five environmental impact potentials were analysed i.e. global warming, acidification, eutrophication, photochemical ozone formation (smog formation), and solid waste generation.

The results showed that the most important process with respect to environmental impacts was landfilling of the corrugated box after use. For energy use, the drying process in the manufacture of paperboard was the major contributor. For solid waste generation, board and box production were the major sources.

The most significant energy consumption in this study has been attributed to the paper machines.

4.4.8 Australia

In 2001, a study was conducted in Australia that used LCA to answer the question '*Does the current recycling system (..kerbside recycling) result in a net reduction of environmental impacts (…as compared to land-filling) and if so what is the magnitude of this saving?*' [Grant et al. 2001].

The five impact categories under consideration were: Greenhouse Effect, Energy Embodied, Water Use, Solid Waste and Smog Precursors.

It was concluded from the indicators assessed that on a system wide level, recycling provides substantial environmental savings originating from both avoided virgin material production and avoided landfill space.

Although this result is not applicable to the results of this (Mondi) study, it will be useful to studies that further the research incorporating this study.

4.5 Conclusion

LCA has been applied to the pulp and paper industry since the early 1980's and various work groups around the world have been formed to progress on standardising the stages of the studies. The Nordic region has taken the lead in the development of the methodology regarding pulp and paper LCA studies.

The cost and time required to accomplish complete LCA studies in this field is prohibitive due to the large quantity of data assimilation required. Various software tools have developed to facilitate studies and assist users by supplying quality generic input and output data relating to processes and products used. In this study, KCL-Eco 3.01 calculation software and Eco-Indicator 95 impact assessment software is used.

The literature review conducted of pulp and paper related LCA studies internationally resulted in two similar conclusions. The first being that the pulp, paper or board manufacturing stage contributes most to the environmental burden of a cradle-to-grave study. The second being that the process related to the production of energy within the manufacturing process contributes significantly to the overall burden on the environment.

CHAPTER FIVE: Goal and Scope

This chapter defines the purpose of this study, the boundaries of the system studied and its intended application, including the limitations.

5.1 The Purpose of the LCA: Defining Goal and Scope

As presented in Chapter Two, defining of the goal and scope of the study is one of the most important steps in performing LCA. This step defines the boundaries of the system to be studied in relation to the objectives of the study and determines the applications of this study.

5.1.1 Goal of the Study

The study was conducted on behalf of Mondi Kraft Richards Bay whose requirements were:

- To identify and document all processes during the manufacturing of pulp and paper, that interact with and affect the environment.
- To identify "hotspot" areas during the manufacturing process that could be improved in order to reduce environmental impacts, by process improvements, redesign or by implementation of best available technology (BAT).
- To be able to supply information to export customers with regard to environmental aspects and impacts,
- To allocate environmental burdens to the Baycel and Baywhite products independently.

The study was granted to an academic institution as the focused technical ability and time needed to perform the work was not available in-house.

This study is also applicable to existing and future needs in the South African Pulp and Paper Industry and to academia as:

- A source of information to compare the environmental impacts and loadings of comparative pulp and paper products and of the same product made differently.
- The potential to compare paper and pulp products produced from virgin fibre (this case study), to that produced from recovered, reclaimed or recycled fibre.

- Assist SA technical associations such as the Technical Association of Pulp and Paper South Africa (TAPPSA) and the Paper Manufacturers Association of South Africa (PAMSA) to scientifically influence legislative and regulatory changes that impact on the industry.
- A source of information towards a complete cradle-to-grave study of pulp and paper products in a South African context.
- A benchmarking exercise for MKRB which has, since the project completion, undertaken vast upgrade and process improvements.

The objectives of this study as presented in Chapter One are:

- To conduct a *gate-to-gate* study on the production of 1 BDton of Baycel off PM1 using LCA methodology.
- To conduct a *gate-to-gate* study on the production of 1 BDton of Baywhite off PM2 using LCA methodology
- To determine the environmental impact category that is most impacted on and by which process.
- To determine whether the processes incurred to produce of 1 BDton of Baywhite have a greater or lesser impact on the environment compared to the processes incurred in the generation of 1 BDton of Baycel

The ***intended audience*** or the target group for this study are the managers and decision makers at Mondi Richards Bay, technical pulp and paper research institutes such as PAMSA and TAPPSA, and LCA practitioners.

5.2 Scope of the LCA

Issues considered when defining the scope of the study are: the system under study with its functions and boundaries, the functional unit, allocation procedures of the environmental burdens for products and by-products resulting from the same process, data requirements, assumptions, limitations, type of critical review (if any) and type and format of the report for the study. [Friedrich, 2001]

The ***systems*** studied are that of the production of Baywhite and Baycel at MKRB as described in Chapter Four.

5.2.1 System Boundaries

As per the goals set for the intended study, the boundaries of the system were set as *gate-to-gate*. This also satisfied the two-year time constraint on the project when considering the extended time period required for a complete cradle-to-grave study as experienced by international LCA studies in pulp and paper.

The *gate-to-gate* boundary included all processes and services that occur at MKRB. Air emissions, effluent generated and waste production data were assessed for this site only. Data has not been included for ultimate disposal of wastes and effluents and regional or national and global air pollution effects. Upstream processes that resulted in the production of raw materials delivered to the site are also excluded as per the goal of the study.

5.2.1.1 Spatial Boundaries

The *gate-to-gate* manufacturing process was further divided into the following process modules:

1. Wood Yard
2. Chemical Plant
3. Bleach Plant
4. Power Plant
5. Pulp Mill
6. PM1
7. PM2
8. Recovery
9. Finishing and Dispatch

Each module was treated as a sub-process of the system and its inventory and impacts individually evaluated. This enabled a comparison of the different sub-processes and for focus to be placed on the sub-process with the greatest environmental burden.

A schematic of the system boundary and the interaction between the processes and the environment is detailed in figure 5.1 below.

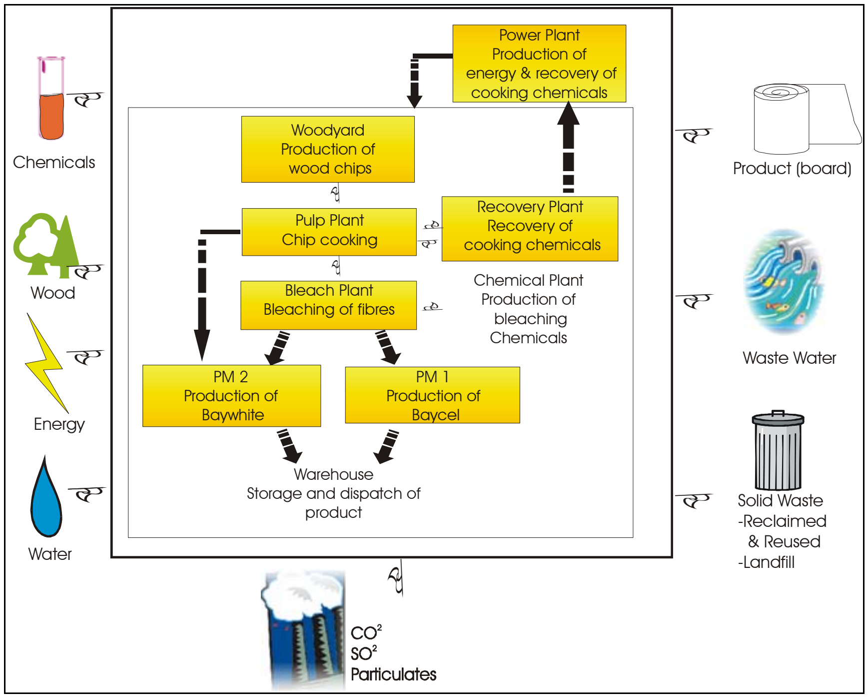


Figure 5.1: Manufacturing Process Flow

(Adapted from 2001 Mondi Kraft Sustainability Report)

The process begins with the input of timber into the *woodyard* and the chipping, screening and washing thereof. Thereafter, the chips are fed to a digester where the lignin is removed during the *cooking* process. The cellulose fibre that remains is then bleached at the *bleach plant*. The bleach chemicals required at this stage are produced on site at the *chemical plant*. Chemicals used during the cooking process are recovered in the *recovery plant* and returned to the cooking process. Electricity is generated at the *power plant*, which forms part of the recovery plant process.

The differentiation between *PM1* and *PM2* product occurs after the bleaching stage. Bleach pulp is sent to PM1 where it is pressed into sheet form and dried in a convective dryer. Baycel is purchased by intermediate users for conversion to an end product. For example, Mondi Springs Mill purchases PM1 pulp and reconstitutes it with water to produce cartonboard.

Bleached pulp sent to PM2 as white topliner and unbleached softwood pulp is the underliner. Baywhite is purchased by the packaging sector for further converting.

5.2.1.2 Temporal Boundaries

Week 11 to 36 of 2000 (March 2000 to August 2000) was selected as the time period within which data was collected and evaluated. During this time, production off both machines was steady and no major upsets or equipment changes were made to the process.

At the start of the project a period during 1999 was chosen as the data collection period. This was altered due to the making of a third product, Bayliner, on PM2 during this period.

5.2.2 The Level of Detail of the LCA

An LCA is predominantly a quantitative study and actual usage and generation data has been used in this study. These were available from monthly report books generated for operational control at Mondi. Where actual data was not available, either due to lack of monitoring instrumentation or when not required for operational purposes, generic and qualitative data has been sourced and referenced.

To standardise this study and thereby facilitate comparison between different studies in the pulp and paper industry, the recommendations regarding the choice of parameters, units and allocation have been defined as per Stromberg et al. (1997).

All incoming streams that accounted for less than 1% of the total mass of the generated product was excluded as per the recommendations and methodology framework generated for the pulp and paper industry [Stromberg et al., 1997]. The streams were screened for toxicity by evaluation of their Material and Safety Data sheets prior to exclusion.

5.2.3 Allocation Procedures

Allocation of burdens calculated for modules have been made as follows:

- Wherever possible, allocation was avoided by unit process division or system boundaries expansion,
- Where allocation could not be avoided, the outputs and inputs of the system were portioned among its different products or functions in a way that reflects physical relationships among them,
- When physical relationships could not be established, the inputs and outputs were allocated between the products and functions in a way that reflects other relationships among them such as mass or volumes.

5.2.4 Data Requirements

Data has been acquired through the following means:

- Interviews with Mondi employees and experts,
- Literature data, including published Mondi Kraft reports,
- Process and Operational Reports
- Mass balances when necessary
- Databases and KCL Software
- Experts in LCA related to pulp and paper through the KCL website.

As the initial step to data capture, an inventory questionnaire (see Appendix 1) was distributed to section leaders. This questionnaire simplified the task of getting appointments with mill personnel and gave them the opportunity to feed back information without my presence at the mill. The qualitative information provided was then used as a guide for the quantitative assimilation of data.

5.3 Assumptions and Limitations of the Study

The data collected is assumed to be indicative of normal running conditions and accidental spillages and environmental burdens caused by abnormal fluctuations in the performance of the mill are not evaluated.

Impacts related to mill staff have also not been assessed as the quantities of lunchroom waste; sanitary facilities etc. are insignificant when compared to the manufacturing process.

The collection of data (which was originally scheduled for a two month period), took the major part of 2000 to complete. Communication of data requirements and time investment by mill personnel was problematic as the writer was based 200km away from the mill at the university. The writer therefore moved to Richards Bay and lived there between May and October 2000.

The collection of data was a tedious process of convincing mill personnel to release data and of the importance of the study. Particular problems were experienced with on-site chemical contractors who treated their information regarding their chemicals as proprietary.

Transport within MKRB between the different plants is assumed negligible and has therefore been excluded.

5.4 Matching Scope with Purpose

The motivation for the study was to enable MKRB to identify the process that has the most significant contribution towards a negative environmental impact within the mill during the production of Baywhite and Baycel. This information would be used to focus attention (prioritise) on high environmental impact sub-processes for e.g.

- ISO 14 001 continuous improvement;
- To persuade decision-makers that one action should have a higher priority than another (e.g. air pollution vs. water vs. chemical substitution etc)
- To provide background information to enable MKRB to compare its product with that of a competitor
- To reduce total site environmental burden by selecting to manufacture one product in preference to another.

To fulfil these requirements it was sufficient to evaluate a *gate-to-gate* scenario as these processes are in direct control of MKRB.

5.5 The Functional Unit of the LCA

The study was structured such that the functional unit can be either;

One bone-dry tonne of saleable quality (bleached pulp) Baycel product off PM1 or,
One bone-dry tonne of saleable (white topliner board) Baywhite product off PM2.

This differentiation enabled the burdens associated with these two different production processes to be evaluated.

5.6 Inventory Data

An inventory of all inputs and outputs around each module was compiled by the assimilation of information from actual reports and qualitative assessments where actual values were not available.

Each modules impact was evaluated based on its inventory and a comparison of modules was conducted. In this way it was ascertained which process or module that had the greatest burden on the environment, and identified what that impact was. The collation of data for each process and the boundaries of each of the modules are presented in Chapter Six.

5.7 Conclusion

This chapter defines the aims, goal and scope of this study. This is considered the first phase of the LCA and defines the parameters for data collection for the next phase. The functional units of the study and the exclusion principles have been defined.

Phase 2 is the *life cycle inventory* phase, which is discussed in Chapter Six.

CHAPTER SIX: Results

To achieve the goals and aims of the study as defined in Chapter Five, the proceeding steps of *Life Cycle Inventory* and *Life cycle Impact Assessment* are reported. Assumptions made during the study are documented and explained.

Included in the body of this report are the data tables and flow sheet of the first module in the process, the woodyard, to illustrate the process layout and detail of the data collection process. The flow sheet and data inventory of subsequent modules have been annexed as follows: Pulp plant: Appendix 2; Bleach plant: Appendix 3; Chemical plant: Appendix 4; Recovery plant: Appendix 5; Power plant: Appendix 6; Paper machines: Appendix 12.

6.1 Introduction

The different processes incurred at the mill have been colour coded. Blue modules are specific to the production of HW bleached pulp. Yellow modules are processes necessary for the production of unbleached SW pulp Green modules provide utilities or serve a function in the production of both HW pulp and SW pulp.

6.2 The Woodyard

The primary function of the woodyard operation is the chipping of HW and SW logs. The output is chipped logs sent to the pulp plant for cooking.

6.2.1 Process Description

At the woodyard, hardwood and softwood logs are delivered via rail from the forest. Hardwoods are eucalyptus and wattle and softwood is pine. These are chipped and screened to differentiate between different chip sizes. Large shives (clumps of wood fibres) are returned to the chipper to be re-chipped and undersized chips are conveyed to the bark pile.

Softwood logs require debarking (removal of the bark) prior to chipping. The removed bark is shredded before being fed to the power plant module as a source of fuel.

The chips are stock piled in heaps and are conveyed to the cooking digesters in batches as required. A percentage of HW chips are supplied to *SilvaCel* which is a sister company and is not situated on site. The processing of chips at SilverCel are therefore not included in this study.

The process including all inputs and outputs to the woodyard is presented in 6.1 below.

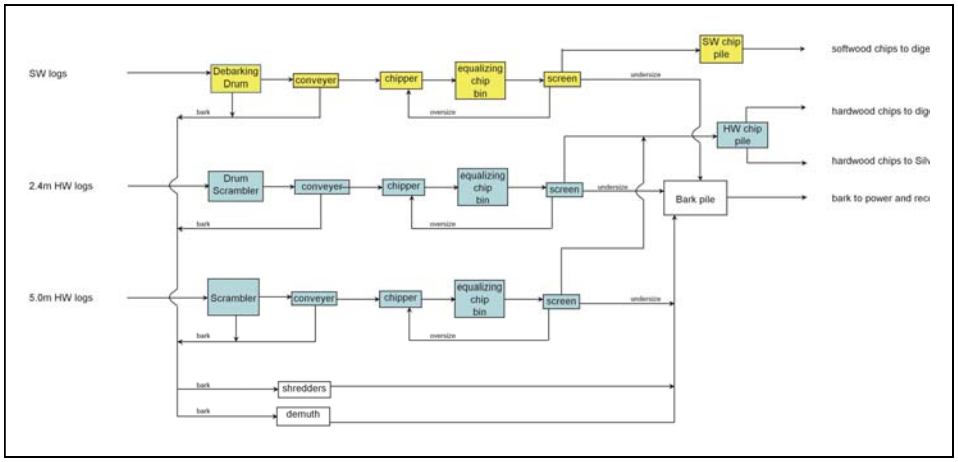


Figure 6.1: Woodyard Process Flow Diagram

6.2.2 Assumptions

- The quantity of bark sent to the power plant was reported as bone dry mass.
- The fines generated during the chipping process are 2% for SW and 3% for hardwoods HW, which are losses incurred in the chipping process.
- The effluent output was calculated by mass balance as no actual data was available. SW logs entered at 52% moisture and HW at 32% moisture. SW chips exiting the woodyard were at 52% moisture and HW at 42%. These were best estimates obtained from the technical manager at Mondi.
- The chip piles are stored in an area that does not allow wood residue leachate to exit the mills water system. The piles are stored on a concrete slab therefore ground water contamination is mitigated.
- Transport of the logs to the mill has been excluded from this *gate-to-gate* study.

6.2.3 Data Collation

Quantitative data are actual values from reports used for process control and financial accounting.

The module *woodyard* has been created in the *KLC-Eco* software tool and the quantitative data captured in *Microsoft Excel* was uploaded into the module.
The functional unit of the 'woodyard, SW' module is 1 BD ton (bone dry) SW chips produced. The functional unit of the 'woodyard, HW' module is 1 BD ton HW chips produced and the data has been normalised to represent this in the modules.

The LCI data captured from the woodyard is presented in table 6.1.

6.2.4 Allocation

There are two main outputs of the woodyard, SW and HW chips. The allocation of burdens to each of these outputs was accomplished by dividing the unit process into *Woodyard, SW* and *Woodyard, HW* as discussed in Chapter Five.

The diesel, energy, water inputs and effluent discharged have been allocated to each sub process by the mass ratio of HW and SW chips produced respectively.
The fuel produced (SW bark) is considered as a 'co-incidental by-product' of the chipping process and therefore has zero burden allocated to it. 100% of the burdens associated with these modules have therefore been allocated to the chipped product produced.

WOODYARD

INPUT

Weeks		11--14	15--18	19--23	24--27	28--32	33--36		Source
Description	unit	march	april	may	june	july	august	total	
SW Logs	ton	40258	27824	48336	43362	43043	35622	238445	Wood and Bark Supply, Tons Pine Supplied, Page 46, Technical Monthly report
Moisture content of SW logs	%	52	52	52	52	52	52		Peter Leah
SW Logs	BD ton	19323.84	13355.52	23201.28	20813.76	20660.64	17098.56	114453.6	
HW logs	ton	121046	106331	177505	138161	156521	112105	811669	Wood and Bark Supply, Tons Hardwood Supplied, Page 46, Technical Monthly report
Moisture content of HW logs	%	32	32	32	32	32	32		Peter Leah
HW logs	BD ton	82311.28	72305.08	120703.4	93949.48	106434.3	76231.4	551934.92	
energy	MWh	2117.92	2117.92	2647.4	2117.92	2647.4	2117.92	13766.48	Mill Specific Energy Consumption, Piet Kotze
diesel	l	59720	51780	52400	2022360	56575	42031	2284866	45.5 MJ/kg ; 38.857 MJ/l ; density = 0.854 kg/l ; information by shell SA Ltd.
diesel	kg	51000.88	44220.12	44749.6	1727095	48315.05	35894.47	1951275.56	Weekly Diesel Report(l) x 0.854 kg/l (Shell SA Ltd.)
Fresh water	m^3	70000	70000	87500	70000	87500	70000	302400	Calculated at 2500m^3/d
								455000	Water Balance (20 l/s*2520000s/month)

OUTPUT

Weeks		11--14	15--18	19--23	24--27	28--32	33--36		Source
Description	unit							total	
SW chips	ton	37747.3	32197.1	32748	33063.3	33643.1	35702	205100.8	Mervin Odayar, Pi, see chips2digester on XL
Moisture content of SW chips	%	52	52	52	52	52	52		
SW chips	BD ton	18118.704	15454.61	15719.04	15870.38	16148.69	17136.96	98448.384	
HW chips	ton	128243.77	132272	150203.5	132878.8	133881.6	142608	819087.56	Mervin Odayar, Pi, see chips2digester on XL
Moisture content of HW chips	%	42	42	42	42	43	42		Digester and Washing Plant, Chips to digester Moisture, Page 27, Monthly Technical report
HW chips	BD ton	74381.3866	76717.78	87118.02	77069.68	75742.5	82712.61	473741.969	
HW chips (to SilverCel)	ton	9759	11509	15323	21955	24174	19622	102342	Mondi Forests- Fibre Resources Dept., Bibi, 035-9022539
Moisture content of HW chips	%	42	42	42	42	43	42		Digester and Washing Plant, Chips to digester Moisture, Page 27, Monthly Technical report
HW chips (to SilverCel)	BD ton	5660.22	6675.22	8887.34	12733.9	13779.18	11380.76	59116.62	
Bark	ton	7138.92	7140.48	10687.26	5067.42	12214.62	10812.62	53061.32	Primary fuel, energy, steam, air production and usage, Technical Report, Page 63
Bark energy	GJ	57111.36	57123.84	85498.08	40539.36	97716.96	86500.96	424490.56	Cv of bark= 8 MJ/kg @ 45-55% moisture
SW fines loss	ton	222.08	220.52	169.74	207.58	116.38	182.38	1118.68	SW fines loss= 2% of logs to chipper, Timber Stock Control Report, Production Monthly Reports
HW fines loss	ton	1154.31	1081.8	1372.38	1203.84	906.75	1019.4	6738.48	HW fines loss= 3% of logs to chipper, Timber Stock Control Report, Production Monthly Reports
Effluent	m^3							302400	Water Balance (20 l/s*2520000s/month)

Table 6.1: Woodyard Inventory Data

6.3 Pulp Plant

Cooking of wood chips to facilitate the removal of lignin is the primary function of the pulp plant.

6.3.1 Process Description

The SW and HW chips are conveyed to the batch digester pulp plant where they are cooked in strong alkaline liquor under pressure at 160-170^{o}C for 40-60mins. During the cooking phase, lignin contained in the wood is dissolved and the cellulose and hemi-cellulose fibres are liberated.

The white liquor contains NaOH and Na_2S as the active pulping constituents. The concentrations of NaOH and N_2S are 90-110g/l and 20-40 g/l respectively. The HW chips are cooked to kappa 17-18 and the SW chips to kappa 35-45 (depending on the grade of linerboard produced). Once cooked, the contents of the digester are released to the *blow-down* tank.

The spent cooking chemicals or *black liquor* containing the reaction products of lignin solubilisation, is sent to the recovery plant. The reactions that occur in the digester are complex and not totally understood. Essentially, the swollen lignin in the wood chips is chemically split into fragments by the hydroxyl and hydrosulphide ions present in the pulping liquor. The lignin fragments are then dissolved as phenolate or carboxylate ions. Carbohydrates, primary hemi-cellulose and cellulose are also chemically attacked and dissolved to some extent.

After washing, the brown stock is screened, and the *accepts* are dewatered and pumped to the bleach plant. The screening rejects are refined and returned to the process.

Cooked SW is referred to as *liner pulp* and is used unbleached as a liner for the production of Baywhite board off PM2. HW pulp washing and screening process is referred to as the *mainline* and it sent to the bleach plant for whitening and brightening.

6.3.2 Assumptions

Each digester is of equal size and is filled with a consistent mass of chips and volume of cooking chemicals. The gases generated and the heat required by HW cook and SW cook are equal due to the fact that separate data regarding the emissions of SW cook and HW cooking was not available.

The emissions to air were calculated based on the US-EPA AP42 emission factors for the chemical wood pulping industry.

6.3.3 Data Collation

Actual data was used as per the monthly production reports and communication with the plant supervisor, Mervin Odayar.

To calculate the amounts of NaOH and Na_2S used, total alkali (TA) = 120 g/l and active alkali (AA) of 103 g/l values on a basis of 25% sulphidity were manipulated.

The collated data for this module has been normalised to *1 BDt of HW pulp produced* from *Cook, HW* module and *1 BDt of SW pulp produced* from *Cook, SW* module respectively. Theses can be regarded as the functional units of each module.

6.3.4 Allocation

Two products, HW and SW pulp, are produced at the pulp plant. It has therefore been divided into two separate modules i.e. *Cook, HW* and *Cook, SW*, each producing HW and SW pulp respectively.

Chemical usage, energy usage and emissions were allocated based on the number of HW blows and SW blows respectively.

Although the residual black liquor has a latent heat value, which is used in the recovery plant as a source of fuel, it is not the primary product of the cooking process and therefore has no burden from the pulping process allocated to it.

6.4 The Bleach Plant

The primary function of the bleach plant is to lighten and brighten HW brown stock by oxidation.

6.4.1 Process Description

Only HW pulp from the pulp plant is pumped to the bleach plant where it is bleached. As discussed in Chapter Three, the bleaching process is a sequence of different oxidising processes utilising different chemicals and conditions in each stage, usually with washing between stages.

The treatments applied at Richards Bay are as follows:

- **Chlorination [C]:** Reaction with elemental chlorine in acidic medium
- **Alkaline Extraction [E]:** Dissolution of reaction products with NaOH
- **Chlorine Dioxide [D]:** Reaction with chlorine dioxide in acidic medium

All chemicals used during the bleaching process are generated and supplied from the on-site chemical plant.

Two different bleaching technologies were used during the data collection period, *Classic* and *ECF*. Classic bleaching sequence is CEDED and ECF bleaching is DEDED.

6.4.2 Assumptions

No differentiation has been made regarding the burdens of these different bleaching methods. This is in reality not the case but the assumption was made due to lack of emission data available. During the data collection period, 107 819 tons of classic bleached pulp and 77 710 tons of ECF bleached pulp were produced.

6.4.3 Data Collation

The operational data published in the *Production Monthly Report* [Mondi, (2000)] was the source of most of the bleach plant information. The emissions and usages for each of the different bleaching processes could not be determined from the data available.

The plant data has been normalised to *1 BDt of bleached HW pulp produced*.

6.4.4 Allocation

Only HW pulp from the pulp plant is bleached, therefore 100% of the bleach plant burden is allocated to bleached HW pulp pumped to PM1 and PM2.

These two processes, ECF and Classic bleaching, are very different and no direct relationship between the two for the allocation of burdens to one or the other could be established.

6.5 Chemical Plant

The chemical plant supplies the bleach plant chemicals and produces the intermediate chemicals needed to make these chemicals.

6.5.1 Process Description

The primary raw material input is raw salt, sulphuric acid and sulphur, and the following chemicals are manufactured:

- Chlorine
- Chlorine dioxide solution
- Sulphur dioxide solution
- Dilute caustic soda

As per the process flow diagram for the bleach plant [see, Appendix 4], salt is dissolved to form brine, which is purified by settling and filtration, in the *brine preparation and primary brine treatment plant (611).*

In the *secondary brine treatment and Chlor-Alkali Electrolysis plant (621),* the brine is treated by ion exchange to a very high level of purity. During electrolysis, eighteen *ICI FM21* membrane cells produce chlorine and spent brine on one side of the membrane and hydrogen and 33% sodium hydroxide solution on the other.

At the *caustic handling plant (631)* the sodium hydroxide solution is stored and diluted and vent gases are handled. Vent gases pass through scrubbers where chlorine, chlorine dioxide and hydrogen chloride are removed by circulating sodium hydroxide solution before release of invert gases to the atmosphere.

Chlorine produced from the electrolysis of brine is cooled to remove the bulk of the water vapour and then dried with sulphuric acid at the *chlorine handling plant (641).* The diluted sulphuric acid is then used for the production of chorine dioxide.

The dry chlorine is compressed and most of it is liquefied by refrigeration and stored. The balance is used for the production of hydrochloric acid. The liquefied chlorine is taken from storage by padding with compressed dry air to the steam heated vaporisers. Vaporised chlorine is supplied to the bleach plant.

Vent gases and uncondensed chlorine are passed to the scrubber to be used for hypochlorite production.

At the *sodium chlorate plant (651),* sodium chlorate is produced from treated brine using chlorate electrolysers. Hydrogen from the electrolysis process is scrubbed and collected to the hydrogen gas-holder. The cell liquor containing sodium chlorate and salt at the correct concentration is collected to the storage tank and pumped to the chlorine dioxide production plant as required.

The *hydrochloric acid production plant (661)* produces HCl by combustion of chlorine gas in hydrogen gas from the hydrogen compression plant. The bulk of the chlorine gas is from the chlorine dioxide process with a make-up from the chlorine vaporisation plant. The 32% HCl produced is stored and pumped to the chlorine dioxide plant, for pH adjustment in the chlor-alkali plant, the sodium chlorate plant and in the brine dechlorination plant.

Chlorine dioxide is produced by the *ERCO R3H process (671*), which uses diluted sulphuric acid from the chlorine drying plant and hydrochloric acid from the HCl

burner tail gas scrubbing plant as feed. The produced ClO_2 is stored at a concentration of 6-8g/l.
The process also produces salt cake (Na_2SO_4) as a by-product, which is dissolved in weak black liquor at the recovery plant.

At the *sulphur dioxide plant (681)*, sulphur dioxide is produced by the combustion of sulphur. Aqueous sulphur dioxide is dissolved in water and stored. Part is used in dechlorination of the weak brine and chlorate solution and the bulk is sent to the pulp mill

In the hydrogen compression plant the cooled hydrogen gas from the chlor-alkali electrolysis and the scrubbed and cooled hydrogen gas from the chlorate electrolysis are collected to the hydrogen gas holder. The gas is compressed and is led through the gas compressor liquid separator to the lime kiln and HCl plant.

6.5.2 Assumptions

The additives, *Free Zone RB276* (refrigerant), *Sulkaflok BW 100, Duolite C467* and *BL-339 inhibitor* have been excluded from the inventory, as per the guidelines, due to the quantities in which they are used. The MSDS's for these chemicals have been evaluated and are non-toxic.

6.5.3 Data Collation

The inventory data for this plant was collated from the weekly stock balance produced at the plant. The chemical plant data has been normalised to *1 kg of sodium hydroxide produced,* as this is the chemical of highest volume produced. This was a matter of choice as any of the chemicals produced and supplied could have been chosen as the functional unit.

6.5.4 Allocation

The burden attributed to the chemical plant has been allocated to the bleaching of HW pulp.

6.6 Recovery Plant

The white liquor required for cooking is regenerated and in the process energy is generated.

6.6.1 Process Description

Weak black liquor from brown stock washing is pumped to a multiple effect evaporator. The liquor is concentrated from 13% dry solids for HW and 14% dry solids for SW, to 62-65% dry solids.

As described in Chapter Three, the concentrated (strong) black liquor is burnt in the recovery furnace, where the organics (lignin) is oxidised to produce heat and steam, while the non-combustible chemicals are recovered as sodium carbonate (soda ash) and sodium sulphide in the form of a red hot molten smelt which flows out of the furnace and into a dissolving tank. The smelt is dissolved in weak white liquor to become green liquor, which is pumped to the green liquor clarifier.

Raw green liquor is primarily sodium carbonate and sodium sulphide but also contains carbon particles and iron compounds from incomplete combustion. The iron compounds give the green liquor its characteristic green colour. These impurities called dregs, are removed by clarification. The dregs are washed with warm water and are disposed of while the wash water is pumped back to the green liquor clarifier. The clarified green liquor is pumped to the slaker where reburnt lime is added.

The liquor flows from the slaker proper into the classifier and to the causticisers. Un-reacted particles of lime are deposited in the classifier and are extracted as grits by a screw conveyor. The liquor is pumped from the third causticiser to the white liquor filter.

The white liquor filter separates the lime mud from the white liquor. Pure white liquor flows by gravity to the white liquor tank, from where it is pumped to the digester as required.

The lime mud is diluted and mixed with different process liquors and pumped to the lime mud wash filter. After separation in the lime mud washer filter, the weak white liquor flows to the weak white liquor tank and the lime mud is pumped to the lime mud tank.

The lime mud is fired in the limekiln (calcination) to produce the burnt slaked lime required to causticize the green liquor to white liquor in the slaker. The limekiln is fired with heavy fuel oil (HFO), gas or hydrogen from the chemical plant and malodorous gases from the digesters and evaporators are also burnt.

Flue gases from the kiln are washed in a venturi scrubber and the undissolved particles in the recirculated wash water are pulped back to the process.

6.6.2 Assumptions

Although the evaporators and recovery furnace do not fall under the management of the recovery process, these processes have been included in the recovery module. This enables the recovery process to be evaluated holistically (i.e. the complete recovery/regeneration of digester cooking chemicals).

6.6.3 Data Collation

Actual values from the chemical plant weekly stock balance were used where available. Water flows were assumed based on design specifications.

The data has been normalised to *1 kg of white liquor produced* at the plant.

6.6.4 Allocation

The environmental burden associated with this module has been allocated to the chemical recovery of the digester chemicals. The fact that useable energy has been generated is an addition, but not the primary aim. The energy created could have been supplied by external sources or directly from the power plant. The process was initiated as a cooking chemical cost saving.

The allocation of the burdens due to this process have therefore been divided between the volume of regenerated white liquor pumped to either HW or SW cooking.

6.7 Power Plant

At the power plant, steam is produced and supplied to the mill.

6.7.1 Process Description

Three power boilers operate in parallel with the recovery furnace and supply additional steam. The boilers are fired with bark, coal, and wood waste.

The steam generated from the boilers power a turbine that generates electricity to parts of the mill.

6.7.2 Assumptions

All energy requirements at MKRB originate from the power plant. External Eskom supply (from the national grid) is allocated to the power plant and distributed from here as part of the total electricity requirements.

6.7.3 Data Collation

Data was acquired from the Mill specific energy distribution reports. The functional unit of the power plant is *1 MWh generated and supplied to the mill*.

6.7.4 Allocation

The burden associated with the process of generating steam and electricity has been allocated to each of the plants receiving energy from the power plant as per the energy consumption of that plant.

6.8 Paper machines

Mondi Richards Bay produces two key products. These are Baycel, a premier grade bleached hardwood pulp, which is made from 100% eucalyptus fibre (HW) and Baywhite, a whitetop kraft liner board. Baycel is produced off PM1 and Baywhite off PM2.

6.8.1 PM1

6.8.1.1 Process Description

As described in Chapter Three, bleached HW pulp from the bleach plant is formed, pressed air dried in a convective dryer at PM1 before being sheeted. The sheets are baled and sold as market pulp.

6.8.1.2 Assumptions

When evaluating the affects of the production off PM2, the production of Baycel off PM1 is set at zero.

6.8.1.3 Data Collation

Actual data from the *monthly production reports* were captured.
The overall functional unit for the study is *1 BDt of Baycel produced off PM1*.

6.8.1.4 Allocation

The burden attributed to HW processing has been allocated to PM1 product by mass distribution.

6.8.2 PM2

6.8.2.1 Process Description

As discussed in Chapter Three, *Baywhite* is a whitetop linerboard consisting of two layers. The top sheet is bleached HW pulp and the base sheet in unbleached SW pulp. Seventy five percent of production is exported to Western Europe, Australia, New Zealand, South America, Asia and the Middle East and 25% is sold to the local market.

6.8.2.2 Assumptions

It is assumed that during the data collection period, that only one grade and grammage of Baywhite was produced.

The burden attributed to this product by the processing of HW and bleaching has been allocated to PM2 by mass distribution.

Allocation of 100% of the burden of producing SW pulp has been transferred to PM2.

When evaluating the affects of the production off PM1, the production of Baywhite off PM2 is set at zero.

6.8.2.3 Data Collation

Actual data from the monthly production reports were captured.
The overall functional unit for the study is *1 BDt of Baywhite produced off PM2.*

6.8.2.4 Allocation

All processes involving SW unbleached pulp have been allocated to PM2.
The burden attached to HW processing has been allocated to PM1 and PM2 products by mass distribution.

6.9 Life Cycle Inventory Analysis

The calculation summary, using KCL-ECO software tool as introduced in chapter four and results of the life cycle inventory assessment are discussed.

The inventory data collected has been normalised and transferred to the software. The process flow was modelled as illustrated in figure 6.2 and the burdens allocated based on weight ratios.

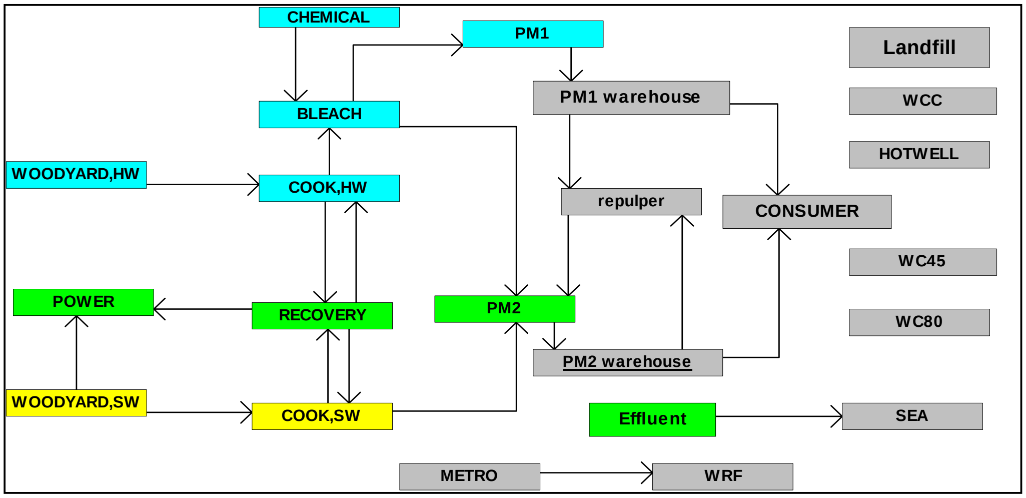


Figure 6.2: Process flow of LCI modules

Modules have been sorted into primary and secondary codes to allow outputs to be calculated by grouping them according to source. Each module has been classified into primary codes based on the process occurring in that module. Secondary codes have been classified as either contributing towards bleached pulp, unbleached pulp or a both.

Blue modules indicate processes that are incurred for the purpose of generating and consuming HW bleached eucalyptus pulp only (*bleached pulp, secondary code*).
Yellow modules are for the purpose of generating SW pine unbleached pulp (*unbleached pulp, secondary code*).

Green modules indicate processes that impact on both SW unbleached and HW bleached pulp generation and consumption (*combination, secondary code*).

Grey modules have not been classified as having an impact on either process due to lack of detailed data regarding the impact of these processes.

Only the main material flows are indicated in the diagram above. A complete flow diagram indicating all connecting flows is annexed to Appendix 7.

Fresh water and process water flows have been included in the calculations.

All fuels usage has been captured in mass and volumetric units of measure as per the requirements of the software package. The fuel inputs in the data inventory tables are also reported as per its specific energy content in GJ (giga joules) as per Stromberg, 1997.

The flowsheet can be manipulated such that any mass of either product or a combination of both products can be assessed. In this report the burden of generating 1 BDt of Baycel only and 1 BDt of Baywhite only will be assessed and environmental impacts compared. The modules contributing most significantly to a particular impact are identified and the process within that module has been identified.

The equations within the model are assumed linear and have been solved sequentially. As discussed in Chapter Five, all transport related data have been excluded from the study.

6.10 Life Cycle Inventory Analysis Conclusions

From the Life cycle inventory analysis it is difficult to ascertain the burdens associated with the production of either product, and even more so to identify the type of burden impacted upon.

These classified inventory tables can be used as is in further LCA work related to the pulp and paper industry.

The inventory of PM1 product, Baycel, is representative of an integrated kraft mill, producing one bone-dry tonne of bleached pulp sheets to market and includes:

- Eucalyptus wood chipping and screening,
- Batch cooking to kappa 17-18,
- 42% Classic and 58% ECF bleaching
- HW Weak black liquor TDS = 13%
- HW Strong black liquor TDS = 62-65%
- Recovery boiler efficiency = 63%
- LVHC incineration in lime kiln
- Lime kiln with ESP
- Limekiln is HFO fired.
- Pulp brightness > ISO90
- Dirt < ISO 4.9

Unlike the inventory compiled for Baywhite, the LCI data for 1 BDt of Baycel can be considered generic.

6.11 Life Cycle Impact Assessment

Life Cycle Impact Assessment is the third phase of a complete LCA study as introduced in chapter two. The purpose is to assess the systems LCI results to understand their environmental significance (i.e. how emissions and resource consumptions affect the environment). Impact assessment consists of separate steps, namely '*selection of impact categories*', '*classification*', '*characterisation*', '*normalisation'* and '*weighting*' (the latter two are optional as per ISO 14042 and NordPap).

Eco-Indicator 95 software, as introduced in chapter four, is used to determine the impacts of the data presented in the life cycle inventory analysis. The *distance-to-target* methodology is used and has been used in many popular LCIA methods [Baumann and Rydberg 1994, Goedkoop 1995]. It determines environmental effects that damage ecosystems or human health on a European scale.

In the distance-to-target approach, weights are derived from the extent to which actual environmental performance deviates from a goal or standard. As described by Powell et al. (1997), the method ranks impacts as being more important the further away society is from achieving the desired standard for the pollutant [Seppala et al. (2001)].

The discussion of the results obtained during the steps in the LCIA phase satisfies the final stage of the LCA, that of *interpretation.*

6.11.1 Impact Categories

The affects have been divided into the following impact categories: climate change, acidification, eutrophication, ozone layer depletion, heavy metals, carcinogenic substances, winter smog, summer smog and pesticides. Impacts due to depletion of resources have not been evaluated.

These categories conform to the CML guide used in the SimaPro2 method, however the toxicity scores are specified into heavy metals, carcinogenic substances, pesticides and winter smog.

6.11.1.1 Climate Change

The figure below shows the most important mechanisms regulating the temperatures on earth.

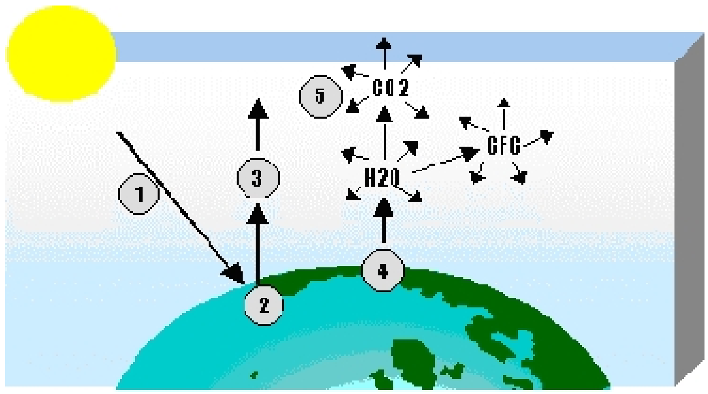


Figure 6.3: Schematic representation of climate change

Source: www.scienceinthebox.com

1. *short wave and ultraviolet light and visible light pass through the atmosphere.*
2. *Most of the light is absorbed by the earth and converted into heat in water and land.*
3. *Some of the light is reflected back into space.*
4. *The warm surface of the earth radiates the heat back into space as long-wave infrared light.*
5. *Some gases such as water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs)absorb infrared light and re-emit the heat radiation in all directions.*

The gases, which absorb infrared light in the atmosphere allow ultraviolet light and visible light from the sun to pass, but tend to trap the heat radiation (infrared light) from the earth's surface, just like the glass in a green house. These gases are therefore often referred to as greenhouse gases (GHGs). The temperature of the earth is determined by the balance between the input of light from the sun and the output of heat radiation from the earth's surface, which in turn is determined by the composition of GHGs in the atmosphere. Human activity is continuously increasing the concentration of GHGs in the atmosphere by emissions of naturally occurring gasses such as CO_2, CH_4 and N_2O and new substances such as halogenated carbons (CFCs, HCFCs and PFCs).

A *GHG indicator* is derived from two basic properties of each gas;

1. Its ability to reflect heat
2. The longevity of the gas in the atmosphere.

These properties are then compared to the properties of carbon dioxide and converted into carbon dioxide equivalents. The individual equivalents are added together to obtain an overall score that represents the total quantity of GHGs released. This methodology has been based on the work done by the Intergovernmental Panel on Climate Change (IPPC). This is an international panel of researchers established by the United Nations Environmental Programme (UNEP) and the World Meteorological Organisation (WMO)

6.11.1.2 Acidification

Natural rain is slightly acidic due to the presence of various acids in the air that are washed out by rain. A number of man-made substances are either acid or converted to acid by processes in the air. Examples of such emissions are sulphur dioxide, which becomes sulphuric acid and nitrogen oxide, which becomes nitric acid.

An acidification indicator is derived by assuming that 100% of an emission is converted to acid and falls into a sensitive area. The acidity of each emission is converted to equivalent amounts of SO_2. All emissions are then added into an overall acidification indicator score that represents the total emission of substances that may form acids.

6.11.1.3 Eutrophication

Aquatic plants and algae grow gradually in fresh water overtime in a process called eutrophication. This process is controlled by low concentrations of certain nutrients such as phosphate and nitrogen.

Usually phosphorous is the limiting nutrient in fresh water and nitrogen in estuaries and salt water. When humans release these nutrients, the process of eutrophication is accelerated. The excessive growth of plants and algae can smother and kill other organisms by depleting the available oxygen.

A eutrophication indicator is derived by converting the different chemical forms of phosphorous and nitrogen into an equivalent form. The proportion normally found in aquatic algae is used to weight the phosphorous and nitrogen. These values are added to get an overall indicator.

To interpret the eutrophication indicator, it is important to realize that the background concentration of the nutrient is the baseline. A similar quantity of added phosphorous may trigger a substantial increase in the level of the nutrient, while remaining small at another site. Thus the actual impact cannot be precisely predicted.

6.11.1.4 Ozone Layer Depletion

In the earth's stratosphere, chemical processes maintain a balanced concentration of ozone. This protects the earth by absorbing much of the harmful ultraviolet radiation from the sun.

If a gas can stay in the atmosphere long enough to reach the stratosphere and if the gas carries bromine or chlorine atoms, the ozone balance may be threatened as free bromine and chlorine can accelerate the breakdown of ozone.

Ozone depletion indicator is derived through several properties of a gas. These include its stability to reach the stratosphere and the amount of bromine or chlorine the gas carries. The properties of each gas are then compared to the properties of trichlorofluoromethane-CFC-11 (with the chemical formula $CFCl_3$) and converted into CFC-11 equivalents. The individual equivalents are summed to obtain the overall ozone depletion indicator, which represents the total quantity of ozone depleting gases released.

6.11.1.5 Toxicity

Toxicity to flora and faunas is caused by a plethora of substances. The Eco-Indicator 95 methodology has divided this effect into sub-effects, *carcinogenic substances*, *heavy metals* and *pesticides.*

For *heavy metals*, the WHO specify a number of values for persistent substances based on long term low level exposure. These criteria were established to evaluate drinking water, based on identified health effects. The identified substances are persistent to a greater or lesser extent and tend to accumulate in the environment. A weighting factor was determined in order to calculate a lead equivalent of these substances.

To determine an equivalency factor for *carcinogenic substances*, the probability of cancer at $1ug/m^3$ is calculated. This is then expressed as the number of people from a group of 1 million who will contract cancer at this exposure level.

Pesticides cause a number of problems, including:

- Ground water becomes too toxic for human consumption.
- Biological activity in the soil is impaired, resulting in damage to vegetation.

This implies that account must be taken of both eco-toxicity and human toxicity in the effect score. The final weighting has been based on the amount of active ingredient in categories of disinfectants, fungicides, herbicides and insecticides.

6.11.1.6 Smog

Smog is also known as photochemical ozone production. Ground-level ozone is formed by a combination of sun, nitrogen dioxide (NO_2) and volatile organic compound (VOC). Humans in urban areas often release large quantities of organic compounds and at the same time, large amounts of nitrogen oxides (NO_X) from combustion, to create electricity and to power cars. In warm temperatures and in sunlight (hence, the name summer smog), these processes generate additional quantities of ozone at ground level. Winter smog occurs in cold conditions and is made up mainly by small particulates and SO_2.

At ground level, this increase in low levels of natural ozone and dust can harm some plants and may irritate the lining of our lungs. This chemical reaction process of VOCs, NO_X, and sunlight is highly complex. The particular chemistry of a VOC, the local concentrations, how high the temperature may be, the wind conditions and other factors are all involved.

The reaction process is non-linear, meaning that sometimes the NO_X concentration will drive the reaction. At other times, it is the VOC that drive the reaction. Various indicators take low, average and high NOx concentrations to calculate an overall score.

A photochemical ozone indicator is derived by finding conversion or reactivity factors for each of the hundreds of possible VOCs. This is then used to convert the many possible inventory VOCs into ethylene equivalents.

6.11.1.7 Natural resources

In this study, natural resources have not been included as an impact category due to limitations of the LCI software tool. The reason for omission of the effects is given in the Eco-Indicator 95 Manual for Designers, (1996) as:

> *…If a product made of very rare raw materials is used, this rarity is not expresses in the indicator; after all, the fact that a substance is rare does not cause any damage to health. The emissions arising from the extraction* (or discharge) *of the raw materials are included and are usually extensive…*

This implies that even though the effect of the use of raw materials is not evaluated, the effects of the extraction or discharge have been included by their secondary effects on air, land and water.

Water consumption has not been included as an impact category in this study, due to its exclusion in the software used. This is largely due to the demand for water being a non-event in the northern hemisphere. The effects of discharging effluent with high inorganic concentration (TDS) has been highlighted as an important impact category for South African LCAs [Friedrich, 2001 and Forbes, 1999]. In this study, effluent is discharged directly to sea and salination is therefore not considered important. When considering pulp and paper industries inland, salination is an impact category that will have to be investigated. The water usage due to each of the processes studied is however reported.

6.11.2 Classification

Classification is the assignment of input and output parameters of the LCI to impact categories. Certain parameters can belong to many categories, for example, NOx causes both summer smog and eutrophication. The Eco-Indicator 95 LCA tool automatically conducted this step.

6.11.2.1 Discussion

To obtain correct results from the software, the names given to variables used in the impact assessment method and in the data inventory have to be the same. This posed a problem where for example, the data had been captured as ‘carbon dioxide’ in the flowsheet, but in the impact assessment, the symbol used is CO_2. Because the symbols are different (even though they mean the same), the characterisation factors for CO_2 were not used. Comparing the variables that exist in the program and amending the captured variable names where necessary rectified this.

6.11.3 Characterisation

Characterisation is the calculation of category indicator results and involves mathematical conversion of LCI results to common units and aggregation of the converted results within the impact category. This is an automatic linear process in the KCL software used. Each parameter within each impact category has a *characterisation factor* (*Ci)* [see, Appendix 8 for table of characterisation factor].

The *indicator* or the score *(Si)* is calculated by multiplying the *value of the input/output (Bi)* with the characterisation factor *(Ci)*: $Si=CixBi$. The *total indicator* (the total score) of an impact category is the sum of the indices (scores): $S = \Sigma Si$.

6.11.4 Normalisation

The aim of normalising the indicator results is to allow for better understanding of the magnitude of the impact relative to pre-selected reference values. The reference value used by Eco Indicator-95 is based on 1990 levels for Europe excluding the former USSR. Its applicability to South African conditions has not been established. I have included the results such that future LCA's and previous LCA's conducted using Eco-Indicator can be compared and evaluated and that the applicability to South African context can be evaluated by further research.

The normalisation step has also been conducted with the aim of comparing the magnitude of impact categories for each product (Baywhite and Baycel) to determine the greater relative impact. The normalisation reference values as used by Eco-Indicator 95 is as per table 6.2 below.

6.11.5 Weighting

This is where the relative importance of each impact category is assessed. This is accomplished by assigning a weighting factor to each category. The final weighting score is then calculated by multiplying the indicators (scores) with these factors and by summing the results. The weighting factors used by Eco-Indicator 95 method are presented in table 6.3 below.

Weighting factors have been determined based on the distance to target methodology and the criteria for target levels are:

- One excess death per million per year
- 5% ecosystem damage
- Avoidance of smog periods.

Impact Categories	Normalisation values (N)
Climate change	13100 [kg CO2]
Ozone Layer depletion	0.926 [kg CFC11]
Acidification	113 [kg SO2]
Eutrophication	38.2 [kg PO4]
Heavy Metals	0.0543 [kg Pb]
Carcinogenic Substances	0.0109 [kg B(a)P]*
Winter Smog	94.3 [kg SPM]**
Summer Smog	17.9 [kg C2H4]
Pesticides	0.962 [kg act. S]***

Table 6.2: Normalisation factors as per Eco-Indicator 95 methodology

***Benzo[a]pyrene; **Suspended Particulate Matter; *** Active Substance**

Impact Categories	***Weighting values (W)***	***Criterion***
Climate change	2.5	0.1^{o}C rise every 10 years, 5% ecosystem degradation
Ozone Layer depletion	100	Probability of 1 fatality per year per million inhabitants
Acidification	10	5% ecosystem degradation
Eutrophication	5	Rivers and lakes, degradation of an unknown number of aquatic ecosystems
Heavy Metals	5	Lead content in children's blood, reduced life expectancy and learning performance
Carcinogenic Substances	10	Probability of 1 fatality per year per million people;
Winter Smog	5	Occurrence of smog periods, health complaints, particularly amongst asthma patients and the elderly.
Summer Smog	2.5	Occurrence of smog periods, health complaints, particularly amongst asthma patients and the elderly.
Pesticides	25	5% ecosystem degradation

Table 6.3: Weighting factors as per Eco-Indicator 95 methodology

CHAPTER SEVEN: Interpretation of the results

The final phase of an LCA study is the *interpretation* of results obtained. The objectives of this chapter are to present and analyse the results, explain limitations, and to reach conclusions.

7.1 Results for the production of Baycel off PM1

As discussed in chapter 5.2.1.1, the process of manufacturing Baycel has been divided into 9 different unit processes. Information regarding the inputs and outputs associated with each process has been presented in the previous chapter.

An impact assessment of energy and water usage has been excluded from the impact category assessment due to limitations of the software used (see 6.11.1.7). Table 7.1 below lists the energy and water requirements of each of the unit processes during the production of 1 BDt of Baycel.

Process	**Water usage (m^3/ton)**	**Energy usage (MWh/ton)**
Woodyard, HW	2.236	0.050
Cook, HW	37.762	2.132
Bleach plant	34.854	0.527
Power plant	44.880	1.25
Chemical plant	85.739	0.156
PM1	31.892	1.358
Cook, SW	0	0
Woodyard, SW	0	0
PM2	0	0
Fresh Water	68.819	-
Purchased electricity	-	0.347
Recovery	91.873	2.488

Table 7.1: Water and Energy Consumption for the production of Baycel

The water system has a number of recycle and treatment loops, thus the water figures in table 7.1 above represent the equivalent “open loop” water consumptions and the values are not additive.

The process of recovering cook chemicals (*recovery*) consumes the most water during the production of baycel and therefore carries the highest burden for the consumption of water. The process of chipping HW logs (*woodyard*) carries the lowest burden in this regard. The temperature of water supplied to each process further distinguishes the water supply. In the total inventory (see Appendix 9), the supply of 45°C (WC45), 80°C (WC80) and water from condensate recovery to each of the unit processes is included. The overall depletion of our natural resource due to the use of fresh water is 68.81kl/t. From figure 7.1, it is evident that fresh water is consumed by the chemical and power plants (from the WRF tank). Fresh water consumed by the chemical and power plants are 8.32 m^3/t and 6.78 m^3/t respectively. The balance of 53.71 m^3/t is dilution and top-up water to the WCC tank from where water is distributed mill wide as per the diagram below.

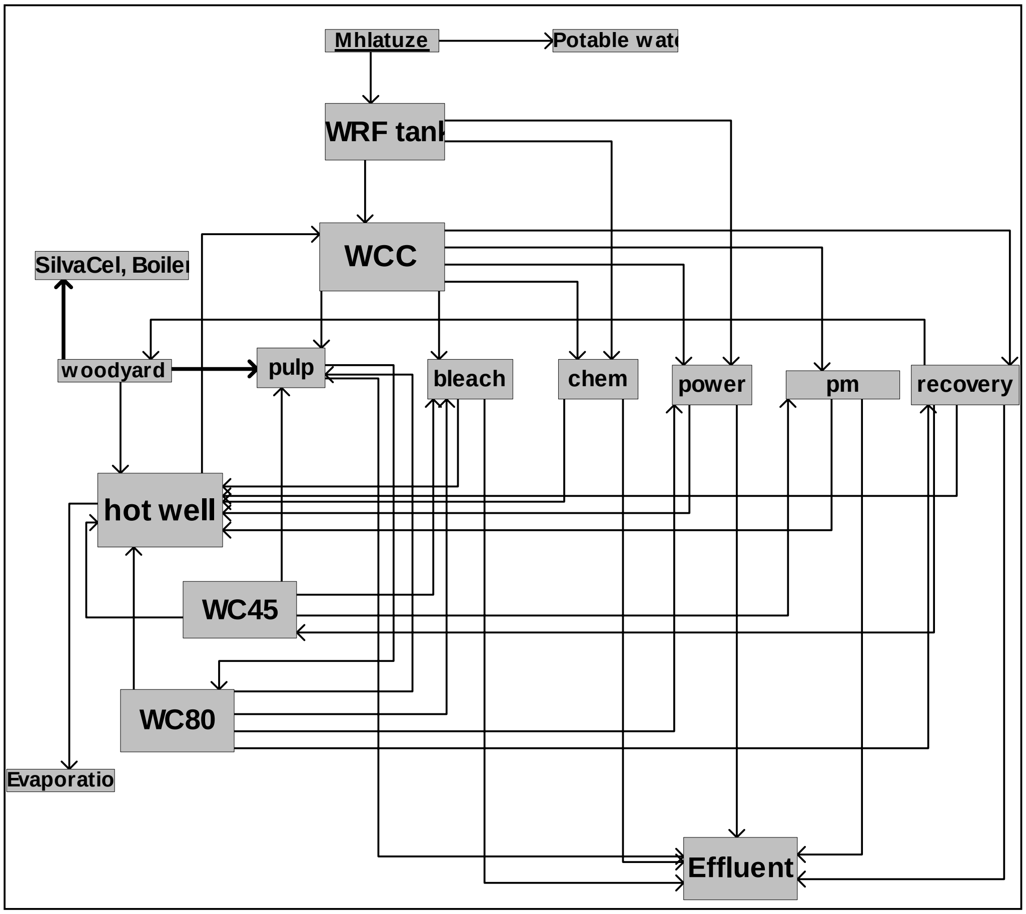


Figure 7.1: Overview of Mill Water flow

For the burden associated with energy consumption as a non-renewable resource, the recovery process is once again the process with the largest contribution. The attribution of this burden could be argued, as the recovery process is also a source of energy by the process of black liquor oxidation. In this study, the recovery process has been classified as being for the sole purpose of regenerating cook chemicals and the fact that energy is created is co-incidental. If we consider the balance between the energy used in this process and the energy generated, the process is still an energy sink (see Appendix 13), with an overall usage of 0.198 MWh. This is highly unlikely and the energy consumption value is questionable. Further investigation into the validity of this value is required but due to the time constraints of this project could not be confirmed.

If the energy usage value is found to be incorrect and higher than expected, then the process of cooking HW chips is the greatest electricity consumer for the production of Baycel. The module that consumes the least energy is the woodyard.

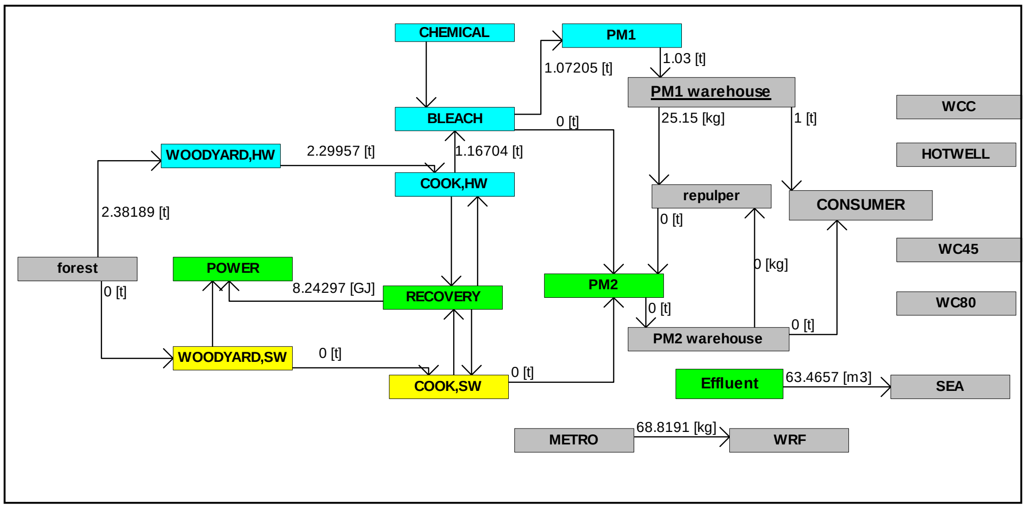


Figure 7.2: KCL-Eco Material Flow Balance for Baycel

Figure 7.2 above, quantifies the material flows between unit processes. From this balance carried out by the software, the following conclusions regarding the production of 1 BDt of saleable Baycel can be made:

- 2.4 tons of eucalyptus logs as raw material input
- 2.3 tons of HW chips produced
- 1.2 tons of HW pulp produced
- 1.1 tons gross production off PM1.

The outputs of the process have been calculated as presented in Chapter Six and are presented in table 7.2 below.

Description	**Units**	**Score**
Climate change	[kg CO_2]	601.109
Ozone layer depletion	[kg CFC-11]	0
Acidification	[kg SO_2]	12.1478
Eutrophication	[kg PO_4]	1172.78
Heavy metals	[kg Pb]	0
Carcinogenic substances	[kg B(a)P]	0
Winter smog	[kg SPM]	626.026
Summer smog	[kg C_2H_4]	0.0799516
Pesticides	[kg act.s]	0

Table 7.2: Overall environmental profile for the production of Baycel

The most significant contribution attributed to the overall process is to eutrophication. Environmental effects caused by ozone depletion, heavy metals, carcinogenic substances and pesticides are not affected by the production of Baycel. Although a refrigerant is used at the power plant, analysis of its technical data sheet indicates that it is not an ozone-depleting substance.

The overall score is the summation of the scores attributed to the unit processes. Table 7.3 lists the impacts caused by each process, excluding the categories that have zero impact.

From the percentages in table 7.3, the power and recovery processes have the most significant contribution to the overall environmental profile.
The contribution towards *climate change* from the power plant is due to the burning of coal (fossil fuel), which generates CO_2.

PM1	Climate Change	Acidification	Eutrophication	Winter Smog	Summer Smog
	[kg CO_2]	[kg SO_2]	[kg PO_4]	[kg SPM]	[kg C_2H_4]
Bleach	0	0	0	0	0.00473186 *(6%)**
Chemical	0	5.42595 *(45%)*	0	5.42595 *(0.87%)*	0
Effluent	0	0	1172.63 *(99.987%)*	0	0
PM1	0	0	0	0	0.013823 *(17%)*
Power	601.109 *(100%)*	4.47607 *(37%)*	0.000236 *(0.00002%)*	6.35853 *(1.02%)*	0.011505 *(14%)*
Pulp	0	0	0	0	0.000372 *(0.465%)*
Recovery	0	2.24582 *(18%)*	0.145574 *(0.01241%)*	614.241 *(98.12%)*	0.04952 *(62%)*
Woodyard	0	0	0	0	0

* values in brackets represent the percentage value of the total score for that category

Table 7.3: Environmental profiles of the unit processes for the production of Baycel

Table 7.4 below presents the contributing emissions generated by the respective unit processes toward the *acidification* impact category.

	SO_2	NOx	SUM
Entire system	11.3627	0.78513	12.1478
chemical	5.42595	0	5.42595
power	4.4748	0.0012695	4.47607
recovery	1.46196	0.78386	2.24582

Table 7.4: Eco-Indicator 95, Acidification contributing variables [kg SO_2] for the production of Baycel

Eutrophication is caused by the release of effluent from the effluent plant. The discharge volume from each unit process to the effluent plant is known, but the quality of discharge streams from each unit process is not known. The burdens could not be transferred back to the processes by volume basis, as each process has a unique impact on the effluent quality. The eutrophication impact score can therefore only be attributed to the overall process (see, Appendix 14) and not to a specific unit process. Table 7.5 below presents the contributing emission variables responsible for the burdens on the eutrophication impact category.

	P, tot	COD	NOx	SUM
Entire system	1170.7	1.93084	0.14581	1172.78
Effluent	1170.7	1.93084	0	1172.63
power	0	0	0.0002358	0.00023 6
recovery	0	0	0.145574	0.14557 4

Table 7.5: Eco-Indicator 95, Eutrophication contributing variables [kg PO_4] for the production of Baycel

Table 7.6 below presents the emissions from each of the process units that contribute to the *winter smog* impact category.

	Particulates	SO_2	SUM
Entire system	614.663	11.3627	626.026
chemical	0	5.42595	5.42595
power	1.88373	4.4748	6.35853
recovery	612.779	1.46196	614.241

Table 7.6: Eco-Indicator 95, Winter smog contributing variables [kg SPM] for the production of Baycel

The contribution to the *summer smog* impact category is due to air VOC emissions from the unit processes presented in table 7.6 below.

Effluent quality has been included in the eco-impact categories above but the volume of effluent discharged (which has a direct impact on the usage efficiency) has not been considered. The amount of effluent discharged to sea during the production of 1 BDt of Baycel is 63.47kl. The effluent to fresh water ratio for this process is therefore 92%.

	VOC	SUM
Entire system	0.0799516	0.0799516
bleach	0.00473186	0.0047319
PM	0.0138232	0.0138232
power	0.0115049	0.0115049
Pulp	0.000371585	0.0003716
recovery	0.04952	0.04952

Table 7.7: Eco-Indicator 95, Summer smog contributing variables [kg C_2H_4] for the production of Baycel

7.2 Interpretation of results for the production of Baycel

The unit process that contributes most significantly to environmental impacts due to the consumption of energy and water is the recovery plant where the regeneration of cooking chemicals is facilitated.

The impact category with the largest significant impact is that of eutrophication due primarily to the total phosphate content of the final effluent. The relative importance of this impact category compared to the other impact categories affected has not been established. By applying the weighting factors tabled in Chapter Six, the significance of the impacts in relative terms, figure 7.3, indicates the impact caused by eutrophication of environmental systems is the most significant.

As discussed in chapter 6.11.1.3, to interpret the eutrophication indicator, it is important to realise that the background concentration of the nutrient is the baseline. A similar quantity of added phosphorous may trigger a substantial increase in the level of the nutrient, while remaining small at another site. Thus the actual impact cannot be precisely predicted

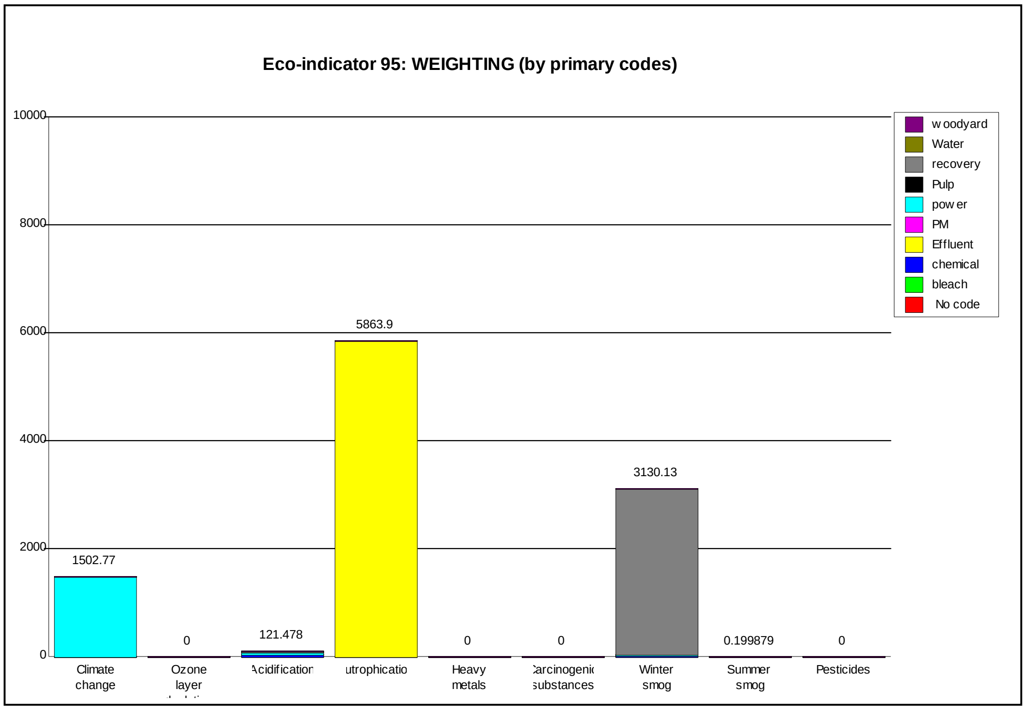


Figure 7.3: Weighted scores for the production of Baycel

In this study, effluent is discharged to sea and hence the impact of phosphates will be negligible. Eutrophication is therefore not the impact most significantly affected in this study as the weighting is calculated for discharge to a fresh water source.

This being so, the next most significant impact category is that of winter smog which is due (mainly) to the combustion of organic solids and hence the emission of particulates by the *recovery* unit process

The recovery process has also been identified, as the largest consumer of energy and the efficient use of energy at this plant should therefore be investigated.

These results can be used in other pulp and paper studies where bleached HW pulp is used as input material or as a comparison with other SA mills producing bleached HW market pulp.

7.3 Results for the Production of Baywhite off PM2

The power and water usages, table 7.8, for each of the unit processes is for the production of 1 BDt of saleable quality Baywhite produced off PM2.

Process	**Water usage (m^3/ton)**	**Energy usage (MWh/ton)**
Woodyard, HW	0	0
Cook, HW	17.620	1.029
Bleach plant	16.825	0.254
Power plant	43.344	-
Chemical plant	41.389	0.075
PM1	0	0
Cook, SW	16.146	0.867
Woodyard, SW	0.538	0.024
PM2	34.369	1.647
Fresh Water	33.221	-
Purchased electricity	-	0.335
Recovery	88.728	2.403

Table 7.8: Water and Energy Consumption for the production of Baywhite

The water usage figures presented in table 7.8 above represent an open system and are not additive. Numerous recycle and treatment loops do exist in the actual process but were beyond the scope of this study to model.

The use of water at the recovery plant is almost twice that of any of the other unit process plants and therefore carries the highest burden for the consumption of water. The overall depletion of our natural resource due to the use of fresh water is 33.22kl. From figure 7.2, it is evident that fresh water is consumed by the chemical and power plants (from the WRF tank). From the total inventory (see Appendix 10), the fresh water volumes consumed by the chemical and power plants are 4.01 m^3 and 6.55 m^3 respectively. The balance of 22.66 m^3 is dilution and top-up water to the WCC tank from where water is distributed mill wide as per figure 7.1.

The unit process that has most significant energy usage during the production of Baywhite is the recovery process.
By performing the energy balance calculation in chapter 7.1 above [appendix 13], the recovery process has an overall energy usage of 0.192 MWh.

The second most significant energy consuming unit process is then that of the paper machine PM2.

The material flows into and between unit processes are illustrated in figure 7.4 below.

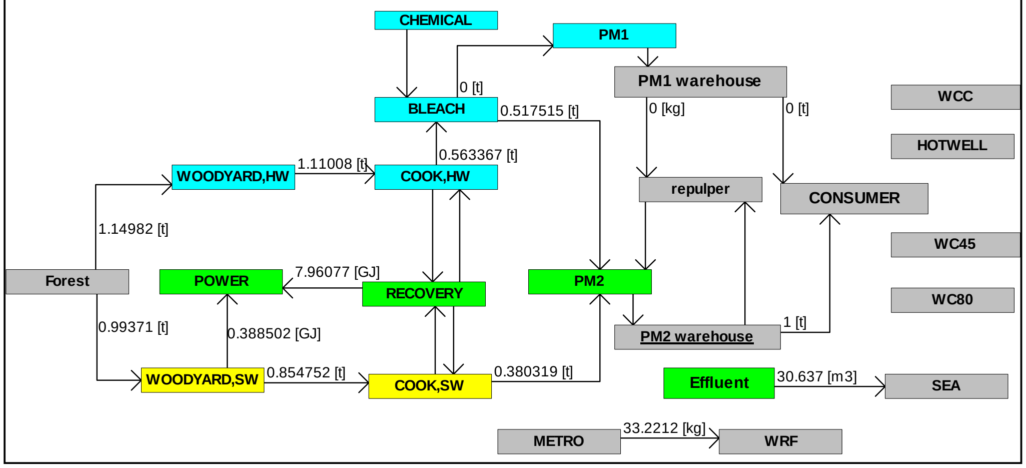


Figure 7.4: KCL Eco Material Flow for Baywhite

The following data can be concluded for the production of 1 BDt of Baywhite:

- 1.15 tons of eucalyptus logs as raw material input
- 0.99 tons of pine logs as raw material input
- 1.11 tons of HW chips produced
- 0.86 tons of SW chips produced
- 0.56 tons of HW pulp produced
- 0.38 tons of SW pulp produced and processes at PM2
- 0.52 tons of bleached HW pulp processed at PM2
- 1.11 tons gross production off paper machine 2

The overall environmental profile for the production of Baywhite is as per table 7.9.
The most significant environmental impact attributed to the overall process is eutrophication. There are no effects on the impact categories, ozone depletion, heavy metals, carcinogenic substances or pesticides by the production of Baywhite.

The unit processes have the following contribution, table 7.10, to the impact categories affected.

Description	Units	Score
Climate change	[kg CO_2]	580.532
Ozone layer depletion	[kg CFC-11]	0
Acidification	[kg SO_2]	9.11104
Eutrophication	[kg PO_4]	1597.96
Heavy metals	[kg Pb]	0
Carcinogenic substances	[kg B(a)P]	0
Winter smog	[kg SPM]	601.973
Summer smog	[kg C_2H_4]	0.061547
Pesticides	[kg act.s]	0

Table 7.9: Overall environmental profile for the production of Baywhite

PM2	**Climate change**	**Acidification**	**Eutrophication**	**Winter Smog**	**Summer Smog**
	[kg CO2]	**[kg SO2]**	**[kg PO4]**	**[kg SPM]**	**[kg C2H4]**
bleach	0	0	0	0	0.00228422 *(3.71%)*
chemical	0	2.61928 *(28.75%)*	0	2.61928 *(0.44%)*	0
Effluent	0	0	1597.82 *(99.99%)*	0	0
PM	0	0	0	0	2.65E-05 *(0.043%)*
power	580.532 *(100%)*	4.32284 *(47.45%)*	0.000228 *(0.00001%)*	6.14084 *(1.02%)*	0.011111 *(18.05%)*
Pulp	0	0	0	0	0.00030047 *(0.49%)*
recovery	0	2.16894 *(23.81%)*	0.14059 *(0.0088%)*	593.213 *(98.55%)*	0.047825 *(77.7%)*
woodyard	0	0	0	0	0

* values in brackets represent the percentage value of the total score for that category

Table 7.10: Environmental profile of the unit processes for the production of Baywhite

From table 7.10 above, the recovery unit process is identified as contributing most significantly to the overall environmental profile.

The contribution to the overall score for *climate change* is attributed to the power unit process.

Tables 7.11 to 7.14 indicate the emissions that contribute towards the impact categories in relation to the unit processes.

	SO_2	NOx	SUM
Entire system	8.35279	0.758251	9.11104
chemical	2.61928	0	2.61928
power	4.3216	0.001226	4.32283
recovery	1.41191	0.757025	2.16894

Table 7.11: Eco-Indicator 95, Acidification contributing variables [kg SO_2] for the production of Baywhite

The largest contributing emission to the *acidification* impact is that of SO_2, and the unit process that contributes most to this impact is the power plant.

	P, tot	COD	NOx	SUM
Entire system	1595.18	2.63094	0.140818	1597.96
Effluent	1595.18	2.63094	0	1597.82
power	0	0	0.000228	0.000228
recovery	0	0	0.14059	0.14059

Table 7.12: Eco-Indicator 95, Eutrophication contributing variables [kg PO_4] for the production of Baywhite

The most significant contribution towards the *eutrophication* impact category is the emission of phosphate discharged in the effluent.

The generation of particulates from the recovery plant processes is the most significant contributor to the *winter smog* impact category.

	Particulates	SO_2	SUM
Entire system	593.62	8.35279	601.973
chemical	0	2.61928	2.61928
power	1.81924	4.3216	6.14084
recovery	591.801	1.41191	593.213

Table 7.13: Eco-Indicator 95, Winter smog contributing variables [kg SPM] for the production of Baywhite

	VOC	SUM
Entire system	0.061547	0.061547
bleach	0.002284	0.002284
PM	2.65E-05	2.65E-05
power	0.011111	0.011111
Pulp	0.0003	0.0003
recovery	0.047825	0.047825

Table 7.14: Eco-Indicator 95, Summer smog contributing variables [kg C_2H_4] for the production of Baywhite

The contribution to *summer smog* impact category is due to VOC emissions primarily from the recovery unit process.

The amount of effluent discharged to sea during the production of 1 BDt of Baywhite is 30.64kl. The effluent to fresh water ratio for this process is therefore 92%.

7.4 Interpretation of results for the production of Baywhite

The unit process identified as having the most significant impact due to resources (water and energy) consumed, is the recovery plant.

The impact category with the greatest significant impact is eutrophication due to the phosphate content of the effluent. To determine the relative importance of impact categories, a weighting step has been conducted and the results are presented in figure 7.4 below.

As discussed in chapter 7.2, the results of figure 7.5 do not hold true for the scenario where effluent is discharged to sea (as in this study). The next significant impact is that of winter smog due to the emission of particulates from the *recovery* process.

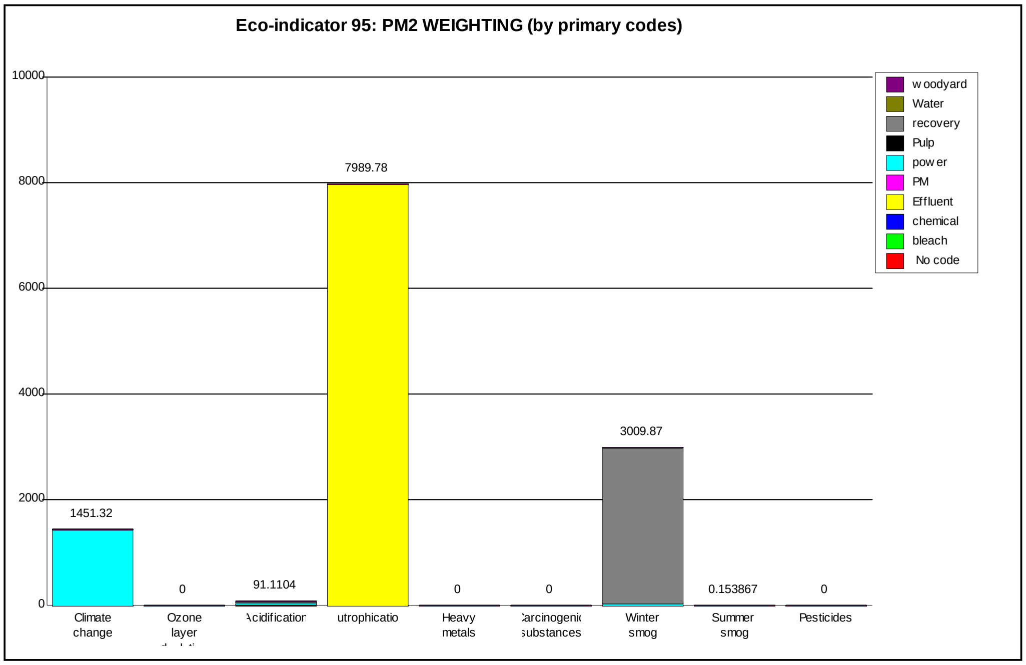


Figure 7.5: Weighted scores for the production of Baywhite

7.5 Comparison of Environmental Effects of Baycel and Baywhite Production

The two products produced at Mondi do not serve the same function. The comparison is therefore not based on a functional unit and is carried out purely to satisfy the aim of determining which of the products carry the higher environmental burden.

Table 7.15 is a comparison of input data for the production of PM1 and PM2 products.

Total fresh water usage to produce Baycel is more than twice that required to produce Baywhite and the energy consumptions for both manufacturing processes is relatively equal.

The difference in fresh water consumption is due to the use of water at the chemical and bleach plants. The energy used at the bleach plant and the chemical plant is lower for the production of Baywhite but the energy usage on PM2 compared to PM1 is significantly higher.

Process	PM1 Water usage (m^3/ton)	PM2 Water usage (m^3/ton)	PM1 Energy usage (MWh/ton)	PM2 Energy usage (MWh/ton)
Woodyard, SW	0	0.538	0	0.024
Woodyard, HW	2.236	0	0.050	0
Cook, HW	37.762	17.620	2.132	1.029
Cook, SW	0	16.146	0	0.867
Bleach plant	34.854	16.825	0.527	0.254
Power plant	44.880	43.344	-	-
Chemical plant	85.739	41.389	0.156	0.075
PM1	31.892	0	1.358	0
PM2	0	34.369	0	1.647
Fresh Water	68.819	33.221	-	-
Purchased electricity	-	-	0.347	0.335
Recovery	91.873	88.728	2.488	2.403

Table 7.15: Baycel (PM1) and Baywhite (PM2) input comparison

The process unit consuming the most water is the recovery plant for the production of Baycel off PM1. Effluent discharged by the production of Baycel is more than twice that discharged for the production of Baywhite.

A comparison of the outputs of both processes is illustrated in figure 7.6, which indicates that the production of Baycel has a greater impact than the production of Baywhite on climate change and winter smog.

For the impact on eutrophication however, the most significant contributor is the production of Baywhite due to the inclusion of SW processing.

The effect of either process on acidification and summer smog on the eco system is very slight.

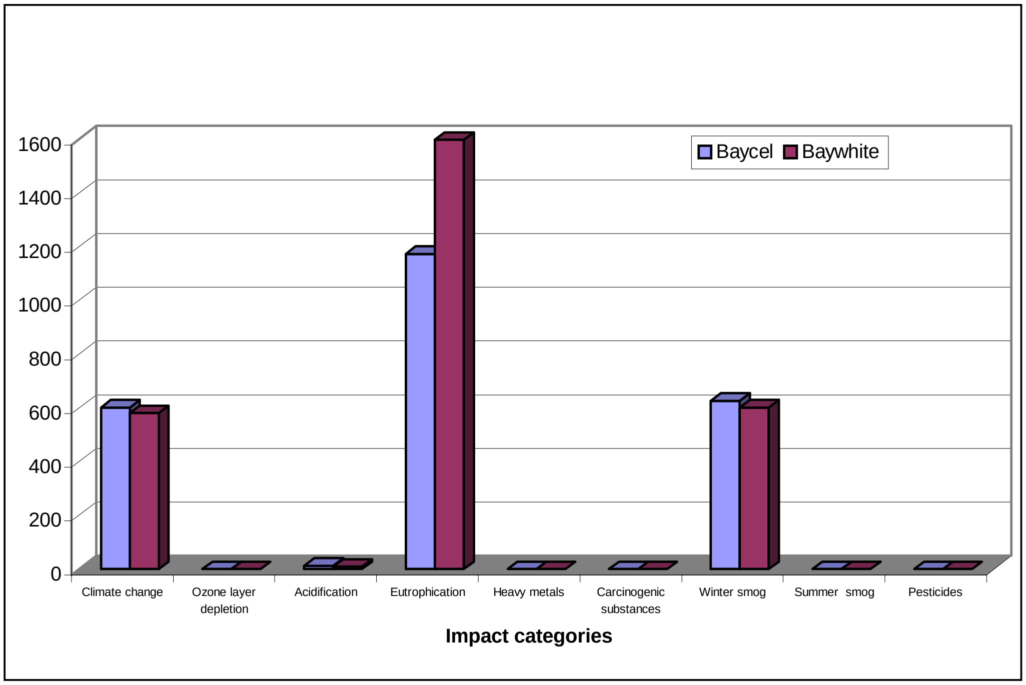


Figure 7.6: Overall Environmental Profile for Baycel and Baywhite Production

The unit processes contributing to each of these effects have been discussed in chapters 7.1 and 7.3 and will therefore not be investigated here.

7.6 Comparison of Finnish and SA Process for the Production of Market Pulp

As a benchmarking exercise, a Finnish module [HW/KCL, 1998] has been purchased in which the output is bleached HW market pulp similar to that of Baycel, (i.e. both products fulfil the same purpose).

The processes assessed in this study for the production of HW pulp (Baycel) include:

- Eucalyptus wood chipping and screening,
- Batch cooking to kappa 13,
- 42% Classic and 58% ECF bleaching
- HW Weak black liquor TDS = 13%
- HW Strong black liquor TDS = 62-65%
- Recovery boiler efficiency = 63%
- LVHC incineration in lime kiln
- Lime kiln with ESP
- Limekiln is HFO fired.

- Pulp brightness > ISO90
- Dirt < ISO 4.9
- 840 gsm average

The Finnish module purchased from the KCL database represents an agglomeration of the different process modules occurring in this (MKRB) study and is reflective of an un-integrated kraft mill, producing bleached market pulp and includes pulp processing, bleaching, drying, activated sludge combustion, energy generation from bark and black liquor, and mill condensation power plant: The woodyard processes are not included in this model. This should not have an impact on the comparison as the woodyard environmental impacts are insignificant in this study.

- Conventional pulping technology
- Kappa 13
- ECF bleaching only
- Pulp brightness = ISO89
- Black liquor TDS- 70%
- Recovery boiler efficiency = 65%

The technology level at the mill is typically Finnish, 1997. Major differences between the PM1 process of generating dried HW bleached pulp and the Finnish equivalent process is the inclusion of an activated sludge treatment plant for effluent and only ECF bleaching is done. A comparison of the two inventories for the two systems is in Appendix 11.

Major differences between the two inventories are the emissions to water. That of the Mondi study far exceeds that of the Finnish study. This can be attributed to the activated sludge plant in the Finnish model. The effluent from the Mondi plant is discharged directly to sea and does not get extensively treated before discharge. The effluent plant at Mondi facilitates the removal of suspended solids by flocculation and does not have biological treatment.

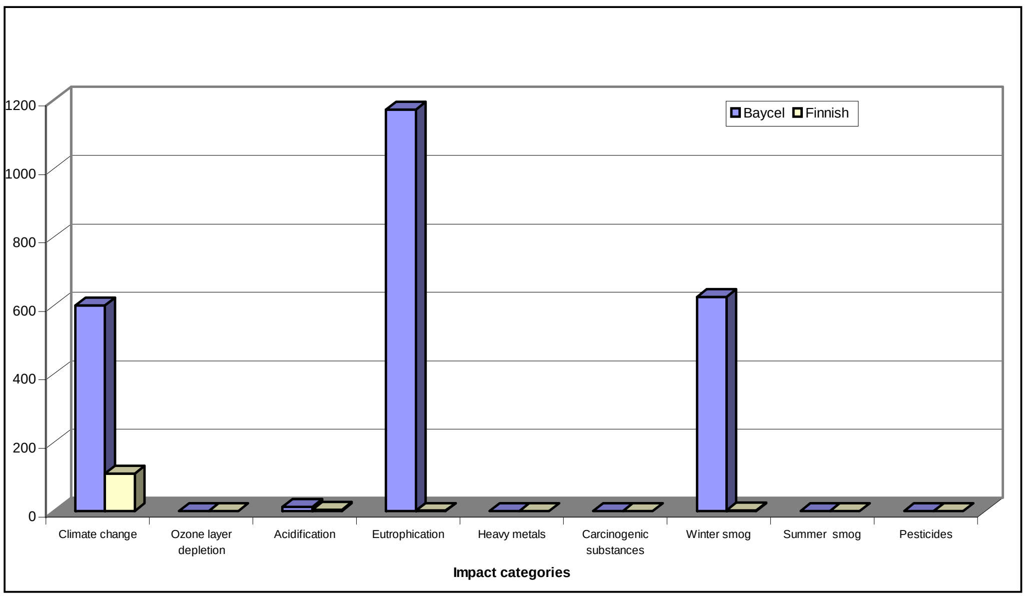
Water usage is not considered a scarce resource in northern hemisphere and is therefore not considered in the Finnish model. In South Africa, water is a scarce resource and has therefore been included in the inventory.

Birch is used as the input material and is seen as a resource in the Finnish model whereas in the Mondi model, eucalyptus is used and is supplied as a renewable raw material.

Solid waste ash generated by the Mondi process is approximately 17 times greater than that of the Finnish model. This is due to the extensive coal usage in South Africa compared to the usage of HFO in Finland. The HFO usage in Finland is approximately 24 times greater than the Mondi study. Energy usage in the Finnish model is 18 times less than that of the energy usage at the mill in this study (Finland = 0.192MWh and SA = 3.50MWh, see Appendix 11).

The raw material wood input is captured with units of kg in the Finnish model and per ton in the Mondi model (as recommended by NordPap guidelines).

The profiles of the overall environmental score for these two processes are as per figure 7.5 below indicates that the local process of producing market pulp far exceeds the environmental impacts due to that of the Finnish process.



<u>Figure 7.7: Comparison between Finnish Process and Baycel Process</u>

When comparing environmental scores for the two processes of producing bleached HW market pulp, the figure involved are of the same magnitude and therefore, from an environmental point of view the two methods are comparable and result in as SA score of 4247.39 and a Finnish score of 2833.31.

7.7 Limitations of this study

This is the first study on the use of LCA in the pulp and paper industry in South Africa and its one of its aims has been to provide Mondi and the SA pulp and paper industry with data on the actual process as it occurs. Areas where lack of data have been identified could have been rectified by the inclusion of generic data from international databases that reflect the same unit processes, but as per the comparison in 7.6 above, our technology level is not yet par and therefore the data would not have been compatible in most instances.

Sources of international data regarding specific emissions to water and air from unit processes studied are available from the USA Environmental Protection Agency (US-EPA) website as well as the Food and Agriculture Organisation of the United Nations (FAO-UN).

The equivalency factors used within impact categories of this study are derived from industrial processes operating in Europe and America, and therefore do not relate directly to the South African situation.

LCA in principle, should be conducted by persons who work or are considered knowledgeable in the field in which the study is conducted. As a student with no practical experience in a pulp and paper mill environment, the understanding of critical unit process interactions was lacking. Hence, all the information collated has been exclusively from data available at the mill and from communication with pulp and paper experts in South Africa.

The life cycle assessment phase is a somewhat subjective phase of the study and someone with a greater insight into the pulp and paper industry could perhaps interpret the results differently.

The definition of each of the unit processes for this study could perhaps have been done differently, where for example the *power* and *recovery* modules could be viewed as one process to facilitate the link between the chemical recovery process and the production of energy. In this study, the function of the *recovery* process is the recovery of chemicals only. No benefit has been allocated to the *recovery* module for the production of energy (this has been allocated to the *power* plant). The reason for this approach has been presented in chapter 6.6.4.

Data available regarding the quality of effluent streams from each of the unit processes was not available. The overall mill effluent impact could therefore not be established and no allocation rules were available with which to allocate this burden to specific unit processes.

The value for electrical energy supplied to the recovery plant is questionable. As discussed on pg 85 the value quoted (as supplied by the power plant manager in 2000) seems unreasonably high and results in the recovery plant being an energy sink which is highly unlikely.

The industry standard is to measure and supply the final product based on air-dry tons. In this study all balances were conducted based on bone-dry tons to simplify the flow of data. This could cause confusion in the industry and should be noted.

7.8 Summary of Results

For the production of Baywhite and Baycel, the recovery process dominates by having the highest water and energy consumption. The woodyard process for both Baywhite and Baycel is considered as having the least impact. Baycel production has an overall higher energy and fresh water consumption.

For the impact categories considered, the eutrophication impact score is the highest due to the impurity level in the mills overall effluent discharged. Winter smog, climate change, acidification and summer smog are affected but not to the same degree.

When comparing the environmental scores for the two products (Baycel and Baywhite), the production of Baycel had a greater impact on climate change and winter smog and Baywhite has a greater impact on the eutrophication category.

A comparison of a Finnish model producing market pulp and the production of Baycel resulted in similar profiles of the environmental score when one considers the biological effluent treatment plant included in the Finnish model and the fact the coal is replaced by HFO to raise steam and energy. This exercise could be of value as a benchmarking exercise to the South African pulp and paper industry.

Various limitations to this study have been identified and the following chapter will attempt in identifying the solutions.

As per the results of surveys conducted internationally, the production phase of a complete (*cradle-to-grave*) pulp and paper LCA results in the greatest burdens on the environment (see Chapter Four). The exclusion of *transport* within the mill can therefore be considered valid in this *gate-to-gate* study as the bulk of the transporting occurs in the shipping of raw material to the mill (*cradle-to-gate*) and of the product to customers (*gate-to-grave*).

CHAPTER EIGHT: Conclusions and recommendations

This chapter presents the conclusion and recommendations of this study. The recommendations section relates the analysis and theory used with reality and attempts to give relevance to this research.

8.1 Conclusion

The concept of *Life Cycle Thinking* integrates consumption and production strategies, preventing a piece meal approach. A holistic view is created which prevents shifting of burdens from one phase to another and from one environmental medium to another.

Human needs should be met by providing functions of products and services, such as food, shelter and mobility, through optimised consumption and production systems that are contained within the capacity of the ecosystem. The concept of Sustainable Development is key to the pursuit of a sustained eco-system and to which tools such as Life Cycle Assessment are critical.

LCA is a unique, scientific cradle-to-grave approach, taking into account the entire system necessary for the manufacture, use and disposal of a product, service or activity. The international growth of LCA is testament to its value as a tool used by industry to facilitate information reconciliation and process improvement.

In South Africa, LCA studies are relatively new and have been conducted in various fields with this study being the first in the SA pulp and paper industry. A major limitation of LCA studies in SA is the availability of data. This has improved over the last five years however, due in part to the interventions by government and the amendment of the National Environmental Management Act (NEMA), which requires industry to be accountable for their environmental impacts and facilitates the collation of environmental data in the public domain. Another contributing factor is research conducted by academia in formulating 'home-grown' emission factors and weighting data that is applicable to SA and reflects local environmental concerns and values.

The pulp and paper industry is an important part of the SA economy and its sustainability is therefore important. LCA studies relating to the pulp and paper industry have been successfully conducted internationally for the last 15 years and this study is considered as being the first in SA.

It should therefore be seen as a base-line study for the production of bleached HW market pulp and the production of white top linerboard. The production of pulp for both these products is by the established kraft process and is implemented worldwide.

The LCA methodology has been applied to a *gate-to-gate* study of the Mondi Richards Bay mill and follows the process from raw wood chipping to production off the paper machines. The four stages of LCA (as defined by ISO 14040): goal and scope definition, inventory analysis, impact assessment and interpretation have been conducted, The LCI phase of the study has been conducted by following the guidelines for pulp and paper LCA studies by the Nordic Pulp and Paper Research Institute (Nordpap). For the LCIA phase, the Eco-Indicator 95, *distance-to-target* methodology has been used. In conducting this study the KCL-Eco 3.01 software tool played an important role and partially pre-empted the methodological choices, since it is programmed to use the above-mentioned methodology in the LCIA phase.

The results of this study identify the process of recovering spent chemicals as contributing most significantly to energy usage. This has been based on the assumption that harnessed energy liberated during the process is a *bonus* and its benefits have not been attributed to this module. If this were to be the case, the overall energy requirements of the module would drop considerably and paper machine 2 would be the greatest consumer of energy.

Recycling of water does occur within the mill and the usages per unit process have been identified. The recovery process has been identified as the process that consumes the most water. Only two units have been identified as using fresh water directly, the chemical and power plant.

The results of the impact assessment phase of this study indicate that eutrophication of fresh water systems has the greatest burden attributed to the production of either product. As the mill in question discharges directly to sea, the weighting factor used in the assessment is not applicable and the resulting conclusion is that winter smog is has the greatest burden.

This burden has been traced to the emission of particulates from the process of burning organic solids to recover spent chemicals at the *recovery* module.

Overall, the largest environmental impact from the mill at Richards Bay is attributed to the production of Baywhite with a final weighted score of 5016.89 compared to that of Baycel production at 4247.39.

8.2 Recommendations

The first set of recommendations pertain to environmental improvements pertinent to this study and secondly to further South African studies in this field.

8.2.1 Recommendations for Environmental Improvement

Concerning energy usage, focus should be directed to the recovery plant process as an optimisation of energy used will have a greater impact on the overall energy balance of the module due to the energy created by its supply of organic fuel to the power plant.

The energy consumption of PM2 is also of concern and energy optimisation should be investigated.

The effluent to freshwater ratio of 92% for both processes is comparable to the 98% ratio achieved at the Finnish Mill compared in this study. A closed water system would however be the ideal situation.

Effluent quality should be analysed from all streams feeding into the effluent plant such that burdens can be allocated to each of the unit processes. Even though eutrophication is not considered a significant burden due to discharge to sea, improved effluent treatment should be implemented to decrease the suspended solids and hence perhaps the phosphates, AOX and biological oxygen demand of the discharge.

The generation of particulate that contribute to winter smog has been traced to the recovery boiler. The efficiency of the particulate entrapment measures should be checked and optimised.

8.2.2 Recommendation for Further Research

LCA will certainly make a mark in the South African pulp and paper industry as one of the strongest ways to manage the environment. To facilitate further research organisations such as ALCA-Net, the African network of LCA practitioners is valuable to the understanding of the current standing of LCA in SA and for the review of published reports and investigation of sources of fundamental data and figures.

Driven through National paper associations (PAMSA and TAPPSA), intensive data regarding investigations into local wood species, secondary fibre, recycling and the technology levels of the local industry should be collated. Such information does currently exist, but as results of studies conducted by various industries in isolation. This collation of information at a central point will facilitate further LCA studies by reducing time spent on sourcing information.

Since the completion of this study in 2002, the mill at Richards Bay has undergone a major upgrade to all its' unit processes and the production output has increased significantly. A comparison LCA study should now be conducted on the 'new' process of producing the two products as the actual outcome of the capital invested in the upgrade can, in-part, be justified by the environmental improvements if any exist.

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World Resource Foundation website, www.wrf.org

Appendix One

Qualitative Data Form

Date 26-Jun-00

Module Woodyard

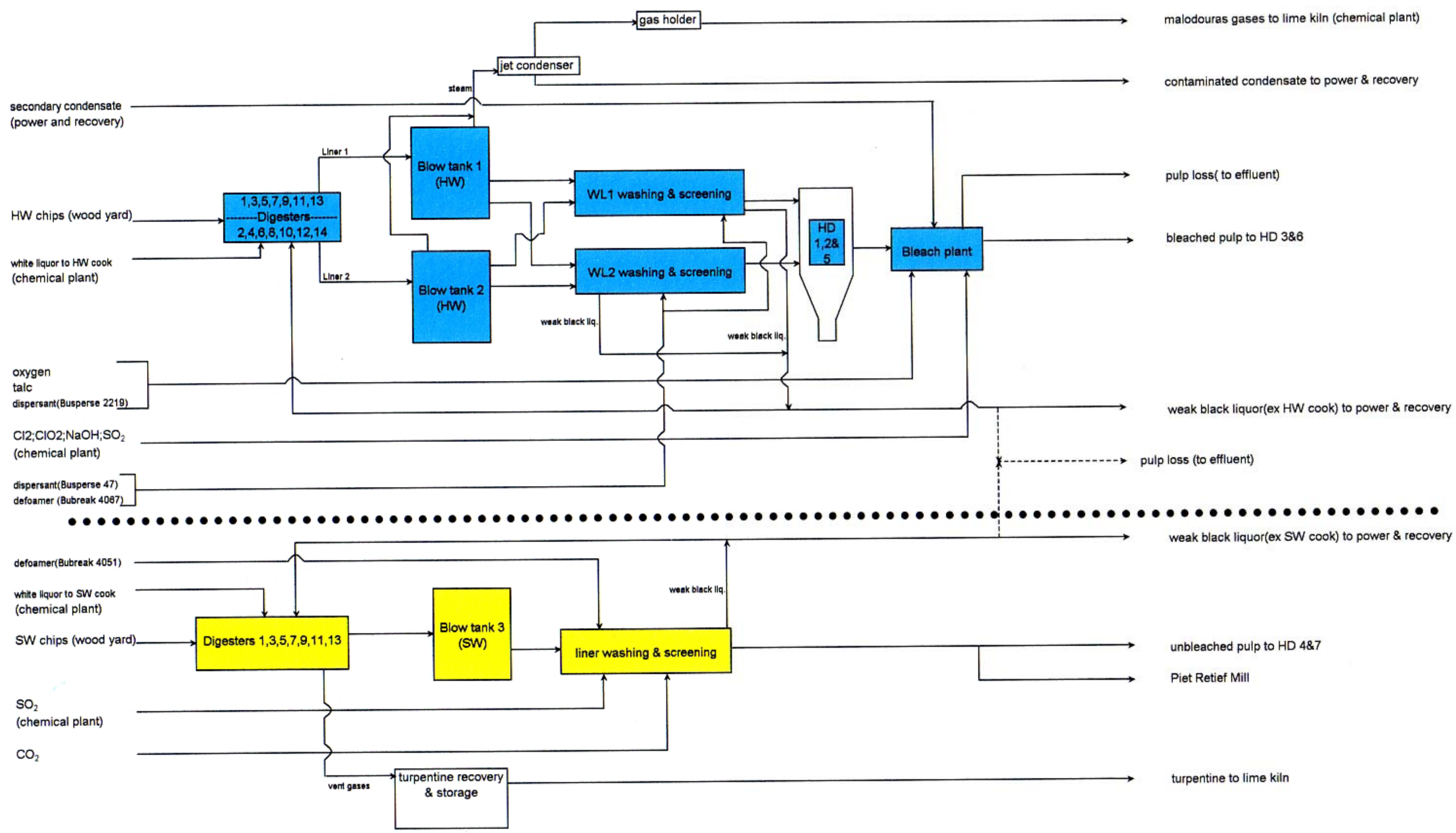
	INPUTS	OUTPUTS	EMISSIONS
Identification	HW Logs	HW chips	
Source/ Destination	forest	pulp mill	
Classification	Resources	Materials/Products	
Tag. No.			
Identification	SW Logs	SW chips	
Source/Destination	forest	pulp mill	
Classification	Resources	Materials/Products	
Tag. No.			
Identification		Bark	
Source/Destination		Power boilers	
Classification		Fuel	
Tag. No.			
Identification	Fresh water	Waste water	
Source/Destination	Umhlatuzi	effluent plant	
Classification	Resources	waste	
Tag. No.			
Identification		SW chips	
Source/Destination		SilverCel	
Classification		Materials/Products	
Tag. No.			
Identification			
Source			
Classification			
Tag. No.			

Name Alan Drew (Woodyard trainer)

Appendix Two

Pulp Plant

Pulp Mill Flow sheet



PULP MILL

INPUT

Weeks Description	unit	11--14 march	15--18 april	19--23 may	24--27 june	28--32 july	33--36 august	Total	Source
HW COOK									
HW chips	BD ton	74381.3866	76717.7774	87118.0184	77069.675	75742.5006	82712.611	473741.97	
heavy white liquor to HW cook	m^3	102480.00	104981.00	147681.00	108885.00	133468.00	139446.00	736941.00	No. of Euca blows (Production monthly reports) * 61m3/blow(Mervin Odayar)
heavy white liquor to HW cook	l	89113043.48	91287826.09	###########	94682608.70	###########	###########	640,818,260.87	specific gravity of white liquor from Weyerhaeuser MSDS=1.15
NaOH	kg	8880114.78	9096831.87	12796879.70	9435121.96	11565292.35	12083299.04	63857539.70	Calc from TA = 120g/l and AA = 103 g/l and sulphidity on AA = 25%
Na2S	kg	2886371.48	2956812.69	4159467.47	3066769.70	3759155.23	3927526.90	20756103.47	Calc from TA = 120g/l and AA = 103 g/l and sulphidity on AA = 25%
SW COOK									
SW chips	BD ton	18118.70	15454.61	15719.04	15870.38	16148.69	17136.96	98448.38	
heavy white liquor to SW cook	m^3	28130.00	31610.00	55970.00	25085.00	30740.00	27477.50	199012.50	No. of Pine blows (Production monthly reports) * 72.5m3/blow(Mervin Odayar)
heavy white liquor to SW cook	l	24460869.57	27486956.52	48669565.22	21813043.48	26730434.78	23893478.26	173,054,347.83	specific gravity of white liquor from Weyerhaeuser MSDS=1.15
NaOH	kg	2437525.65	2739075.22	4849922.17	2173669.78	2663687.83	2380985.11	17244865.76	Calc from TA = 120g/l and AA = 103 g/l ans sulphidity on AA = 25%
Na2S	kg	792287.57	890302.52	1576407.22	706524.48	865798.78	773909.76	5605230.33	Calc from TA = 120g/l and AA = 103 g/l ans sulphidity on AA = 25%
WL1 & WL2									
Busperse 47 (to WL1 & WL2)	kg	72000	52650	63950	71900	56350	65500	382350	Item no. 800-0002-0420, Item Ledger (The Cardex), Stores
Bubreak 4067(defoamer) (WL1 & WL2)	kg	8947.08	3377.08	7776	10050.54	8060.64	5666.19	43877.53	Operating Data-Pulp Mill, Production Monthly Reports 80-0002-0430
LINER WASHING									
Bubreak 4051(defoamer) (to liner washing)	kg	18434.07	44108.8	46656	44062.15	58439.64	45329.52	257030.18	Operating Data-Pulp Mill, Production Monthly Reports 80-0002-0418
CO2	kg	38000	38000	42000	53000	42000	46000	259000	Item no. 80.0002.0300, Item Ledger (The Cardex), Stores
SO2 (to liner washing)	l	24078600	23637600	46116000	6350400	7660800	6350400	114193800	421-fc-1457, Pi, SO2 to liner
SO2 conc.	g/l	9.21	9.21	9.21	9.1	9.38	9.15	9.21	SO2TWRSTR.LAB, Pi
SO2 to liner washing	kg	221763.906	217702.296	424728.36	57788.64	71858.304	58106.16	1051947.666	
white liquor concentration AA	g/l	105	105	105	105	105	105		Mervin Odayar
energy + steam (to pulp mill)	MWh	71110.76	71110.76	88888.45	71110.76	88888.45	71110.76	462219.94	Mill Specific Energy Distribution, Piet Kotze
water (to pulp mill)	m^3							**2204916**	
WCC	m^3	255220	187684	354200	113988	222320	301672	1435084	Mill Water Balance, Ciska Tereblanche
WC45	m^3	84672	84672	105840	84672	105840	84672	550368	Mill Water Balance, Ciska Tereblanche
WC80	m^3	115892	25200	75600	280	784	1708	219464	Mill Water Balance, Ciska Tereblanche
Main line blow heat	m^3	1013376	1047900	934052	934052	903644	744324	5577348	
Liner blow line	m^3	131964	111804	124404	128828	126224	116928	740152	

OUTPUT

Weeks Description	unit	11--14 march	15--18 april	19--23 may	24--27 june	28--32 july	33--36 august	Total	Source
Total dry solids in black liq from HW cook	tons	39724.72	43069.15	34150.01	39264.77	38801.95	38305.35	233315.95	
Total energy from HW black liq solids	GJ	536283.68	581433.54	461025.11	530074.45	523826.30	517122.24	3149765.33	
pulp losses WL1&WL2 (2%)	BD ton	592.15	574.93	905.02	645.94	631.17	758.75	4107.96	Pulp losses to effluent drain, Technical Report, page 20
HW pulp exiting digester	BD ton	34656.67	33648.63	52968.01	37804.90	36940.55	44407.26	240426.02	
HW COOK YIELD	%	53.41	56.14	39.20	50.95	51.23	46.31	49.54	
weak black liquor ex HW cook (to P&R)	l	294591412	271715980	275831134	299359326	282506317	317758289	1,741,762,458.44	421-fi-1105, Pi (ratioed by the no. of HW blows to total blows)
weak black liquor ex SW cook (to P&R)	l	68036588.01	68836820	87956065.9	58027073.9	54745282.7	52681711.1	390,283,541.56	421-fi-1105, Pi (ratioed by the no. of SW blows to total blows)
Total dry solids in black liqour from SW coo	tons	11038.17	9127.75	8580.67	9184.59	7339.56	9373.43	54644.18	Mill specific energy distribution, Energy sources. LBH= 2524 TDS/d
Total energy from SW black liq solids	GJ	160053.47	132352.40	124419.74	133176.56	106423.62	135914.79	792340.58	
Unbleached pulp	BD ton	6498.00	5965.20	6084.00	5571.90	7597.80	6234.30	37951.20	Mervin Odayor, Pulp Mill, see e-mail
unbleached pulp (to Piet Retief)	BD ton	443.7	237.6	914.4	982.8	1038.6	1377	4994.10	Raymond Du Preez, Accountant, see e-mail
liner washing losses(2%)	BD ton	138.834	124.056	139.968	131.094	172.728	152.226	858.906	
SW pulp exiting digester	BD ton	7080.53	6326.86	7138.37	6685.79	8809.13	7763.53	43804.206	
SW COOK YIELD	%	60.92	59.06	54.59	57.87	45.45	54.70	55.43	
turpentine (to lime kiln)	kg	0	0	43106	0	32585	0	75691.00	481-FRSQ-1024, Pi, Turpentine to burner
Water (ex pulp mill)								**8544312.00**	
to WC 80 tank ex Mainline	m^3	1013376	1047900	934052	934052	903644	744324	5577348.00	
to WC 80 tank ex liner line	m^3	131964	111804	124404	128828	126224	116928	740152.00	Mill Water Balance, Ciska Tereblanche
to effluent	m^3	458584	297556	554540	198940	329140	388052	2226812.00	Mill Water Balance, Ciska Tereblanche
VOC	tons							11.75	Emmission data for mondi kraft richards bay

HW blows	1680.00	1721.00	2421.00	1785.00	2188.00	2286.00	12081.00	0.81	Operating Data-Pulp Mill, Production Monthly Reports
Liner blows	388.00	436.00	772.00	346.00	424.00	379.00	2745.00	0.23	Operating Data-Pulp Mill, Production Monthly Reports

Appendix Three

Bleach Plant

BLEACH PLANT

INPUT

Weeks		11--14	15--18	19--23	24--27	28--32	33--36		
Description	unit	march	april	may	june	july	august	Total	Source
BLEACH PLANT									
HW pulp exiting digester	BD ton	34656.67	33648.63	52968.01	37804.90	36940.55	44407.26	240426.02	Operating Data-Pulp Mill, Production Monthly Reports
oxygen	kg	154592.5	221976	358220	182688.3	217892.4	201785.5	1337154.753	Operating Data-Pulp Mill, Production Monthly Reports
H2O2	kg	61253.62	106719.2	NA	NA	NA	NA	167972.844	Operating Data-Pulp Mill, Production Monthly Reports
talc	kg	140008.3	221976	358220	178882.3	260986.7	258811.9	1418885.178	Item no. 800-0002-0422, Item Ledger (The Cardex), Stores
Busperse 2219 (to bleach plant)	kg	103600	60350	83550	89600	80900	78900	496900	Operating Data-Pulp Mill, Production Monthly Reports
Cl2	kg	498779.5	580552.6	1791100	1880167	605256.8	886101.7	6241957.945	Operating Data-Pulp Mill, Production Monthly Reports
ClO2	kg	1764688	2885688	3653844	2123752	2871338	2399493	15698802.54	Operating Data-Pulp Mill, Production Monthly Reports
NaOH	kg	1163819	1763002	2650828	1282624	1617246	1022088	9499606.339	Operating Data-Pulp Mill, Production Monthly Reports
SO2 (to bleach plant)	kg	186677.7	256126.1	358220	216942.4	261470.9	157919.1	1437356.263	Operating Data-Pulp Mill, Production Monthly Reports
energy + steam (to bleach plant)	MWh	16691.92	16691.92	20864.9	16691.92	20864.9	16691.92	108497.48	Mill Specific Energy Distribution, Piet Kotze
water (to bleach plant)	m^3							**7266476**	
WCC	m^3	245952	308308	378280	302624	338625	246764	1820553	Mill Water Balance, Ciska Tereblanche
WC45	m^3	283640	227220	292635	224812	298585	236936	1563828	Mill Water Balance, Ciska Tereblanche
WC80	m^3	592620	547652	768180	530376	845215	598052	3882095	Mill Water Balance, Ciska Tereblanche

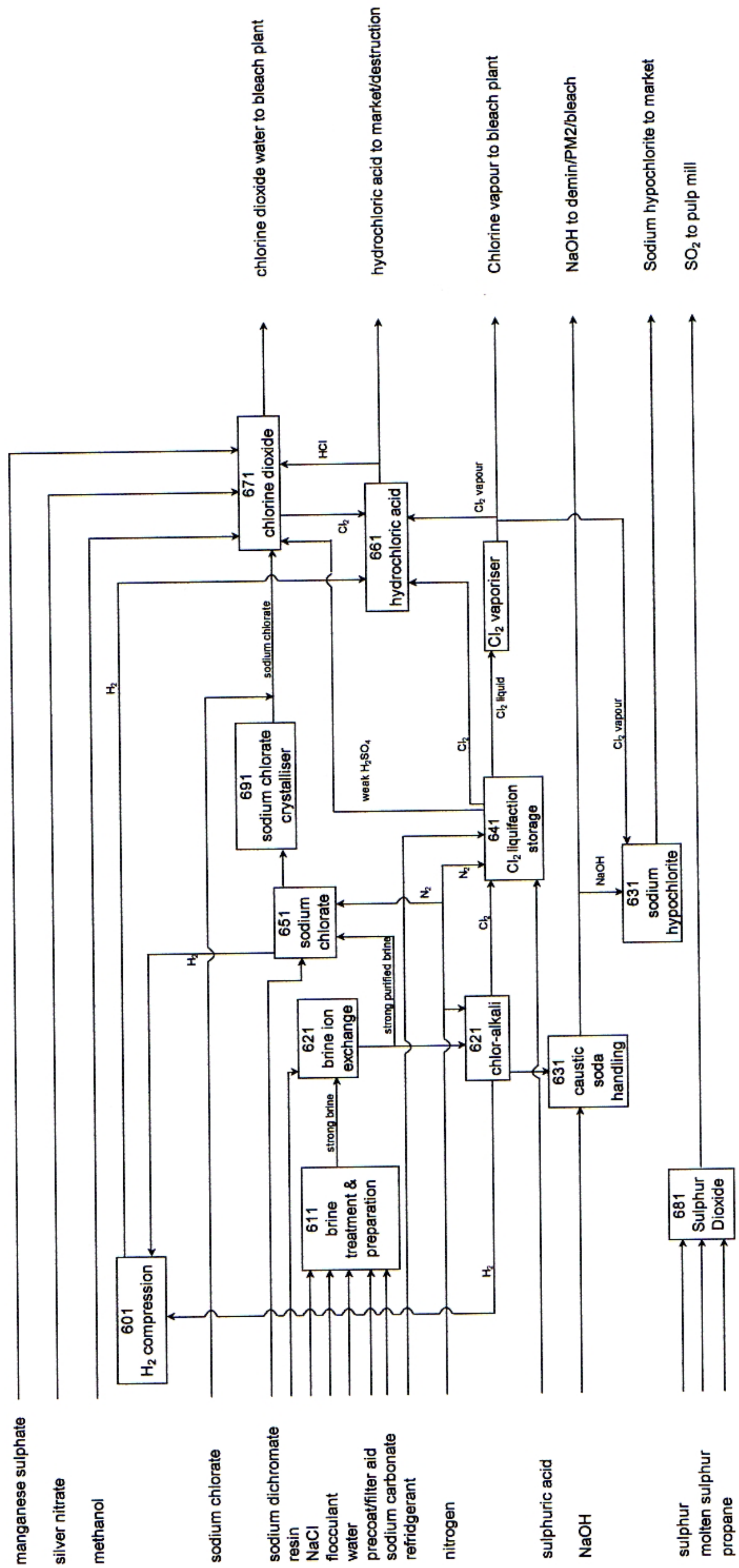
OUTPUT

Weeks		11--14	15--18	19--23	24--27	28--32	33--36		
Description	unit	march	april	may	june	july	august	Total	Source
pulp losses from bleach plant(7%)	BD ton	2228.52	2163.70	3405.99	2430.96	2375.38	2855.51	15460.06	Pulp losses to effluent drain, Technical Report, page 20
bleached pulp	BD ton	31836.00	30910.00	48657.00	34728.00	33934.00	40793.00	220858.00	Mervin Odayor, Pulp Mill, see e-mail
Water (ex bleach plant)	m^3							**8106476.00**	
to WCC return	m^3	181440	181440	226800	181440	226800	181440	1179360.00	Mill Water Balance, Ciska Tereblanche
to effluent	m^3	940772	901740	1212295	1716372	1255625	900312	6927116.00	Mill Water Balance, Ciska Tereblanche
AOX	kg							137594.53	EPA-BAT effluent discharge from bleach plant
VOC	tons							2.45	
ClO_2	tons							9.08	
Cl_2	tons							2218.74	

Appendix Four

Chemical Plant

Chemical Plant Process flow



CHEMICAL PLANT

INPUTS

Weeks Description	Unit	11--14 March	15--18 April	19--23 May	24--27 June	28--32 July	33--36 August	Total	Source
Manganese Sulphate	kg	15.00	10.00	12.50	9.50	12.00	11.00	70.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Silver Nitrate	kg	6.50	38.50	15.50	6.00	11.00	7.00	84.50	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Methanol	ton	100.30	67.50	93.00	114.10	74.60	43.80	493.30	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Sodium Chlorate	ton	147.00	336.00	462.00	336.00	252.00	504.00	2037.00	Monthly Production report, Chemical plant: production figures 2000
Resin (duolite C467)	kg	100.00	0.00	1050.00	0.00	3800.00	0.00	4950.00	90.0001.0133, Item Ledger (The Cardex), Stores
Sodium Dichromate	kg	5125.00	6400.00	8425.00	6150.00	7265.00	5440.00	38805.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Sodium Chloride	ton	3758.00	3142.00	5057.00	3386.00	4176.00	3214.00	22733.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
flocculant (MagnaFlok 156)	kg	65.00	55.00	50.00	45.00	55.00	50.00	320.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Precoat/filter aid (Sulkaflok BW 100)	kg	4160.00	3400.00	5180.00	3620.00	5880.00	2880.00	25120.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Sodium Carbonate	kg	18250.00	19250.00	22750.00	17700.00	18900.00	16050.00	112900.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Nitrogen	ton	45.90	36.20	56.80	42.20	52.10	42.30	275.50	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Sulphuric acid	ton	1169.90	1217.80	1859.60	1273.50	1314.80	1239.50	8075.10	Chemical Plant- weekly stock balance, Raw Materials Brought In.
NaOH	ton	471.00	452.00	1052.00	450.00	383.00	589.00	3397.00	Monthly Production report, Chemical plant: production figures 2000
Molten Sulphur	ton	113.30	107.35	135.65	104.65	140.10	84.40	685.45	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Sodium sulphite	kg	900.00	825.00	775.00	500.00	575.00	650.00	4225.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
liquid sulphur dioxide	kg	1.50	3.40	2.50	7.50	7.10	6.00	28.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
inhibitor (BL-339)	kg	75.00	0.00	0.00	0.00	50.00	0.00	125.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
energy & steam	MWh	5705.84	5705.84	7132.3	5705.84	7132.3	5705.84	37087.96	Mill Specific Energy Distribution-Average of Chlorate, clorine and chlorine dioxide production.
diesel	l	42000	32100	6000	8000	49500	5500	143100.00	weekly diesel report
	GJ	1631.994	1247.3097	233.142	310.856	1923.4215	213.7135	5560.44	cv=32.857 MJ/l
refridgerant (Free Zone RB 276)	cylinder	16.00	13.00	10.00	12.00	5.00	10.00	66.00	70.0001.0035, Item Ledger (The Cardex), Stores
water	m^3							**20306055.00**	
WCC chem plant	m^3	3276868	3135748	3141180	2487184	3762710	2505804	18309494.00	Mill water balance
WRF brineprep and coal	m^3	2744	1680	4375	4256	2100	13048	28203.00	Mill water balance
WRF chemical plant	m^3	378924	347732	390635	236656	355495	258916	1968358.00	Mill water balance

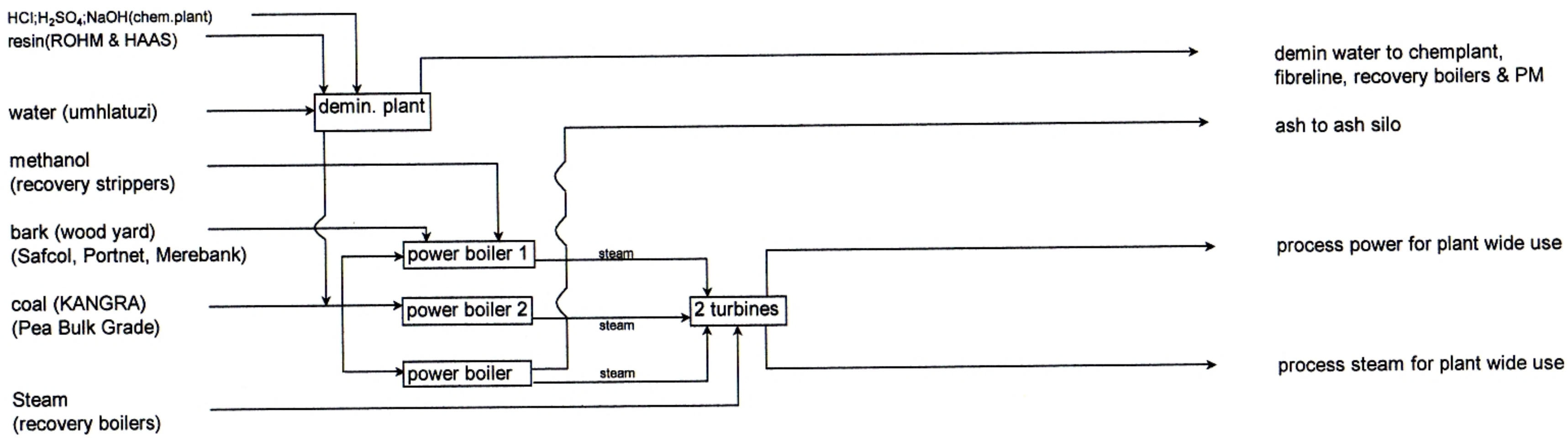
OUTPUTS

Weeks Description	Unit	11--14 March	15--18 April	19--23 May	24--27 June	28--32 July	33--36 August	Total	Source
chlorine (to bleach plant)	ton	513.40	602.60	1058.40	448.40	596.20	832.20	4051.20	Chemical Plant- Weekly Stock Balance,Usage/transfers
chlorine dioxide (to bleach plant)	ton	734.10	794.20	911.20	748.60	819.70	773.40	4781.20	Chemical Plant- Weekly Stock Balance,Usage/transfers
hydrochloric acid (to market/destruction)	ton	1088.80	678.30	825.20	1506.10	1451.20	667.50	6217.10	Chemical Plant- Weekly Stock Balance,Usage/transfers
hydrochloric acid (to power)	ton	49.00	104.00	49.00	2.80	27.00	111.00	342.80	Chemical Plant- Weekly Stock Balance,Usage/transfers
NaOH (to P&R)	ton	103.40	73.60	125.00	71.10	531.90	123.80	1028.80	Chemical Plant- Weekly Stock Balance,Usage/transfers
NaOH (to bleach)	ton	1335.40	1365.50	1902.30	1281.80	1627.70	1469.70	8982.40	Chemical Plant- Weekly Stock Balance,Usage/transfers
NaOH (to PM2)	ton	145.20	133.70	139.60	85.30	231.50	216.20	951.50	Chemical Plant- Weekly Stock Balance,Usage/transfers
								10962.70	
Sodium Hypochlorite (to maket)	ton	171.90	305.10	575.00	510.50	357.50	1052.85	2972.85	Chemical Plant- Weekly Stock Balance,Usage/transfers
Sulphur dioxide (to pulp mill)	ton	210.90	199.30	248.60	215.70	260.00	155.50	1290.00	Chemical Plant- Weekly Stock Balance,Usage/transfers
Sulphuric acid (to demin plant)	ton	238.20	167.40	315.60	225.80	162.50	145.00	1254.50	Chemical Plant- Weekly Stock Balance,Usage/transfers
Sodium Sulphate (salt cake to recovery plant)	ton	1335.70	1698.30	2138.70	1584.50	1756.70	1655.20	10169.10	Chemical Plant- Weekly Stock Balance,Usage/transfers
water								**36647191.00**	
effluent (ex brine prep.)	m^3	2744	1680	4375	4256	2100	13048	28203.00	
chem ret. To WCC	m^3	3276868	3135748	3141180	2487184	3762710	2505804	18309494.00	
effluent (ex chem plant)	m^3	3276868	3135748	3141180	2487184	3762710	2505804	18309494.00	
Cl_2	ton							692.59	
ClO_2	ton							2.74	

Appendix Five

Recovery Plant

Process flow of Power Plant



POWER PLANT

INPUTS

Weeks Description	Unit	11--14 March	15--18 April	19--23 May	24--27 June	28--32 July	33--36 August	Total	Source
resin	kg								
HCl (ex chem plant)	ton	49.00	104.00	49.00	2.80	27.00	111.00	342.80	Chemical Plant - Weekly Stock Balance, Usage/transfer
H2SO4 (ex chem plant)	ton	238.20	167.40	315.60	225.80	162.50	145.00	1,254.50	Chemical Plant - Weekly Stock Balance, Usage/transfer
NaOH (ex chem plant)	ton	103.40	73.60	125.00	71.10	531.90	123.80	1,028.80	Chemical Plant - Weekly Stock Balance, Usage/transfer
Bark (ex woodyard)	ton	1110.40	1102.60	848.70	1037.90	581.90	911.90	5,593.40	Timber Stock Control Report, Production Monthly Reports
	GJ	8883.20	8820.80	6789.60	8303.20	4655.20	7295.20	44,747.20	
Bark (ex. Safcol, Portnet & Merebank)	ton	6250.60	6258.40	10008.30	4237.10	11749.10	10083.10	48,586.60	Technical Dept., Page 63 (Bark fired (tons) - Bark ex woodyard (tons))
	GJ	50004.80	50067.20	80066.40	33896.80	93992.80	80664.80	388,692.80	
coal	ton	11688.00	12829.00	15320.00	13632.00	16732.00	12610.00	82,811.00	Technical Dept., Page 63, coal fired tons
	GJ	321420.00	352797.50	421300.00	374880.00	460130.00	346775.00	2,277,302.50	cv value=27.5 GJ/ton
Heavy fuel oil	kg	18156.60	103519.08	6602.40	118409.76	136820.88	81562.32	465,071.04	461-FI-1210/ 462-FI-3207
	GJ	780.73	4451.32	283.90	5091.62	5883.30	3507.18	19,998.05	cv = 43 MJ/kg @ 100 % efficiency
Eskom power	MWh	16370.28	19549.64	19947.20	16674.05	20021.40	13760.04	106,322.61	Technical Dept., Page 63, supply imported
	GJ	58933.01	70378.70	71809.92	60026.58	72077.04	49536.14	382,761.40	1 kWh=3.6MJ : Eskom
Total dry solids from HW cook	ton	39724.717	43069.1514	34150.0082	39264.7742	38801.9482	38305.3512	233,315.95	mass balance across digesters
	GJ	343221.55	372117.47	295056.07	339247.65	335248.83	330958.23	2,015,849.81	13.5 GJ/TDS cv value; @ 63% efficiency
Total dry solids from SW cook	ton	11038.17	9127.752	8580.672	9184.59	7339.56	9373.434	54,644.18	mass balance across digesters
	GJ	102434.22	84705.54	79628.64	85233.00	68111.12	86985.47	507,097.97	14.5 GJ/TDS cv value; @ 63% efficiency
water	m^3							15,360,548.00	
Umhlatuzi demin	m^3	245364.00	293524.00	328020.00	241192.00	327950.00	237860.00	1,673,910.00	
WCC turbines	m^3	1680000.00	1680000.00	2100000.00	1680000.00	2100000.00	1680000.00	10,920,000.00	
WC80 demin plant	m^3	273532.00	304052.00	330715.00	308812.00	341775.00	264264.00	1,823,150.00	
WCC demin(271-761)	m^3	145152	145152	181440	145152	181440	145152	943,488.00	

OUTPUTS

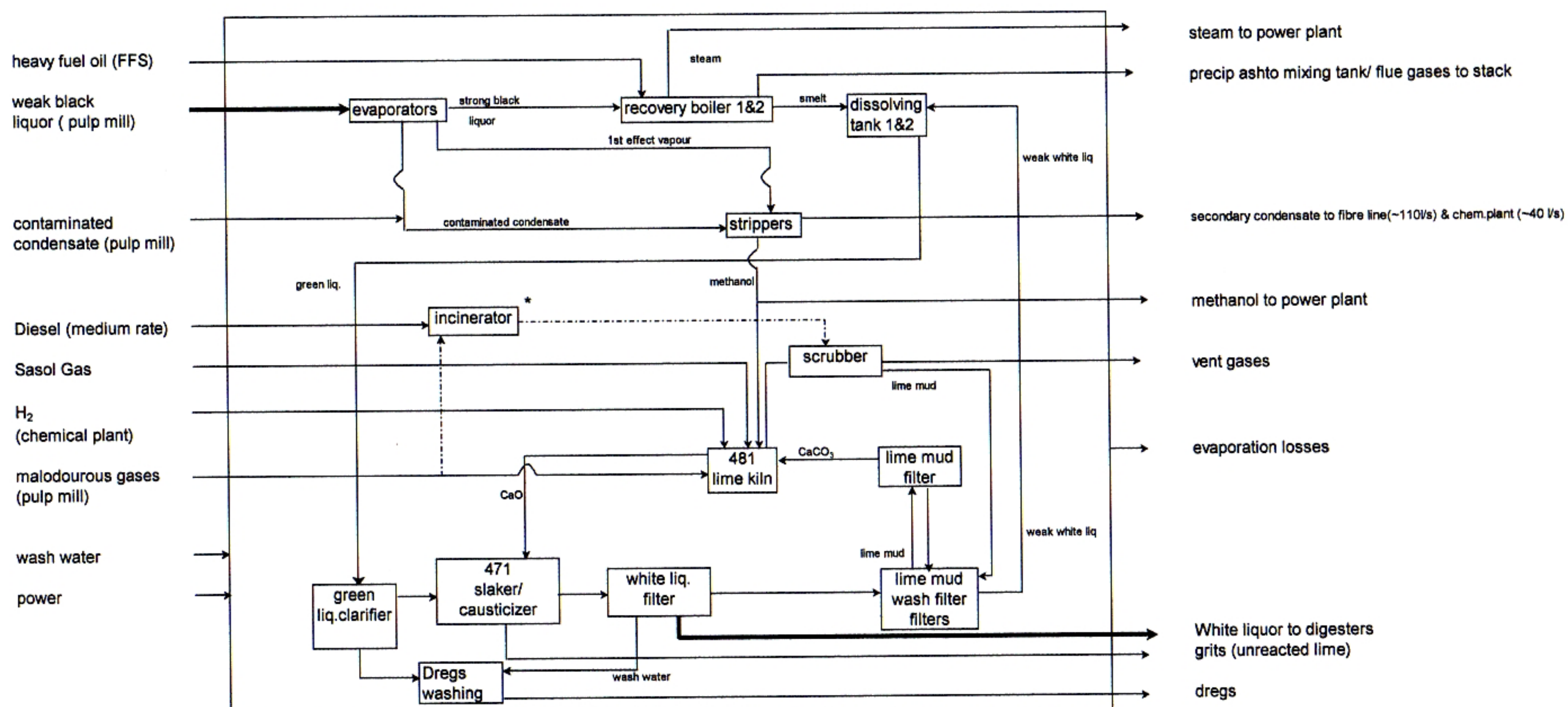
Weeks Description	Unit	11--14 March	15--18 April	19--23 May	24--27 June	28--32 July	33--36 August	Total	Source
Boiler Ash (to landfill)	ton	3545.00	4260.00	5302.00	4192.00	5524.00	4203.00	27026	Technical Dept., Annual and Monthly Statistics, Page61, Boiler ash (total tons to landfill)_
Process power (to chemical plant)	MWh	5705.84	5705.84	7132.3	5705.84	7132.3	5705.84	37087.96	Mill Specific Energy Distribution, Piet Kotze
Process power (to pulp mill)	MWh	82943.84	82943.84	103679.8	82943.84	103679.8	82943.84	539134.96	Mill Specific Energy Distribution, Piet Kotze
Process power (to woodyard)	MWh	2117.92	2117.92	2647.4	2117.92	2647.4	2117.92	13766.48	Mill Specific Energy Distribution, Piet Kotze
Process power (to paper machine 1)	MWh	33040	33040	41300	33040	41300	33040	214760	Mill Specific Energy Distribution, Piet Kotze
Process power (to paper machine 2)	MWh	24416	24416	30520	24416	30520	24416	158704	Mill Specific Energy Distribution, Piet Kotze
Process power (bleach plant)	MWh							108497.5	Mill Specific Energy Distribution, Piet Kotze
Process power (recovery plant)	MWh							610109.5	
Process Power generated	MWh	38652.05	38210.66	46751.25	36953.3	45604.3	37840.11	1682060.4	Technical Dept., Annual and Monthly Statistics, Page 63, Energy supply generated (MWh/t*ton total production (PM1&PM2)
Emissions to air									
Power Boilers									
NOx	ton							0.55	Emission data for Mondi kraft Richards Bay
VOC	ton							8.85	Emission data for Mondi kraft Richards Bay
Particulates	ton							576.56	Emission data for Mondi kraft Richards Bay
CO_2	ton							183,983.50	Emission data for Mondi kraft Richards Bay
CO	ton							475.65	Emission data for Mondi kraft Richards Bay
SO_2	ton							1369.625	Emission data for Mondi kraft Richards Bay
Dioxin	g							0.245	Emission data for Mondi kraft Richards Bay
water	m^3							12743150.00	
to WC 80 ex demin	m^3	273532.00	304052.00	330715.00	308812.00	341775.00	264264.00	1823150.00	
to WCC turb ret	m^3	1680000.00	1680000.00	2100000.00	1680000.00	2100000.00	1680000.00	10920000.00	

No. of HW blows	1680	1721	2421	1785	2188	2286	12081
No. of SW blows	388	436	772	346	424	379	2745

Appendix Six

Power Plant

Recovery Process flow



* used in the event of lime kiln outage

RECOVERY PLANT

INPUTS

Weeks Description	Unit	11–14 March	15–18 April	19–23 May	24–27 June	28–32 July	33–36 August	Total	Source
weak black liquor ex HW cook (to P&R)	l	294591412	271715980	275831134.1	299359326.1	282506317.3	317758288.9	1,741,762,458.44	421-fi-1105, Pi (ratioed by the no. of HW blows to total blows)
weak black liquor ex SW cook (to P&R)	l	68036588.01	68836820.03	87956065.89	58027073.86	54745282.7	52681711.07	390,283,541.56	421-fi-1105, Pi (ratioed by the no. of SW blows to total blows)
Total dry solids from HW cook	tons	39724.717	43069.1514	34150.0082	39264.7742	38801.9482	38305.3512	233315.95	mass balance across digesters
	GJ	536283.6795	581433.5439	461025.1107	530074.4517	523826.3007	517122.2412	3,149,765.33	cv=13.5 GJ/ton
Total dry solids from SW cook	tons	11038.17	9127.752	8580.672	9184.59	7339.56	9373.434	54644.18	mass balance across digesters
	GJ	160053.465	132352.404	124419.744	133176.555	106423.62	135914.793	792,340.58	cv=14.5 ton
Medium Rate Diesel	l	25800.00	32170.00	10180.00	3920.00	58600.00	9580.00	140250.00	Chemical Plant- weekly stock balance, Raw Materials Brought In.
Energy from med. Rate diesel	GJ	1002.51	1250.03	395.56	152.32	2277.02	372.25	5449.69	cv= 38.857 MJ/l
Sasol Gas	Nm^3	2047388.00	2047388.00	2559235.00	2047388.00	2047388.00	2047388.00	12796175.00	Approx. 73121 Nm3/d fired; mill specific energy distribution
Energy from Sasol Gas	GJ	57326.86	57326.86	71658.58	57326.86	57326.86	57326.86	358292.90	cv= 28 MJ/Nm^3; @ 100 % efficiency
CaO	kg	400000.00	1025800.00	512500.00	0.00	3022000.00	366800.00	5327100.00	Monthly Production report, Chemical plant: production figures 2000
Energy & steam	MWh	93863	93863	117328.75	93863	117328.75	93863	610109.5	Mill Specific Energy Distribution
$NaSO_4$ (from chemical plant)	ton	1335.70	1698.30	2138.70	1584.50	1756.70	1655.20	10169.10	Chemical Plant- Weekly Stock Balance,Usage/transfers
water	m^3							**20809131**	
WCC	m^3	3489640	3322956	3822350	2970016	4099725	2877868	20582555	
WC80	m^3	29540	45556	23030	28336	57610	42504	226576	

OUTPUTS

Weeks Description	Unit	11–14 March	15–18 April	19–23 May	24–27 June	28–32 July	33–36 August	Total	Source
recovery boiler									
NOx	ton							203.25	Emission data for Mondi kraft Richards Bay
VOC	ton							9.75	Emission data for Mondi kraft Richards Bay
Particulates	ton							123103.38	Emission data for Mondi kraft Richards Bay
CO_2 biogenic	ton							514015.00	Emission data for Mondi kraft Richards Bay
CO	ton							792.00	Emission data for Mondi kraft Richards Bay
SO_2	ton							292.64	Emission data for Mondi kraft Richards Bay
HCl	ton							63.94	Emission data for Mondi kraft Richards Bay
H_2S	ton							10.00	Emission data for Mondi kraft Richards Bay
Lime kiln									
NOx	ton							67.76	Emission data for Mondi kraft Richards Bay
VOC	ton							5.85	Emission data for Mondi kraft Richards Bay
Particulates	ton							13006.30	Emission data for Mondi kraft Richards Bay
CO_2	ton							41294.00	Emission data for Mondi kraft Richards Bay
SO_2	ton							0.73	Emission data for Mondi kraft Richards Bay
H_2S	ton							0.15	Emission data for Mondi kraft Richards Bay
Incinerator									
SO_2	ton							61.25	Emission data for Mondi kraft Richards Bay
H_2S	ton							1.25	Emission data for Mondi kraft Richards Bay
Slaker & Caustisizer									
VOC								0.90	Emission data for Mondi kraft Richards Bay

Smelt dissolving tank									
NOx	ton							5.65	Emission data for Mondi kraft Richards Bay
VOC	ton							10.80	Emission data for Mondi kraft Richards Bay
Particulates	ton							13842.62	Emission data for Mondi kraft Richards Bay
H_2S	ton							0.27	Emission data for Mondi kraft Richards Bay
Lime mud washing									Emission data for Mondi kraft Richards Bay
VOC	ton							2.20	Emission data for Mondi kraft Richards Bay
heavy white liquor (to pulp mill)	m^3	128658.00	128096.00	176005.00	134655.80	163292.10	144631.90	875338.80	Chemical Plant- Weekly Stock Balance,Usage/transfers
heavy white liquor (to pulp mill)	l	111876521.7	111387826.1	153047826.1	117092000	141993130.4	125766869.6	761,164,173.91	specific gravity of white liquor from Weyerhaeuser MSDS=1.15
NaOH	kg	11148495.39	11099796.87	15251215.87	11668217.8	14149615.45	12532668.55	75,850,009.93	sulphidity=25%
Na2S	kg	3623680.539	3607851.687	4957219.087	3792609.88	4599157.495	4073588.905	24,654,107.59	AA=103g/l and sulphidity=25%
Energy prod from HW TDS	GJ	337858.72	366303.13	290445.82	333946.90	330010.57	325787.01	1,984,352.16	13.5 GJ/TDS cv value; @ 63% efficiency
Energy prod from SW TDS	GJ	6954.05	5750.48	5405.82	5786.29	4623.92	5905.26	34,425.83	14.5 GJ/TDS cv value; @ 63% efficiency
Effluent								**20434043**	
to WC45	m^3	2593304	2368576	2825970	2097368	2987145	1930068	14802431	
to WCC	m^3	873488	931532	967820	849800	1084020	924952	5631612	

NOx	ton	276.65
VOC	ton	29.50
Particulates	ton	149952.29
CO_2	ton	555309.00
CO	ton	792.00
SO_2	ton	354.62
Dioxin	g	0.245
H2S	ton	11.67

Appendix Seven

Flow Diagram

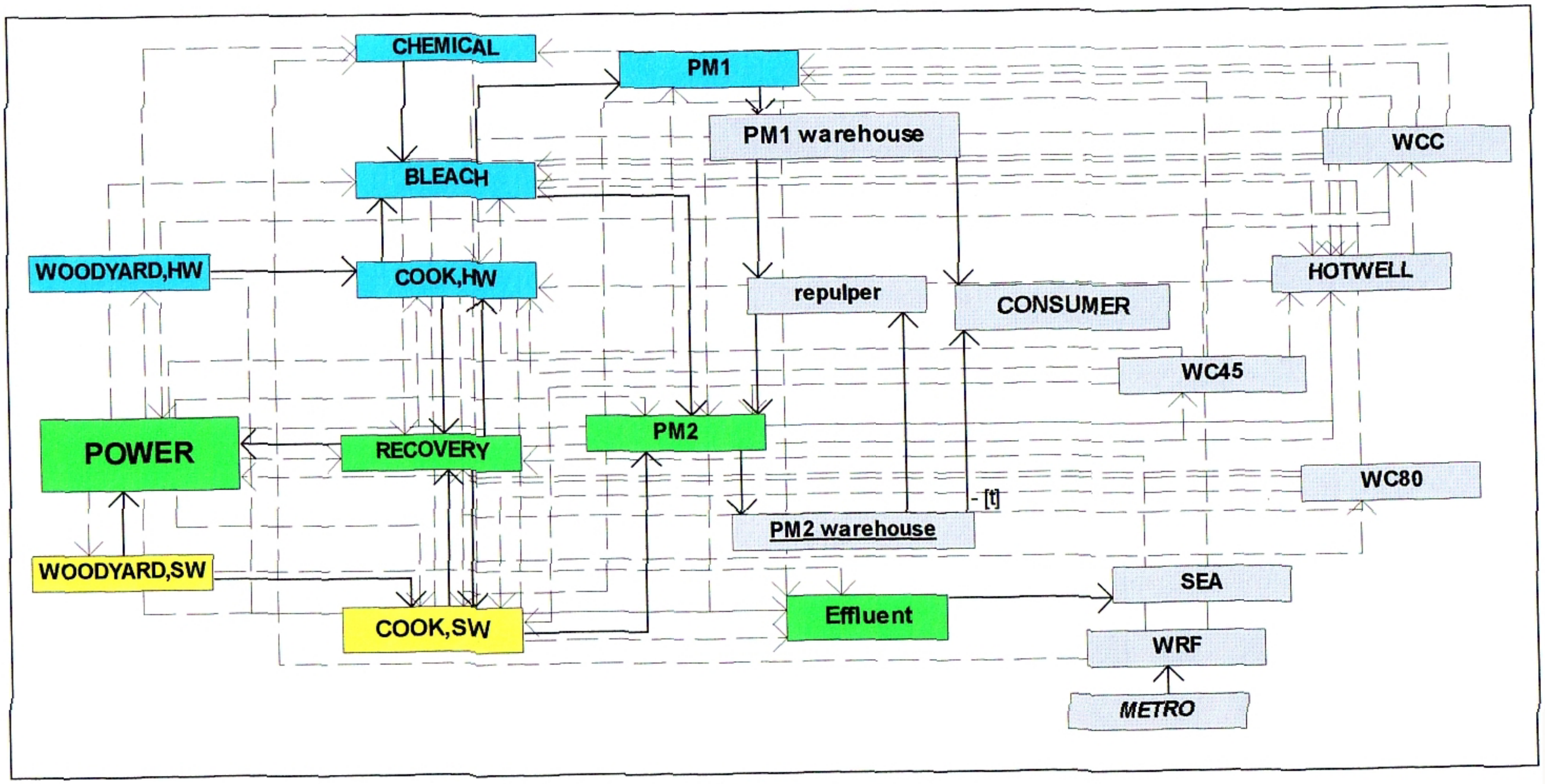


Figure A6-1 Flow diagram of process all process flows from KCL-Eco 95

Appendix Eight

Table of Characterisation Factors

Impact Category	Parameter	Units	Equivalency Factor	Correction Factor
Climate Change				
	1,1,1-trichloroethane	kg	100	1
	CFC (hard)	kg	7100	1
	CFC (soft)	kg	1600	1
	CFC-11	kg	3400	1
	CFC-113	kg	4500	1
	CFC-114	kg	7000	1
	CFC-115	kg	7000	1
	CFC-116	kg	6200	1
	CFC-12	kg	7100	1
	CFC-13	kg	13000	1
	CFC-14	kg	4500	1
	CH4	kg	11	1
	CO^2	kg	1	1
	CO^2 biogenic	kg	0	1
	CO^2 fossil	kg	1	1
	Dichloromethane	kg	15	1
	HALON 1211	kg	4900	1
	HALON1301	kg	4900	1
	HCFC-123	kg	90	1
	HCFC-124	kg	440	1
	HCFC-125	kg	3400	1
	HCFC-134a	kg	1200	1
	HCFC-141b	kg	580	1
	HCFC-142b	kg	1800	1
	HCFC-143a	kg	3800	1
	HCFC-22	kg	1600	1
	HFC-152a	kg	150	1
	Methane	kg	11	1
	N^2O	kg	270	1
	Tetrachloromethane	kg	1300	1
	Trichloromethane	kg	25	1
Ozone Layer Depletion				
	1,1,1-trichloroethane	kg	0.12	1
	CFC (hard)	kg	1	1
	CFC (soft)	kg	0.055	1
	CFC-11	kg	1	1
	CFC-113	kg	1.07	1
	CFC-114	kg	0.8	1
	CFC-115	kg	0.5	1

Impact Category	Parameter	Units	Equivalency Factor	Correction Factor
	CFC-12	kg	1	1
	CFC-13	kg	1	1
	HALON-1201	kg	1.4	1
	HALON-1202	kg	1.25	1
	HALON-1211	kg	4	1
	HALON-1301	kg	16	1
	HALON-2311	kg	0.14	1
	HALON-2401	kg	0.25	1
	HALON-2402	kg	7	1
	HCFC-123	kg	0.02	1
	HCFC-124	kg	0.022	1
	HCFC-141b	kg	0.11	1
	HCFC-142b	kg	0.065	1
	HCFC-22	kg	0.055	1
	HCFC-225ca	kg	0.025	1
	HCFC-225cb	kg	0.033	1
	Metylbromide	kg	0.6	1
	Tetrachloromethane	kg	1.08	1
Acidification				
	ammonia	kg	1.88	1
	HCl	kg	0.88	1
	HCl, air	kg	0.88	1
	HF	kg	1.6	1
	NH3, air	kg	1.88	1
	NHy	kg	1.88	1
	NO2	kg	0.7	1
	NOx	kg	0.7	1
	SO2	kg	1	1
	SOx	kg	1	1
Eutrophication				
	ammonia	kg	0.33	1
	COD	kg	0.022	1
	Kjeldahl-N	kg	0.42	1
	N, tot	kg	0.42	1
	N, water	kg	0.42	1
	NH3	kg	0.33	1
	NH3, water	kg	0.33	1
	NH4, water	kg	0.33	1
	NHy	kg	0.33	1

Impact Category	Parameter	Units	Equivalency Factor	Correction Factor
	Nitrates	kg	0.1	1
	Nitrates, air	kg	0.1	1
	Nitrates, water	kg	0.1	1
	NO	kg	0.2	1
	NO2	kg	0.13	1
	NOx	kg	0.13	1
	P	kg	3.06	1
	P, tot	kg	3.06	1
	P, water	kg	3.06	1
	P, air	kg	3.06	1
	phosphate	kg	1	1
	PO4, air	kg	1	1
	PO4, water	kg	1	1
Heavy Metals		kg		1
	As, water	kg	1	1
	B, water	kg	0.03	1
	Ba, water	kg	0.014	1
	Cadmium oxide, air	kg	50	1
	Cd, air	kg	50	1
	Cd, water	kg	3	1
	Cr, water	kg	0.2	1
	Cu, water	kg	0.005	1
	heavy metals, air	kg	1	1
	Hg, air	kg	1	1
	Hg, water	kg	10	1
	Mn, air	kg	1	1
	Mn, water	kg	0.02	1
	Mo, water	kg	0.14	1
	Ni, water	kg	0.5	1
	Pb, air	kg	1	1
	Pb, water	kg	1	1
	Sb, water	kg	2	1
Carcinogenic Substances				
	acrylonitrile	kg	0.00022	1
	As, air	kg	0.044	1
	benzene	kg	4.4E-005	1
	Benzo(a)pyrene	kg	1	1
	Cr-6	kg	0.44	1
	CxHy aromatic, air	kg	4.4E-005	1
	Ethylbenzene, air	kg	4.4E-005	1

Impact Category	Parameter	Units	Equivalency Factor	Correction Factor
	Fluoanthene, air	kg	1	1
	Ni, air	kg	0.0044	1
	PAH	kg	1	1
	Tar, air	kg	4.4E-005	1
	vinyl chloride	kg	1.1E-005	1
Winter Smog				
	Carbon black, air	kg	1	1
	dust	kg	1	1
	Iron dust	kg	1	1
	particulates	kg	1	1
	SO2	kg	1	1
	Soot, air	kg	1	1
	Sox	kg	1	1
Summer Smog				
	1,1,1,-trichloroethane, air	kg	0.021	1
	1,2-dichloroethane, air	kg	0.021	1
	acetaldehyde, air	kg	0.527	1
	acetone, air	kg	0.178	1
	acetonitrile, air	kg	0.416	1
	acrolein, air	kg	0.603	1
	acrylonitrile, air	kg	0.416	1
	alcohols, air	kg	0.196	1
	aldehydes, air	kg	0.443	1
	alkanes, air	kg	0.398	1
	alkenes, air	kg	0.906	1
	benzadldehyde, air	kg	0.334	1
	benzene, air	kg	0.189	1
	benzo(a)pyrene, air	kg	0.761	1
	butane, air	kg	0.41	1
	butene, air	kg	0.992	1
	caprolactam, air	kg	0.761	1
	CH4	kg	0.007	1
	chlorophenols, air	kg	0.761	1
	crude oil, air	kg	0.398	1
	CxHy aliphatic air	kg	0.398	1
	CxHy aromatic air	kg	0.761	1
	CxHy chloro, air	kg	0.021	1
	CxHy, air	kg	0.398	1
	dichloromethane, air	kg	0.021	1

Impact Category	Parameter	Units	Equivalency Factor	Correction Factor
	diethyl ether, air	kg	0.398	1
	diphenyl, air	kg	0.761	1
	ethanol, air	kg	0.268	1
	ethene, air	kg	1	1
	ethylene glycol, air	kg	0.196	1
	ethylene oxide, air	kg	0.377	1
	ethyne, air	kg	0.168	1
	formaldehyde, air	kg	0.421	1
	HC	kg	0.398	1
	heptane, air	kg	0.529	1
	hexachlorobiphenyl, air	kg	0.761	1
	hexane, air	kg	0.421	1
	hydroxy compounds, air	kg	0.377	1
	isopropanol, air	kg	0.196	1
	kerosene, air	kg	0.398	1
	ketones, air	kg	0.326	1
	methane	kg	0.007	1
	methanol, air	kg	0.123	1
	methyl ethyl ketone, air	kg	0.473	1
	methyl mercaptane, air	kg	0.377	1
	naphthalene, air	kg	0.761	1
	NMVOC	kg	0.416	1
	PAH	kg	0.761	1
	pentachlorophenol, air	kg	0.021	1
	pentane, air	kg	0.408	1
	petrol, air	kg	0.398	1
	phenol, air	kg	0.761	1
	phthalic acid anhydride, air	kg	0.761	1
	propane, air	kg	0.42	1
	propene, air	kg	1.03	1
	propionaldehyde, air	kg	0.603	1
	propionic acid, air	kg	0.377	1
	styrene air	kg	0.761	1
	tar, air	kg	0.416	1
	turpentine, air	kg	0.377	1
	tetrachloroethene, air	kg	0.005	1
	tetrarchloromethane, air	kg	0.021	1
	toluene, air	kg	0.563	1
	trichloroethene, air	kg	0.021	1

Impact Category	Parameter	Units	Equivalency Factor	Correction Factor
	trichloromethane, air	kg	0.021	1
	vinyl acetate, air	kg	0.223	1
	vinyl chloride, air	kg	0.021	1
	Vinylacetate, air	kg	0.223	1
	Vinylchloride, air	kg	0.021	1
	VOC	kg	0.398	1
	xylene, air	kg	0.85	1
Pesticides				
	Disinfectants, water	kg	1	1
	Fungicides, water	kg	1	1
	Herbicides, water	kg	1	1
	Insecticides, water	kg	1	1

Appendix Nine

Inventory Calculation Results
For PM1 : Baycel

****** KCL-ECO REPORT ******

Report calculated at: 11/30/05 13:33:52

CALCULATION STATUS: CALCULATION SUCCESSFUL

****** MODULES ******

BLEACH (Calculation results)

Codes: bleach, bleached pulp

Values calculated per 1 t of PM1 saleable product

Weighted score: 0.00473186

Inputs:

Chemicals			
Cl2	30.2987	kg	
ClO2	76.2027	kg	
H2O2	0.815351	kg	
NaOH	46.1115	kg	
O2, chem	6.49061	kg	
talc	6.88733	kg	
Emissions to air			
SO2	6.977	kg	0
Energy			
electric power	0.526647	MWh	
Materials/Products			
dispergent	2.41197	kg	
HW kraft	1.16704	t	
Water			
WC45	7.55522	m3	
WC80	18.6765	m3	
WCC	8.62145	m3	

Outputs:

Chemicals			
Cl2	10.7699	kg	
ClO2	0.0440722	kg	
Emissions to air			
VOC	0.0118891	kg	0.00473186
Emissions to water			
AOX	0.66789	kg	
Materials/Products			
HW kraft	1.07205	t	
PM2	0	t	
PM1	1.07205	t	
Solid wastes			
waste, organic	96.4849	kg	
Water			
Effluent	29.0933	m3	
Hotwell	5.72467	m3	

Equations:

Chemicals
Cl2[o]=10.046*HW kraft[o]
Cl2[i]=28.2623*HW kraft[o]
ClO2[i]=71.081*HW kraft[o]
ClO2[o]=0.04111*HW kraft[o]
H2O2 =0.76055*HW kraft[o]
NaOH=43.0123*HW kraft[o]
O2, chem=6.05436*HW kraft[o]
talc=6.42442*HW kraft[o]

Emissions to air
SO2=6.50806*HW kraft[o]
VOC=0.01109*HW kraft[o]

Emissions to water
AOX=0.623*HW kraft[o]

Energy
electric power=0.49125*HW kraft[o]

Materials/Products
dispergent=2.24986*HW kraft[o]
HW kraft[i]=1.0886*HW kraft[o]

Solid wastes
waste, organic=90*HW kraft[o]

Water
Effluent=27.1379*HW kraft[o]
Hotwell=5.3399*HW kraft[o]
WC45=7.04742*HW kraft[o]
WC80=17.4212*HW kraft[o]
WCC=8.04199*HW kraft[o]

CHEMICAL (Calculation results)

Codes: chemical, bleached pulp

Values calculated per 1 t of PM1 saleable product

Weighted score: 32.5557

Inputs:

Chemicals			
AgNO3	0.0004611	kg	
flocculants	0.106979	kg	
H2SO4	33.9658	kg	
MgSO4	0.0004611	kg	
N2, chem	1.15878	kg	
Na dichromate	0.163235	kg	
Na2CO3	0.474949	kg	
Na2SO3	0.0179835	kg	
NaClO3	8.56799	kg	
NaOH	14.2886	kg	
S, chem	2.88336	kg	
SO2, chem	0	kg	
Emissions to air			
CH4	2.07502	kg	0
Energy			
electric power	0.155857	MWh	
Fuels			
Diesel	0.0235169	GJ	
Materials/Products			
resin	0.0207502	kg	
Resources			
salt rock	95.6201	kg	
Water			
WCC	77.4227	m3	
WRF	8.31576	m3	

Outputs:

Chemicals			
Cl2	30.2987	kg	
ClO2	76.2027	kg	
H2SO4	5.27654	kg	
HCl, chem	27.5922	kg	
NaOCl	12.5045	kg	
NaOH	46.1115	kg	
NaSO4	42.7735	kg	
Emissions to air			
Cl2, air	2.91333	kg	
ClO2, air	0.0115279	kg	
SO2	5.42595	kg	32.5557
Water			
Effluent	2.24471	m3	
Hotwell	77.3051	m3	

Equations:

Chemicals

AgNO3=1E-005*NaOH[o]
flocculants=0.00232*NaOH[o]
H2SO4[i]=0.7366*NaOH[o]
H2SO4[o]=0.11443*NaOH[o]
HCl, chem=0.59838*NaOH[o]
MgSO4=1E-005*NaOH[o]
N2, chem=0.02513*NaOH[o]
Na dichromate=0.00354*NaOH[o]
Na2CO3=0.0103*NaOH[o]
Na2SO3=0.00039*NaOH[o]
NaClO3=0.18581*NaOH[o]
NaOCl=0.27118*NaOH[o]
NaOH[i]=0.30987*NaOH[o]
NaSO4=0.92761*NaOH[o]
S, chem=0.06253*NaOH[o]
SO2, chem=0*NaOH[o]

Emissions to air

CH4=0.045*NaOH[o]
Cl2, air=0.06318*NaOH[o]
ClO2, air=0.00025*NaOH[o]
SO2=0.11767*NaOH[o]

Energy

electric power=0.00338*NaOH[o]

Fuels

Diesel=0.00051*NaOH[o]

Materials/Products

resin=0.00045*NaOH[o]

Resources

salt rock=2.07367*NaOH[o]

Water

Effluent=0.04868*NaOH[o]
Hotwell=1.67648*NaOH[o]
WCC=1.67903*NaOH[o]
WRF=0.18034*NaOH[o]

CONSUMER (Calculation results)

Codes:

consumer

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Materials/Products

PM1 saleable produ(	1	t
PM2 saleable produ(	0	t

Outputs:

Equations:

COOK,HW (Calculation results)

Codes: Pulp, bleached pulp

HW kraft changed from kg to tons

Values calculated per 1 t of PM1 saleable product

Weighted score: 0.000371585

Inputs:

Chemicals		
Na2S	0.0724148	kg
NaOH	0.222788	kg
Energy		
electric power	2.13246	MWh
Materials/Products		
chips, HW	2.29957	t
defoamers	1.16899	kg
dispergent	10.1866	kg
white liquor	3110.56	l
Water		
Fibre H2O in	1.26076	m3
WC45	22.0046	m3
WC80	2.62493	m3
WCC	11.8712	m3

Outputs:

Chemicals			
organic solids	1.13252	t	
Emissions to air			
H2S	3.50112E-(	kg	
VOC	0.0009336:	kg	0.000371585
Materials/Products			
HW kraft	1.16704	t	
weak black liquor	8454.59	l	
Solid wastes			
waste, organic	19.9403	kg	
Water			
Effluent	1.77507	m3	
Fibre H2O out	0.0068972	m3	
WC 80	29.5024	m3	

Equations:

Chemicals

Na2S=0.06205*HW kraft

NaOH=0.1909*HW kraft

organic solids=0.970423*HW kraft

Emissions to air

H2S=3E-005*HW kraft

VOC=0.0008*HW kraft

Energy

electric power=1.82724*HW kraft

Materials/Products

chips, HW=1.97043*HW kraft

defoamers=1.00167*HW kraft

dispergent=8.72861*HW kraft

weak black liquor=7244.48*HW kraft

white liquor=2665.34*HW kraft

Solid wastes

waste, organic=17.0862*HW kraft

Water

Effluent=1.521*HW kraft

Fibre H2O in=1.08031*HW kraft

Fibre H2O out=0.00591*HW kraft

WC 80=25.2797*HW kraft

WC45=18.8551*HW kraft

WC80=2.24922*HW kraft

WCC=10.1721*HW kraft

COOK,SW (Calculation results)

Codes: Pulp, unbleached pulp

SW kraft changed from kg to tons

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Chemicals		
CO2, chem	0	kg
Na2S	0	kg
NaOH	0	kg
SO2, chem	0	kg
Energy		
electric power	0	MWh
Materials/Products		
chips, SW	0	t
defoamers	0	kg
white liquor	0	l
Water		
Fibre H2O in	0	m3
WC45	0	m3
WC80	0	m3
WCC	0	m3

Outputs:

Chemicals			
organic solids	0	t	
Emissions to air			
H2S	0	kg	
VOC	0	kg	0
Materials/Products			
PRetief	0	t	
SW kraft	0	t	
turpentine	0	kg	
weak black liquor	0	l	
Solid wastes			
waste, organic	0	kg	
Water			
Effluent	0	m3	
Fibre H2O out	0	m3	
WC80	0	m3	

Equations:

Chemicals
CO2, chem=5.91267*SW kraft
Na2S=0.09197*SW kraft
NaOH=0.28296*SW kraft
organic solids=1.24746*SW kraft
SO2, chem=24.0148*SW kraft

Emissions to air
H2S=3E-005*SW kraft
VOC=0.0008*SW kraft

Energy
electric power=2.27877*SW kraft

Materials/Products
chips, SW=2.24746*SW kraft
defoamers=5.86771*SW kraft
PRetief=0.11401*SW kraft
turpentine=1.72794*SW kraft
weak black liquor=8909.73*SW kraft
white liquor=3950.63*SW kraft

Solid wastes
waste, organic=19.6078*SW kraft

Water
Effluent=1.89685*SW kraft
Fibre H2O in=2.83058*SW kraft
Fibre H2O out=0.02464*SW kraft
WC45=34.1813*SW kraft
WC80[i]=2.80502*SW kraft
WC80[o]=17.7535*SW kraft
WCC=5.46877*SW kraft

Effluent (Calculation results)

Codes: Effluent, Combination

Values calculated per 1 t of PM1 saleable product

Weighted score: 2345.27

Inputs:			Outputs:			
Water			Chemicals			
bleach	29.0933	m3	NaClO3	35.2956	kg	
chemical	2.24471	m3	Emissions to water			
cook,HW	1.77507	m3	AOX	1.89752	kg	
cook,SW	0	m3	BOD	109.829	kg	
pm1	4.53448	m3	COD	87.7655	kg	3.86168
pm2	0	m3	Fe2+, water	0.330328	kg	
power	4.41847	m3	heavy metals, water	8.24469	g	
recovery	3.79488	m3	P, tot	382.583	kg	2341.41
total	46.6565	m3	SO4, water	108.672	kg	
wood	0.795536	m3	sulfide	6.47498	kg	
WOODYARD,HW	0.795536	m3	TDS	985.338	kg	
WOODYARD,SW	0	m3	TSS	11.9347	kg	
			Water			
			sea	63.4657	m3	

Equations:

Chemicals

NaClO3=0.7565*total

Emissions to water

AOX=0.04067*total
BOD=2.354*total
COD=1.8811*total
Fe2+, water=0.00708*total
heavy metals, water=0.176711*total
P, tot=8.2*total
SO4, water=2.3292*total
sulfide=0.13878*total
TDS=21.119*total
TSS=0.2558*total

Water

sea=28.2735*chemical
total=bleach+chemical+cook,HW+cook,SW+pm1+pm2+power+recovery+wood

HOTWELL (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:			Outputs:		
Water			Water		
bleach	5.72467	m3	WCC	181.266	m3
chemical	77.3051	m3			
pm1	14.8173	m3			
pm2	0	m3			
power	65.5868	m3			
recovery	22.8937	m3			
WC45	23.633	m3			

Equations:

Water

WCC=2.34481*chemical

METRO (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:	Outputs:		
	Miscellaneous		
	raw water	68.8191	kg

Equations:

Piet Retief (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Materials/Products

SW kraft	0	t

Outputs:

Equations:

PM1 (Calculation results)

Codes: PM, bleached pulp

Values calculated per 1 t of PM1 saleable product

Weighted score: 0.0138232

Inputs:

Chemicals		
flocculants	0.227331	kg
Energy		
electric power	1.35808	MWh
Materials/Products		
HW kraft	1.07205	t
Miscellaneous		
Baling Wire	3.77523	kg
Water		
WC45	11.2888	m3
WCC	20.6031	m3

Outputs:

Emissions to air			
VOC	0.0347316	kg	0.0138232
Emissions to water			
TSS	6.36983	kg	
Materials/Products			
PM 1 gross producti	1.03	t	
Solid wastes			
Waste, baling wire	0.106873	kg	
Water			
Effluent	4.53448	m3	
Hotwell	14.8173	m3	

Equations:

Chemicals

flocculants=0.22071*PM 1 gross production

Emissions to air

VOC=0.03372*PM 1 gross production

Emissions to water

TSS=6.1843*PM 1 gross production

Energy

electric power=1.31852*PM 1 gross production

Materials/Products

HW kraft=1.04083*PM 1 gross production

Miscellaneous

Baling Wire=3.66527*PM 1 gross production

Solid wastes

Waste, baling wire=0.10376*PM 1 gross production

Water

Effluent=4.40241*PM 1 gross production
Hotwell=14.3857*PM 1 gross production
WC45=10.96*PM 1 gross production
WCC=20.003*PM 1 gross production

PM1 warehouse (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Fuels		
Diesel	0.02592	GJ
Materials/Products		
PM 1 gross producti	1.03	t

Outputs:

Materials/Products		
PM1 Broke	25.15	kg
PM1 saleable produ	1	t
PM1 Wrapper	9.5	kg

Equations:

Fuels

Diesel=0.02592*PM1 saleable product

Materials/Products

PM 1 gross production =1.03*PM1 saleable product
PM1 Broke=25.15*PM1 saleable product
PM1 saleable product=1
PM1 Wrapper=9.5*PM1 saleable product

PM2 (Calculation results)

Codes: PM, Combination

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Chemicals		
alum	0	kg
Biocide	0	kg
flocculants	0	kg
NaOH	0	kg
rosin size	0	kg
Energy		
electric power	0	MWh
Materials/Products		
broke	0	t
cat. starch	0	kg
dispergent	0	kg
HW kraft	0	t
optical brightener	0	kg
SW kraft	0	t
Miscellaneous		
Core Plugs	0	ea
Water		
WC45	0	m3
WCC	0	m3

Outputs:

Emissions to air			
VOC	0	kg	0
Emissions to water			
TSS	0	kg	
Materials/Products			
Deckle loss	0	t	
PM2 gross productic	0	t	
Water			
Effluent	0	m3	
Hotwell	0	m3	

Equations:

Chemicals

alum=9.98266*PM2 gross production
Biocide=0.71926*PM2 gross production
flocculants=4.7684*PM2 gross production
NaOH=8.89373*PM2 gross production
rosin size=12.2073*PM2 gross production

Emissions to air

VOC=6E-005*PM2 gross production

Emissions to water

TSS=22.8424*PM2 gross production

Energy

electric power=1.48342*PM2 gross production

Materials/Products

broke=0.13324*PM2 gross production
cat. starch=39.4373*PM2 gross production
Deckle loss=0.05478*PM2 gross production
dispergent=0.42996*PM2 gross production
HW kraft=0.46623*PM2 gross production
optical brightener=0.84124*PM2 gross production
SW kraft=0.34263*PM2 gross production

Miscellaneous

Core Plugs=0.23046*PM2 gross production

Water

Effluent=33.0224*PM2 gross production
Hotwell=14.3857*PM2 gross production
WC45=10.96*PM2 gross production
WCC=20.003*PM2 gross production

PM2 warehouse (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Fuels

Diesel	0	GJ

Materials/Products

glues	0	kg
PM2 gross productic	0	t

Miscellaneous

inner discs	0	unit
PM2 wrapper	0	kg
roundels	0	unit

Outputs:

Materials/Products

PM2 Broke	0	kg
PM2 saleable produc	0	t

Equations:

Fuels

Diesel=0.02592*PM2 saleable product

Materials/Products

glues=0.0132*PM2 saleable product
PM2 Broke=111.683*PM2 saleable product
PM2 gross production=1.11*PM2 saleable product
PM2 saleable product=0

Miscellaneous

inner discs=1.25322*PM2 saleable product
PM2 wrapper=3.232*PM2 saleable product
roundels=1.31918*PM2 saleable product

POWER (Calculation results)

Codes: power, Combination

Values calculated per 1 t of PM1 saleable product

Weighted score: 631.742

Inputs:

Chemicals		
H2SO4	4.09868	kg
HCl, chem	1.12	kg
NaOH	3.36128	kg
Energy		
electric power	0.347377	MWh
Fuels		
bark, HW	158.742	kg
bark, SW	0	GJ
coal	270.559	kg
heavy fuel oil	1.51948	kg
TDS energy	8.24297	GJ
Water		
WC 80	6.11974	m3
WCC	38.7602	m3

Outputs:

Emissions to air			
CO	1.55405	kg	
CO2, fossil	601.109	kg	601.109
dioxin	0.0008243	mg	
NOx	0.0018135	kg	0.00554947
Particulates	1.88373	kg	3.76746
SO2	4.4748	kg	26.8488
VOC	0.0289069	kg	0.0115049
Energy			
electric power, Bleac	0.526647	MWh	
electric power, Chem	0.155857	MWh	
electric power, PM1	1.35808	MWh	
electric power, PM2	0	MWh	
electric power, Pulp	2.13246	MWh	
COOK,HW	2.13246	MWh	
COOK,SW	0	MWh	
electric power, Reco	2.48844	MWh	
electric power, total	5.49561	MWh	
electric power, Wooc	0.0501536	MWh	
WOODYARD,HW	0.0501536	MWh	
WOODYARD,SW	0	MWh	
Solid wastes			
waste, ash	88.299	kg	
Water			
Effluent	4.41847	m3	
Hotwell	65.5868	m3	

Equations:

Chemicals

H2SO4=0.74581*electric power, total
HCl, chem=0.2038*electric power, total
NaOH=0.61163*electric power, total

Emissions to air

CO=0.28278*electric power, total
CO2, fossil=109.38*electric power, total
dioxin=0.00015*electric power, total
NOx=0.00033*electric power, total
Particulates=0.34277*electric power, total
SO2=0.81425*electric power, total
VOC=0.00526*electric power, total

Energy

electric power=0.06321*electric power, total

Fuels

bark, HW=28.8852*electric power, total
coal=49.2319*electric power, total
heavy fuel oil=0.27649*electric power, total
TDS energy=1.49992*electric power, total

Solid wastes

waste, ash=16.0672*electric power, total

Water

Effluent=0.804*electric power, total
Hotwell=11.9344*electric power, total
WC 80=1.11357*electric power, total
WCC=7.05295*electric power, total

RECOVERY (Calculation results)

Codes: recovery, Combination

Values calculated per 1 t of PM1 saleable product

Weighted score: 1237.81

Inputs:

Chemicals		
CaO	21.7739	kg
NaSO4	41.557	kg
Energy		
electric power	2.48844	MWh
Fuels		
Diesel	0.0311056	GJ
organic solids ex HW	1.13252	GJ
organic solids ex SW	0	GJ
sasol gas	1.46196	GJ
Materials/Products		
black liquor ex HW c	8454.59	l
black liquor ex SW c	0	l
Water		
WC80	1.04515	m3
WCC	84.0472	m3
WRF	6.78101	m3

Outputs:

Chemicals			
HCl, chem	0.261296	kg	
Na2S	100.751	kg	
NaOH	309.967	kg	
Emissions to air			
CO	3.23498	kg	
CO2, biogenic	2269.31	kg	
dioxin	1.0016E-0(	mg	
H2S	0.0622111	kg	
NOx	1.1198	kg	3.42659
Particulates	612.779	kg	1225.56
SO2	1.46196	kg	8.77177
VOC	0.124422	kg	0.04952
Energy			
energy, inherent	8.24297	GJ	
Materials/Products			
white liquor	3110.56	l	
COOK,HW	3110.56	l	
COOK,SW	0	l	
Water			
Effluent	3.79488	m3	
Hotwell	22.8937	m3	
WC45	60.5314	m3	
woodyard	1.24422	m3	

Equations:

Chemicals

CaO=0.007*white liquor
HCl, chem=8.40029E-005*white liquor
Na2S=0.03239*white liquor
NaOH=0.09965*white liquor
NaSO4=0.01336*white liquor

Emissions to air

CO=0.00104*white liquor
CO2, biogenic=0.72955*white liquor
dioxin=3.22E-013*white liquor
H2S=2E-005*white liquor
NOx=0.00036*white liquor
Particulates=0.197*white liquor
SO2=0.00047*white liquor
VOC=4E-005*white liquor

Energy

electric power=0.0008*white liquor
energy, inherent=0.00265*white liquor

Fuels

Diesel=1E-005*white liquor
sasol gas=0.00047*white liquor

Water

Effluent=0.00122*white liquor
Hotwell=0.00736*white liquor
WC45=0.01946*white liquor
WC80=0.000336*white liquor
WCC=0.02702*white liquor
woodyard=0.0004*white liquor
WRF=0.00218*white liquor

repulper (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Materials/Products		
PM1 Broke	25.15	kg
PM2 Broke	0	kg

Outputs:

Materials/Products		
broke	0	t

Equations:

SEA (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Water

sea	63.4657	m3

Outputs:

Equations:

SilvaCel (Calculation results)

Codes: Water,

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Materials/Products

chips, HW	0.255119	t

Outputs:

Equations:

WC45 (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Water

recovery	60.5314	m3

Outputs:

Water

bleach	7.55522	m3
cook,HW	22.0046	m3
cook,SW	0	m3
Hotwell	23.633	m3
pm1	11.2888	m3
pm2	0	m3

Equations:

Water

Hotwell=0.390426*recovery

WC80 (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Water

cook,HW	29.5024	m3
cook,SW	0	m3

Outputs:

Water

bleach	18.6765	m3
cook,HW	2.62493	m3
cook,SW	0	m3
power	6.11974	m3
recovery	1.04515	m3

Equations:

WCC (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Water

Hotwell	181.266	m3
WRF	53.531	m3

Outputs:

Water

bleach	8.62145	m3
chemical	77.4227	m3
cook,HW	11.8712	m3
cook,SW	0	m3
pm1	20.6031	m3
pm2	0	m3
power	38.7602	m3
recovery	84.0472	m3

Equations:

Water

WRF=0.691413*chemical

WOODYARD,HW (Calculation results)

Codes: woodyard, bleached pulp

chips,HW changed from kg to ton

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Energy		
electric power	0.0501536	MWh
Fuels		
Diesel	0.323388	GJ
Materials/Products		
Euca	2.38189	t
Water		
Fibre H2O in	1.1209	m3
Recovery water	1.11462	m3

Outputs:

Fuels		
wood residuals	29.0801	kg
Materials/Products		
chips, HW	2.29957	t
SilvaCel	0.255119	t
Water		
Effluent	0.795536	m3
Fibre H2O (SilvaCel)	0.186541	m3
Fibre H2O out	1.49035	m3
Hotwell	0.490429	m3

Equations:

Energy

electric power=0.02181*chips, HW

Fuels

Diesel=0.14063*chips, HW

wood residuals=12.6459*chips, HW

Materials/Products

Euca=1.0358*chips, HW

SilvaCel=0.110942*chips, HW

Water

Effluent=0.34595*chips, HW

Fibre H2O (SilvaCel)=0.08112*chips, HW

Fibre H2O in=0.48744*chips, HW

Fibre H2O out=0.6481*chips, HW

Hotwell=0.21327*chips, HW

Recovery water=0.48471*chips, HW

WOODYARD,SW (Calculation results)

Codes: woodyard, unbleached pulp

Bark, SW changed to GJ
Pine is changed to ton

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Energy		
electric power	0	MWh
Fuels		
Diesel	0	GJ
Materials/Products		
Pine	0	t
Water		
Fibre H2O in	0	m3
Recovery water	0	m3

Outputs:

Fuels		
bark, SW	0	GJ
wood residuals	0	kg
Materials/Products		
chips, SW	0	t
Water		
Effluent	0	m3
Fibre H2O pulp	0	m3
Hotwell	0	m3

Equations:

Energy
electric power=0.02181*chips, SW
Fuels
bark, SW=0.45452*chips, SW
Diesel=0.14063*chips, SW
wood residuals=11.3631*chips, SW
Materials/Products
Pine=1.16257*chips, SW
Water
Effluent=2.21842*chips, SW
Fibre H2O in=1.25946*chips, SW
Fibre H2O pulp=1.52364*chips, SW
Hotwell=0.21327*chips, SW
Recovery water=0.48471*chips, SW

WRF (Calculation results)

Codes:

Values calculated per 1 t of PM1 saleable product

Weighted score: 0

Inputs:

Miscellaneous		
raw water	68.8191	kg

Outputs:

Water		
chemical	8.31576	m3
recovery	6.78101	m3
WCC	53.531	m3

Equations:

Miscellaneous
raw water=1.28559*WCC

****** SUMMARIES ******

SUMMARY OF **Entire system**

Values calculated per 1 t of PM1 saleable product

Impact assessment method: Eco-indicator 95

Variable:	Inputs:	Outputs:	Unit:	Weighted score:
Chemicals				
AgNO3	0.000461115		kg	
alum	0		kg	
Biocide	0		kg	
CaO	21.7739		kg	
Cl2		10.7699	kg	
ClO2		0.0440722	kg	
CO2, chem	0		kg	
flocculants	0.33431		kg	
H2O2	0.815351		kg	
H2SO4	38.0644	5.27654	kg	
HCl, chem	1.12	27.8535	kg	
MgSO4	0.000461115		kg	
N2, chem	1.15878		kg	
Na dichromate	0.163235		kg	
Na2CO3	0.474949		kg	
Na2S	0.0724148	100.751	kg	
Na2SO3	0.0179835		kg	
NaClO3	8.56799	35.2956	kg	

NaOCl		12.5045	kg	
NaOH	17.8727	309.967	kg	
NaSO4	41.557	42.7735	kg	
O2, chem	6.49061		kg	
rosin size	0		kg	
S, chem	2.88336		kg	
SO2, chem	0		kg	
talc	6.88733		kg	
Emissions to air				
CH4	2.07502		kg	0
Cl2, air		2.91333	kg	
ClO2, air		0.0115279	kg	
CO		4.78903	kg	
CO2, biogenic		2269.31	kg	
CO2, fossil		601.109	kg	601.109
dioxin		0.000824342	mg	
H2S		0.0622461	kg	
NOx		1.12161	kg	3.43214
Particulates		614.663	kg	1229.33
SO2	6.977	11.3627	kg	68.1762
VOC		0.200883	kg	0.0799516
Emissions to water				
AOX		2.56541	kg	
BOD		109.829	kg	
COD		87.7655	kg	3.86168
Fe2+, water		0.330328	kg	
heavy metals, water		8.24469	g	
P, tot		382.583	kg	2341.41
SO4, water		108.672	kg	
sulfide		6.47498	kg	
TDS		985.338	kg	
TSS		18.3046	kg	
Energy				
electric power	0.347377		MWh	
electric power, total		5.49561	MWh	
Fuels				
bark, HW	158.742		kg	
coal	270.559		kg	
Diesel	0.403931		GJ	
heavy fuel oil	1.51948		kg	
sasol gas	1.46196		GJ	
wood residuals		29.0801	kg	
Materials/Products				
cat. starch	0		kg	
Deckle loss		0	t	
defoamers	1.16899		kg	
dispergent	12.5986		kg	
Euca	2.38189		t	
glues	0		kg	
optical brightener	0		kg	
Pine	0		t	
PM1 Wrapper		9.5	kg	
resin	0.0207502		kg	
turpentine		0	kg	
Miscellaneous				
Baling Wire	3.77523		kg	
Core Plugs	0		ea	
inner discs	0		unit	
PM2 wrapper	0		kg	
roundels	0		unit	
Resources				
salt rock	95.6201		kg	
Solid wastes				
waste, ash		88.299	kg	
Waste, baling wire		0.106873	kg	
waste, organic		116.425	kg	
Water				
Fibre H2O (SilvaCel)		0.186541	m3	
Fibre H2O in	2.38167		m3	
Fibre H2O out		1.49725	m3	
Fibre H2O pulp		0	m3	
Hotwell		0.490429	m3	
Recovery water	1.11462		m3	
total	46.6565		m3	
woodyard		1.24422	m3	
				4247.39

Appendix Ten

Inventory Calculation Results
For PM2 : Baywhite

****** KCL-ECO REPORT ******

Report calculated at: 11/30/05 13:35:03

CALCULATION STATUS: CALCULATION SUCCESSFUL

****** MODULES ******

BLEACH (Calculation results)

Codes: bleach, bleached pulp

Values calculated per 1 t of PM2 saleable product

Weighted score: 0.00228422

Inputs:

Chemicals			
Cl2	14.6262	kg	
ClO2	36.7855	kg	
H2O2	0.393596	kg	
NaOH	22.2595	kg	
O2, chem	3.13322	kg	
talc	3.32474	kg	
Emissions to air			
SO2	3.36802	kg	0
Energy			
electric power	0.254229	MWh	
Materials/Products			
dispergent	1.16434	kg	
HW kraft	0.563367	t	
Water			
WC45	3.64715	m3	
WC80	9.01574	m3	
WCC	4.16185	m3	

Outputs:

Chemicals			
Cl2	5.19896	kg	
ClO2	0.0212751	kg	
Emissions to air			
VOC	0.0057392	kg	0.00228422
Emissions to water			
AOX	0.322412	kg	
Materials/Products			
HW kraft	0.517515	t	
PM2	0.517515	t	
PM1	0	t	
Solid wastes			
waste, organic	46.5764	kg	
Water			
Effluent	14.0443	m3	
Hotwell	2.76348	m3	

Equations:

Chemicals
Cl2[o]=10.046*HW kraft[o]
Cl2[i]=28.2623*HW kraft[o]
ClO2[i]=71.081*HW kraft[o]
ClO2[o]=0.04111*HW kraft[o]
H2O2 =0.76055*HW kraft[o]
NaOH=43.0123*HW kraft[o]
O2, chem=6.05436*HW kraft[o]
talc=6.42442*HW kraft[o]

Emissions to air
SO2=6.50806*HW kraft[o]
VOC=0.01109*HW kraft[o]

Emissions to water
AOX=0.623*HW kraft[o]

Energy
electric power=0.49125*HW kraft[o]

Materials/Products
dispergent=2.24986*HW kraft[o]
HW kraft[i]=1.0886*HW kraft[o]

Solid wastes
waste, organic=90*HW kraft[o]

Water
Effluent=27.1379*HW kraft[o]
Hotwell=5.3399*HW kraft[o]
WC45=7.04742*HW kraft[o]
WC80=17.4212*HW kraft[o]
WCC=8.04199*HW kraft[o]

CHEMICAL (Calculation results)

Codes: chemical, bleached pulp

Values calculated per 1 t of PM2 saleable product

Weighted score: 15.7157

Inputs:

Chemicals			
AgNO3	0.0002225!	kg	
flocculants	0.0516421	kg	
H2SO4	16.3964	kg	
MgSO4	0.0002225!	kg	
N2, chem	0.559382	kg	
Na dichromate	0.0787987	kg	
Na2CO3	*0.229273*	*kg*	
Na2SO3	0.0086812	kg	
NaClO3	4.13604	kg	
NaOH	6.89756	kg	
S, chem	1.39189	kg	
SO2, chem	0	kg	
Emissions to air			
CH4	1.00168	kg	0
Energy			
electric power	0.0752372	MWh	
Fuels			
Diesel	0.0113524	GJ	
Materials/Products			
resin	0.0100168	kg	
Resources			
salt rock	46.1589	kg	
Water			
WCC	37.3744	m3	
WRF	4.01428	m3	

Outputs:

Chemicals			
Cl2	14.6262	kg	
ClO2	36.7855	kg	
H2SO4	2.54716	kg	
HCl, chem	13.3197	kg	
NaOCl	6.03634	kg	
NaOH	22.2595	kg	
NaSO4	20.6482	kg	
Emissions to air			
Cl2, air	1.40636	kg	
ClO2, air	0.0055648:	kg	
SO2	2.61928	kg	15.7157
Water			
Effluent	1.08359	m3	
Hotwell	37.3176	m3	

Equations:

Chemicals
AgNO3=1E-005*NaOH[o]
flocculants=0.00232*NaOH[o]
H2SO4[i]=0.7366*NaOH[o]
H2SO4[o]=0.11443*NaOH[o]
HCl, chem=0.59838*NaOH[o]
MgSO4=1E-005*NaOH[o]
N2, chem=0.02513*NaOH[o]
Na dichromate=0.00354*NaOH[o]
Na2CO3=0.0103*NaOH[o]
Na2SO3=0.00039*NaOH[o]
NaClO3=0.18581*NaOH[o]
NaOCl=0.27118*NaOH[o]
NaOH[i]=0.30987*NaOH[o]
NaSO4=0.92761*NaOH[o]
S, chem=0.06253*NaOH[o]
SO2, chem=0*NaOH[o]
Emissions to air
CH4=0.045*NaOH[o]
Cl2, air=0.06318*NaOH[o]
ClO2, air=0.00025*NaOH[o]
SO2=0.11767*NaOH[o]
Energy
electric power=0.00338*NaOH[o]
Fuels
Diesel=0.00051*NaOH[o]
Materials/Products
resin=0.00045*NaOH[o]
Resources
salt rock=2.07367*NaOH[o]
Water
Effluent=0.04868*NaOH[o]
Hotwell=1.67648*NaOH[o]
WCC=1.67903*NaOH[o]
WRF=0.18034*NaOH[o]

CONSUMER (Calculation results)

Codes:

consumer

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Materials/Products

PM1 saleable produ(	0	t
PM2 saleable produ(	1	t

Outputs:

Equations:

COOK,HW (Calculation results)

Codes: Pulp, bleached pulp

HW kraft changed from kg to tons

Values calculated per 1 t of PM2 saleable product

Weighted score: 0.000179376

Inputs:

Chemicals		
Na2S	0.0349569	kg
NaOH	0.107547	kg
Energy		
electric power	1.02941	MWh
Materials/Products		
chips, HW	1.11008	t
defoamers	0.564308	kg
dispergent	4.91741	kg
white liquor	1501.57	l
Water		
Fibre H2O in	0.608611	m3
WC45	10.6223	m3
WC80	1.26714	m3
WCC	5.73063	m3

Outputs:

Chemicals			
organic solids	0.546704	t	
Emissions to air			
H2S	1.6901E-0(	kg	
VOC	0.0004506!	kg	0.000179376
Materials/Products			
HW kraft	0.563367	t	
weak black liquor	4081.3	l	
Solid wastes			
waste, organic	9.6258	kg	
Water			
Effluent	0.856881	m3	
Fibre H2O out	0.0033295	m3	
WC 80	14.2418	m3	

Equations:

Chemicals
Na2S=0.06205*HW kraft
NaOH=0.1909*HW kraft
organic solids=0.970423*HW kraft

Emissions to air
H2S=3E-005*HW kraft
VOC=0.0008*HW kraft

Energy
electric power=1.82724*HW kraft

Materials/Products
chips, HW=1.97043*HW kraft
defoamers=1.00167*HW kraft
dispergent=8.72861*HW kraft
weak black liquor=7244.48*HW kraft
white liquor=2665.34*HW kraft

Solid wastes
waste, organic=17.0862*HW kraft

Water
Effluent=1.521*HW kraft
Fibre H2O in=1.08031*HW kraft
Fibre H2O out=0.00591*HW kraft
WC 80=25.2797*HW kraft
WC45=18.8551*HW kraft
WC80=2.24922*HW kraft
WCC=10.1721*HW kraft

COOK,SW (Calculation results)

Codes: Pulp, unbleached pulp

SW kraft changed from kg to tons

Values calculated per 1 t of PM2 saleable product

Weighted score: 0.000121094

Inputs:

Chemicals		
CO2, chem	2.2487	kg
Na2S	0.034978	kg
NaOH	0.107615	kg
SO2, chem	9.13329	kg
Energy		
electric power	0.86666	MWh
Materials/Products		
chips, SW	0.854752	t
defoamers	2.2316	kg
white liquor	1502.5	l
Water		
Fibre H2O in	1.07652	m3
WC45	12.9998	m3
WC80	1.0668	m3
WCC	2.07988	m3

Outputs:

Chemicals			
organic solids	0.474433	t	
Emissions to air			
H2S	1.14096E-(	kg	
VOC	0.0003042!	kg	0.000121094
Materials/Products			
PRetief	0.0433602	t	
SW kraft	0.380319	t	
turpentine	0.657169	kg	
weak black liquor	3388.54	l	
Solid wastes			
waste, organic	7.45722	kg	
Water			
Effluent	0.721409	m3	
Fibre H2O out	0.0093710'	m3	
WC80	6.752	m3	

Equations:

Chemicals

CO2, chem=5.91267*SW kraft
Na2S=0.09197*SW kraft
NaOH=0.28296*SW kraft
organic solids=1.24746*SW kraft
SO2, chem=24.0148*SW kraft

Emissions to air

H2S=3E-005*SW kraft
VOC=0.0008*SW kraft

Energy

electric power=2.27877*SW kraft

Materials/Products

chips, SW=2.24746*SW kraft
defoamers=5.86771*SW kraft
PRetief=0.11401*SW kraft
turpentine=1.72794*SW kraft
weak black liquor=8909.73*SW kraft
white liquor=3950.63*SW kraft

Solid wastes

waste, organic=19.6078*SW kraft

Water

Effluent=1.89685*SW kraft
Fibre H2O in=2.83058*SW kraft
Fibre H2O out=0.02464*SW kraft
WC45=34.1813*SW kraft
WC80[i]=2.80502*SW kraft
WC80[o]=17.7535*SW kraft
WCC=5.46877*SW kraft

Effluent (Calculation results)

Codes: Effluent, Combination

Values calculated per 1 t of PM2 saleable product

Weighted score: 3195.63

Inputs:

Water

bleach	14.0443	m3
chemical	1.08359	m3
cook,HW	0.856881	m3
cook,SW	0.721409	m3
pm1	0	m3
pm2	36.6549	m3
power	4.2672	m3
recovery	3.66496	m3
total	63.5734	m3
wood	2.28023	m3
WOODYARD,HW	0.384031	m3
WOODYARD,SW	1.8962	m3

Outputs:

Chemicals

NaClO3	48.0933	kg	

Emissions to water

AOX	2.58553	kg	
BOD	149.652	kg	
COD	119.588	kg	5.26187
Fe2+, water	0.4501	kg	
heavy metals, water	11.2341	g	
P, tot	521.302	kg	3190.37
SO4, water	148.075	kg	
sulfide	8.82272	kg	
TDS	1342.61	kg	
TSS	16.2621	kg	

Water

sea	30.637	m3

Equations:

Chemicals

NaClO3=0.7565*total

Emissions to water

AOX=0.04067*total
BOD=2.354*total
COD=1.8811*total
Fe2+, water=0.00708*total
heavy metals, water=0.176711*total
P, tot=8.2*total
SO4, water=2.3292*total
sulfide=0.13878*total
TDS=21.119*total
TSS=0.2558*total

Water

sea=28.2735*chemical
total=bleach+chemical+cook,HW+cook,SW+pm1+pm2+power+recovery+wood

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HOTWELL (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Water

bleach	2.76348	m3
chemical	37.3176	m3
pm1	0	m3
pm2	15.9681	m3
power	63.3414	m3
recovery	22.1099	m3
WC45	22.824	m3

Outputs:

Water

WCC	87.5028	m3

Equations:

Water

WCC=2.34481*chemical

METRO (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Outputs:

Miscellaneous

raw water	33.2212	kg

Equations:

Piet Retief (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Materials/Products

SW kraft	0.0433602	t

Outputs:

Equations:

PM1 (Calculation results)

Codes: PM, bleached pulp

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Chemicals		
flocculants	0	kg
Energy		
electric power	0	MWh
Materials/Products		
HW kraft	0	t
Miscellaneous		
Baling Wire	0	kg
Water		
WC45	0	m3
WCC	0	m3

Outputs:

Emissions to air			
VOC	0	kg	0
Emissions to water			
TSS	0	kg	
Materials/Products			
PM 1 gross producti	0	t	
Solid wastes			
Waste, baling wire	0	kg	
Water			
Effluent	0	m3	
Hotwell	0	m3	

Equations:

Chemicals

flocculants=0.22071*PM 1 gross production

Emissions to air

VOC=0.03372*PM 1 gross production

Emissions to water

TSS=6.1843*PM 1 gross production

Energy

electric power=1.31852*PM 1 gross production

Materials/Products

HW kraft=1.04083*PM 1 gross production

Miscellaneous

Baling Wire=3.66527*PM 1 gross production

Solid wastes

Waste, baling wire=0.10376*PM 1 gross production

Water

Effluent=4.40241*PM 1 gross production

Hotwell=14.3857*PM 1 gross production

WC45=10.96*PM 1 gross production

WCC=20.003*PM 1 gross production

PM1 warehouse (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Fuels		
Diesel	0	GJ
Materials/Products		
PM 1 gross producti	0	t

Outputs:

Materials/Products		
PM1 Broke	0	kg
PM1 saleable produ	0	t
PM1 Wrapper	0	kg

Equations:

Fuels

Diesel=0.02592*PM1 saleable product

Materials/Products

PM 1 gross production =1.03*PM1 saleable product

PM1 Broke=25.15*PM1 saleable product

PM1 saleable product=0

PM1 Wrapper=9.5*PM1 saleable product

PM2 (Calculation results)

Codes: PM, Combination

Values calculated per 1 t of PM2 saleable product

Weighted score: 2.65068E-005

Inputs:

Chemicals		
alum	11.0808	kg
Biocide	0.798379	kg
flocculants	5.29292	kg
NaOH	9.87204	kg
rosin size	13.5501	kg
Energy		
electric power	1.6466	MWh
Materials/Products		
broke	0.147896	t
cat. starch	43.7754	kg
dispergent	0.477256	kg
HW kraft	0.517515	t
optical brightener	0.933776	kg
SW kraft	0.380319	t
Miscellaneous		
Core Plugs	0.255811	ea
Water		
WC45	12.1656	m3
WCC	22.2033	m3

Outputs:

Emissions to air			
VOC	6.66E-005	kg	2.65068E-005
Emissions to water			
TSS	25.3551	kg	
Materials/Products			
Deckle loss	0.0608058	t	
PM2 gross productic	1.11	t	
Water			
Effluent	36.6549	m3	
Hotwell	15.9681	m3	

Equations:

Chemicals

alum=9.98266*PM2 gross production
Biocide=0.71926*PM2 gross production
flocculants=4.7684*PM2 gross production
NaOH=8.89373*PM2 gross production
rosin size=12.2073*PM2 gross production

Emissions to air

VOC=6E-005*PM2 gross production

Emissions to water

TSS=22.8424*PM2 gross production

Energy

electric power=1.48342*PM2 gross production

Materials/Products

broke=0.13324*PM2 gross production
cat. starch=39.4373*PM2 gross production
Deckle loss=0.05478*PM2 gross production
dispergent=0.42996*PM2 gross production
HW kraft=0.46623*PM2 gross production
optical brightener=0.84124*PM2 gross production
SW kraft=0.34263*PM2 gross production

Miscellaneous

Core Plugs=0.23046*PM2 gross production

Water

Effluent=33.0224*PM2 gross production
Hotwell=14.3857*PM2 gross production
WC45=10.96*PM2 gross production
WCC=20.003*PM2 gross production

PM2 warehouse (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Fuels

Diesel	0.02592	GJ

Materials/Products

glues	0.0132	kg
PM2 gross productic	1.11	t

Miscellaneous

inner discs	1.25322	unit
PM2 wrapper	3.232	kg
roundels	1.31918	unit

Outputs:

Materials/Products

PM2 Broke	111.683	kg
PM2 saleable produ(	1	t

Equations:

Fuels

Diesel=0.02592*PM2 saleable product

Materials/Products

glues=0.0132*PM2 saleable product

PM2 Broke=111.683*PM2 saleable product

PM2 gross production=1.11*PM2 saleable product

PM2 saleable product=1

Miscellaneous

inner discs=1.25322*PM2 saleable product

PM2 wrapper=3.232*PM2 saleable product

roundels=1.31918*PM2 saleable product

POWER (Calculation results)

Codes: power, Combination

Values calculated per 1 t of PM2 saleable product

Weighted score: 610.115

Inputs:

Chemicals		
H2SO4	3.95836	kg
HCl, chem	1.08166	kg
NaOH	3.24621	kg
Energy		
electric power	0.335485	MWh
Fuels		
bark, HW	153.307	kg
bark, SW	0.388502	GJ
coal	261.297	kg
heavy fuel oil	1.46746	kg
TDS energy	7.96077	GJ
Water		
WC 80	5.91023	m3
WCC	37.4333	m3

Outputs:

Emissions to air			
CO	1.50085	kg	
CO2, fossil	580.53	kg	580.53
dioxin	0.0007961:	mg	
NOx	0.0017514(	kg	0.00535948
Particulates	1.81924	kg	3.63848
SO2	4.3216	kg	25.9296
VOC	0.0279173	kg	0.0111111
Energy			
electric power, Bleac	0.254229	MWh	
electric power, Chem	0.0752372	MWh	
electric power, PM1	0	MWh	
electric power, PM2	1.6466	MWh	
electric power, Pulp		1.89607	MWh	
COOK,HW	1.02941	MWh	
COOK,SW	0.86666	MWh	
electric power, Reco	2.40325	MWh	
electric power, total	5.30747	MWh	
electric power, Wooc	0.0428529	MWh	
WOODYARD,HW	0.0242107	MWh	
WOODYARD,SW	0.0186422	MWh	
Solid wastes			
waste, ash	85.2761	kg	
Water			
Effluent	4.2672	m3	
Hotwell	63.3414	m3	

Equations:

Chemicals

H2SO4=0.74581*electric power, total
HCl, chem=0.2038*electric power, total
NaOH=0.61163*electric power, total

Emissions to air

CO=0.28278*electric power, total
CO2, fossil=109.38*electric power, total
dioxin=0.00015*electric power, total
NOx=0.00033*electric power, total
Particulates=0.34277*electric power, total
SO2=0.81425*electric power, total
VOC=0.00526*electric power, total

Energy

electric power=0.06321*electric power, total

Fuels

bark, HW=28.8852*electric power, total
coal=49.2319*electric power, total
heavy fuel oil=0.27649*electric power, total
TDS energy=1.49992*electric power, total

Solid wastes

waste, ash=16.0672*electric power, total

Water

Effluent=0.804*electric power, total
Hotwell=11.9344*electric power, total
WC 80=1.11357*electric power, total
WCC=7.05295*electric power, total

RECOVERY (Calculation results)

Codes: recovery, Combination

Values calculated per 1 t of PM2 saleable product

Weighted score: 1195.43

Inputs:

Chemicals		
CaO	21.0285	kg
NaSO4	40.1343	kg
Energy		
electric power	2.40325	MWh
Fuels		
Diesel	0.0300407	GJ
organic solids ex HW	0.546704	GJ
organic solids ex SW	0.474433	GJ
sasol gas	1.41191	GJ
Materials/Products		
black liquor ex HW c	4081.3	l
black liquor ex SW c	3388.54	l
Water		
WC80	1.00937	m3
WCC	81.1699	m3
WRF	6.54886	m3

Outputs:

Chemicals			
HCl, chem	0.25235	kg	
Na2S	97.3017	kg	
NaOH	299.355	kg	
Emissions to air			
CO	3.12423	kg	
CO2, biogenic	2191.62	kg	
dioxin	9.67309E-(	mg	
H2S	0.0600813	kg	
NOx	1.08146	kg	3.30928
Particulates	591.801	kg	1183.6
SO2	1.41191	kg	8.47147
VOC	0.120163	kg	0.0478247
Energy			
energy, inherent	7.96077	GJ	
Materials/Products			
white liquor	3004.07	l	
COOK,HW	1501.57	l	
COOK,SW	1502.5	l	
Water			
Effluent	3.66496	m3	
Hotwell	22.1099	m3	
WC45	58.4591	m3	
woodyard	1.20163	m3	

Equations:

Chemicals

CaO=0.007*white liquor
HCl, chem=8.40029E-005*white liquor
Na2S=0.03239*white liquor
NaOH=0.09965*white liquor
NaSO4=0.01336*white liquor

Emissions to air

CO=0.00104*white liquor
CO2, biogenic=0.72955*white liquor
dioxin=3.22E-013*white liquor
H2S=2E-005*white liquor
NOx=0.00036*white liquor
Particulates=0.197*white liquor
SO2=0.00047*white liquor
VOC=4E-005*white liquor

Energy

electric power=0.0008*white liquor
energy, inherent=0.00265*white liquor

Fuels

Diesel=1E-005*white liquor
sasol gas=0.00047*white liquor

Water

Effluent=0.00122*white liquor
Hotwell=0.00736*white liquor
WC45=0.01946*white liquor
WC80=0.000336*white liquor
WCC=0.02702*white liquor
woodyard=0.0004*white liquor
WRF=0.00218*white liquor

repulper (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Materials/Products		
PM1 Broke	0	kg
PM2 Broke	111.683	kg

Outputs:

Materials/Products		
broke	0.147896	t

Equations:

SEA (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Water

sea	30.637	m3

Outputs:

Equations:

SilvaCel (Calculation results)

Codes: Water,

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Materials/Products

chips, HW	0.123154	t

Outputs:

Equations:

WC45 (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Water

recovery	58.4591	m3

Outputs:

Water

bleach	3.64715	m3
cook,HW	10.6223	m3
cook,SW	12.9998	m3
Hotwell	22.824	m3
pm1	0	m3
pm2	12.1656	m3

Equations:

Water

Hotwell=0.390426*recovery

WC80 (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Water

cook,HW	14.2418	m3
cook,SW	6.752	m3

Outputs:

Water

bleach	9.01574	m3
cook,HW	1.26714	m3
cook,SW	1.0668	m3
power	5.91023	m3
recovery	1.00937	m3

Equations:

WCC (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Water

Hotwell	87.5028	m3
WRF	25.8412	m3

Outputs:

Water

bleach	4.16185	m3
chemical	37.3744	m3
cook,HW	5.73063	m3
cook,SW	2.07988	m3
pm1	0	m3
pm2	22.2033	m3
power	37.4333	m3
recovery	81.1699	m3

Equations:

Water

WRF=0.691413*chemical

WOODYARD,HW (Calculation results)

Codes: woodyard, bleached pulp

chips,HW changed from kg to ton

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Energy		
electric power	0.0242107	MWh
Fuels		
Diesel	0.15611	GJ
Materials/Products		
Euca	1.14982	t
Water		
Fibre H2O in	0.541095	m3
Recovery water	0.538065	m3

Outputs:

Fuels		
wood residuals	14.0379	kg
Materials/Products		
chips, HW	1.11008	t
SilvaCel	0.123154	t
Water		
Effluent	0.384031	m3
Fibre H2O (SilvaCel)	0.0900493	m3
Fibre H2O out	0.71944	m3
Hotwell	0.236746	m3

Equations:

Energy

electric power=0.02181*chips, HW

Fuels

Diesel=0.14063*chips, HW

wood residuals=12.6459*chips, HW

Materials/Products

Euca=1.0358*chips, HW

SilvaCel=0.110942*chips, HW

Water

Effluent=0.34595*chips, HW

Fibre H2O (SilvaCel)=0.08112*chips, HW

Fibre H2O in=0.48744*chips, HW

Fibre H2O out=0.6481*chips, HW

Hotwell=0.21327*chips, HW

Recovery water=0.48471*chips, HW

WOODYARD,SW (Calculation results)

Codes: woodyard, unbleached pulp

Bark, SW changed to GJ
Pine is changed to ton

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Energy		
electric power	0.0186422	MWh
Fuels		
Diesel	0.120204	GJ
Materials/Products		
Pine	0.99371	t
Water		
Fibre H2O in	1.07653	m3
Recovery water	0.414307	m3

Outputs:

Fuels		
bark, SW	0.388502	GJ
wood residuals	9.71264	kg
Materials/Products		
chips, SW	0.854752	t
Water		
Effluent	1.8962	m3
Fibre H2O pulp	1.30233	m3
Hotwell	0.182293	m3

Equations:

Energy
electric power=0.02181*chips, SW
Fuels
bark, SW=0.45452*chips, SW
Diesel=0.14063*chips, SW
wood residuals=11.3631*chips, SW
Materials/Products
Pine=1.16257*chips, SW
Water
Effluent=2.21842*chips, SW
Fibre H2O in=1.25946*chips, SW
Fibre H2O pulp=1.52364*chips, SW
Hotwell=0.21327*chips, SW
Recovery water=0.48471*chips, SW

WRF (Calculation results)

Codes:

Values calculated per 1 t of PM2 saleable product

Weighted score: 0

Inputs:

Miscellaneous		
raw water	33.2212	kg

Outputs:

Water		
chemical	4.01428	m3
recovery	6.54886	m3
WCC	25.8412	m3

Equations:

Miscellaneous
raw water=1.28559*WCC

****** SUMMARIES ******

SUMMARY OF Entire system

Values calculated per 1 t of PM2 saleable product

Impact assessment method: Eco-indicator 95

Variable:	Inputs:	Outputs:	Unit:	Weighted score:
Chemicals				
AgNO3	0.000222595		kg	
alum	11.0808		kg	
Biocide	0.798379		kg	
CaO	21.0285		kg	
Cl2		5.19896	kg	
ClO2		0.0212751	kg	
CO2, chem	2.2487		kg	
flocculants	5.34457		kg	
H2O2	0.393596		kg	
H2SO4	20.3547	2.54716	kg	
HCl, chem	1.08166	13.572	kg	
MgSO4	0.000222595		kg	
N2, chem	0.559382		kg	
Na dichromate	0.0787987		kg	
Na2CO3	0.229273		kg	
Na2S	0.0699349	97.3017	kg	
Na2SO3	0.00868121		kg	
NaClO3	4.13604	48.0933	kg	

NaOCl		6.03634	kg	
NaOH	20.231	299.355	kg	
NaSO4	40.1343	20.6482	kg	
O2, chem	3.13322		kg	
rosin size	13.5501		kg	
S, chem	1.39189		kg	
SO2, chem	9.13329		kg	
talc	3.32474		kg	
Emissions to air				
CH4	1.00168		kg	0
Cl2, air		1.40636	kg	
ClO2, air		0.00556488	kg	
CO		4.62507	kg	
CO2, biogenic		2191.62	kg	
CO2, fossil		580.53	kg	580.53
dioxin		0.000796121	mg	
H2S		0.0601096	kg	
NOx		1.08322	kg	3.31464
Particulates		593.62	kg	1187.24
SO2	3.36802	8.35279	kg	50.1168
VOC		0.154641	kg	0.061547
Emissions to water				
AOX		2.90794	kg	
BOD		149.652	kg	
COD		119.588	kg	5.26187
Fe2+, water		0.4501	kg	
heavy metals, water		11.2341	g	
P, tot		521.302	kg	3190.37
SO4, water		148.075	kg	
sulfide		8.82272	kg	
TDS		1342.61	kg	
TSS		41.6171	kg	
Energy				
electric power	0.335485		MWh	
electric power, total		5.30747	MWh	
Fuels				
bark, HW	153.307		kg	
coal	261.297		kg	
Diesel	0.343627		GJ	
heavy fuel oil	1.46746		kg	
sasol gas	1.41191		GJ	
wood residuals		23.7505	kg	
Materials/Products				
cat. starch	43.7754		kg	
Deckle loss		0.0608058	t	
defoamers	2.79591		kg	
dispergent	6.559		kg	
Euca	1.14982		t	
glues	0.0132		kg	
optical brightener	0.933776		kg	
Pine	0.99371		t	
PM1 Wrapper		0	kg	
resin	0.0100168		kg	
turpentine		0.657169	kg	
Miscellaneous				
Baling Wire	0		kg	
Core Plugs	0.255811		ea	
inner discs	1.25322		unit	
PM2 wrapper	3.232		kg	
roundels	1.31918		unit	
Resources				
salt rock	46.1589		kg	
Solid wastes				
waste, ash		85.2761	kg	
Waste, baling wire		0	kg	
waste, organic		63.6594	kg	
Water				
Fibre H2O (SilvaCel)		0.0900493	m3	
Fibre H2O in	3.30276		m3	
Fibre H2O out		0.732141	m3	
Fibre H2O pulp		1.30233	m3	
Hotwell		0.419039	m3	
Recovery water	0.952372		m3	
total	63.5734		m3	
woodyard		1.20163	m3	
				5016.89

Appendix Eleven

Inventory Calculation Results
For Finnish Pulp and Baycel

SUMMARY OF Entire system				**SUMMARY OF Entire system**			
Values calculated per one bone-dry tonne of HW kraft (FINNISH)				**Values calculated per 1 t of PM1 saleable product**			
Impact assessment method: Eco-indicator 95				Impact assessment method: Eco-indicator 95			
Variable:	**Inputs:**	**Outputs:**	**Unit:**	**Variable:**	**Inputs:**	**Outputs:**	**Unit:**
Chemicals				**Chemicals**			
				AgNO3	0.000461115		kg
				alum	0		kg
				Biocide	0		kg
CaO	9		kg	CaO	21.7739		kg
				Cl2		10.7699	kg
				ClO2		0.0440722	kg
CO2, chem	0		kg	CO2, chem	0		kg
EDTA	0		kg				
				flocculants	0.33431		kg
H2O2	4		kg	H2O2	0.815351		kg
H2SO4	27		kg	H2SO4	38.0645	5.27654	kg
				HCl, chem	1.11999	27.8535	kg
methanol	2.7		kg	methanol	2.07502		kg
MgSO4	2		kg	MgSO4	0.000461115		kg
N, chem	0.29		kg	N2, chem	1.15878		kg
				Na dichromate	0.163235		kg
				Na2CO3	0.474949		kg
				Na2S	0.0724148	100.751	kg
				Na2SO3	0.0179835		kg
NaCl	0.5		kg				
NaClO3	32		kg	NaClO3	8.56799	34.0832	kg
				NaOCl		12.5045	kg
NaOH	32		kg	NaOH	17.8727	309.967	kg
				NaSO4	41.557	42.7735	kg
O2, chem	20		kg	O2, chem	6.49061		kg
O3, chem	0		kg				
				rosin size	0		kg
				S, chem	2.88336		kg
SO2, chem	2		kg	SO2, chem	0		kg
talc	5		kg	talc	6.88733		kg
Emissions to air				**Emissions to air**			
				Cl2, air		2.91333	kg
				ClO2, air		0.0115279	kg
CO		0.3	kg	CO		4.78901	kg
CO2, biogenic		2520	kg	CO2, biogenic		2269.31	kg

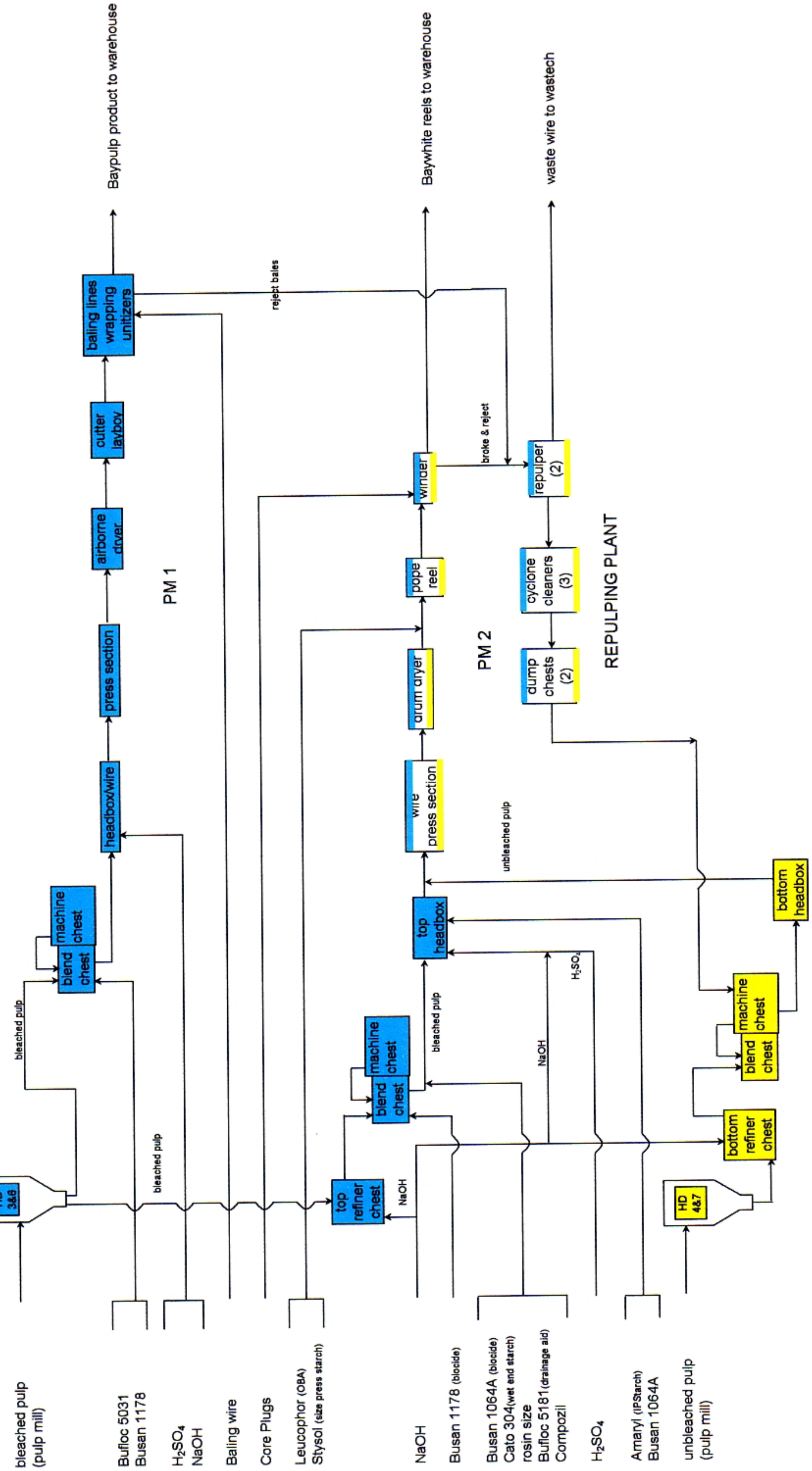
CO2, fossil		110	kg	CO2, fossil		601.111	kg
				dioxin		1.00E-09	kg
				H2S		0.0622461	kg
NOx		2.52	kg	NOx		1.12159	kg
				Particulates		614.663	kg
SO2		1.57	kg	SO2	6.977	11.3627	kg
				VOC		0.200905	kg
TRS		0.5	kg				
TSP		1.37	kg				
Emissions to water				**Emissions to water**			
AOX		0.22	kg	AOX		2.50023	kg
BOD		1.3	kg	BOD		106.057	kg
COD		23	kg	COD		84.7508	kg
N, tot		0.26	kg				
				Fe2+, water		0.318981	kg
				heavy metals, water		7.96149	g
P, tot		0.045	kg	P, tot		369.441	kg
				SO4, water		104.939	kg
				sulfide		6.25257	kg
				TDS		951.492	kg
TSS		2.5	kg	TSS		17.8946	kg
Energy				**Energy**			
electric power		0.192	MWh	electric power, total		3.50228	MWh
				electric power	1.25056		MWh
Fuels				**Fuels**			
				Bark, imported	1.26993		GJ
				Coal energy	7.44042		GJ
				Diesel	0.403931		GJ
heavy fuel oil	36		kg	Heavy fuel oil energy	0.0653526		GJ
				sasol gas	1.46196		GJ
				wood residuals		29.0801	kg
Materials/Products				**Materials/Products**			
				cat. starch	0		kg
				Deckle loss		0	t
				defoamers	1.16899		kg
				dispergent	12.5986		kg
				Euca	2.38189		t
				glues	0		kg
				optical brightener	0		kg
				Pine	0		t
				PM1 Wrapper		9.5	kg
tall oil		15	kg				

				resin	0.0207502		kg
turpentine		0	kg	turpentine		0	kg
Resources				**Resources**			
birch	2430		kg	salt rock	95.6201		kg
Solid wastes				**Solid wastes**			
waste, ash		5.44	kg	waste, ash		88.2995	kg
waste, ind		23	kg	waste, organic		116.425	kg
				Miscellaneous			
				Baling Wire	3.77523		kg
				Core Plugs	0		ea
				inner discs	0		unit
				PM2 wrapper	0		kg
				roundels	0		unit
				Water			
				Fibre H2O (SilvaCel)		0.186541	m3
				Fibre H2O in	2.38167		m3
				Fibre H2O out		1.49725	m3
				Fibre H2O pulp		0	m3
				Hotwell		0.490429	m3
				Recovery water	1.11462		m3
				total	45.0538		m3
				woodyard		1.24422	m3

Appendix Twelve

Paper Machines

Paper Machine Process Overview



PAPER MACHINES

INPUTS

Weeks Description	Unit	11–14 March	15–18 April	19–23 May	24–27 June	28–32 July	33–36 August	Total	Source
PM 1									
Bleached Kraft Pulp	BD ton	25682.70	25426.60	35768.80	24518.70	30113.70	28020.90	169531.40	
Bufloc 5031	kg	11650.00	3500.00	10750.00	4250.00	1000.00	4800.00	35950.00	Item No. 80.0002.0222, Item Ledger, Stores
Baling Wire	ton	154.00	75.00	die	91.00	84.00	95.00	597.00	Item No. 80.0002.0023, Item Ledger, Stores
energy & steam	MWh	33040	33040	41300	33040	41300	33040	214760.00	
PM 2									
Core Plugs(paper spiral round)	each	4928.00	1236.00	6156.00	3708.00	4932.00	3696.00	24656.00	Item No. 95.0001.0312, Item Ledger, Stores
Leucophor (OBA)	ton	19.00	13.00	16.00	12.00	17.00	13.00	90.00	Item No. 80.0002.0610, Item Ledger, Stores
Starch Geltron 24 Cationic	ton	150.00	80.00	98.00	110.00	126.00	55.00	619.00	Item No. 90.0002.9848, Item Ledger, Stores
NaOH	ton	145.20	133.70	139.60	85.30	231.50	216.20	951.50	
Biocide Busan 1178	ton		6.00		5.00		5.00	16.00	Item No. 80.0002.0210, Item Ledger, Stores
Biocide Busan 1009	kg						5000.00	5000.00	Item No.80.0002.0212, Item Ledger, Stores
Biocide Busan 1379	kg	5050.00	10050.00	5000.00	27800.00	8050.00		55950.00	Item No. 80.0002.0056, Item Ledger, Stores
Starch Cato 304 Cationic	ton		49.00	14.00	34.00		34.00	131.00	Item No. 90.0002.9830, Item Ledger, Stores
Alum (Aluminium Sulphate)	ton	78.00	190.00	164.00	307.00	71.00	258.00	1068.00	Item No. 80.0002.0124, Item Ledger, Stores
Bufloc 5181	ton	1.00	2.00	3.00	6.00	7.00	6.00	25.00	Item No. 80.0002.0223, Item Ledger, Stores
Busperse 59LO(dispergent)	ton	5.00	9.00	10.00	11.00	5.00	6.00	46.00	Item No. 80.0002.0224, Item Ledger, Stores
Compozil EKA NP 780(flocculant)	kg	42000.00	75150.00	101300.00	53550.00	112350.00	100800.00	485150.00	Item No. 80.0002.0700, Item Ledger, Stores
Supersize (fortified rosin)	ton	265.00	258.00	116.00	271.00	164.00	232.00	1306.00	Item No. 80.0002.0716, Item Ledger, Stores
H2SO4								0.00	
Starch IPS	ton	319.00	294.00	328.00	362.00	296.00	325.00	1924.00	Item No. 80.0002.0832, Item Ledger, Stores
Starch Systol 70	kg	274700.00	180900.00	315200.00	285450.00	271771.00	217200.00	1545221.00	Item No. 80.0002.0834, Item Ledger, Stores
Unbleached pulp	BD ton	6498.00	6704.10	6027.30	5958.90	5903.10	5564.70	36656.10	Mervin Odayor, Pulp Mill, see e-mail
bleached pulp	BD ton	6133.32	5364.36	11808.36	10089.09	4507.47	11977.65	49880.25	
Energy & steam	MWh	24416	24416	30520	24416	24416	30520	158704.00	
water	m^3							**4613140.0**	
WCC PM's	m^3	345772	352128	406245	357784	373765	290584	2126278.00	Mill water Balance
WCC heat ex.		263676	261912	221900	177520	226800	120316	1272124.00	
WC45	m^3	189336	180180	261345	161252	254485	168140	1214738.00	Mill water Balance

OUTPUTS

Weeks Description	Unit	11–14 March	15–18 April	19–23 May	24–27 June	28–32 July	33–36 August	Total	Source
PM1									
PM 1 saleble production	ADT	27410.00	27128.00	38888.00	25760.00	31670.00	30122.00	180978.00	Raymond
PM 1 saleble production moisture content	%							10.00	
PM 1 saleble production	BD ton	24669	24415.2	34999.2	23184	28503	27109.8	162880.20	
PM1 Reject Bales to repulper	adt	735.00	530.00	258.00	1112.00	1320.00	596.00	4551.00	Raymond
PM1 Reject Bales to repulper	BD ton	661.50	477.00	232.20	1000.80	1188.00	536.40	4095.90	
PM1 Wrapper	ADT	264.00	240.00	376.00	204.00	324.00	312.00	1720.00	
PM1 Wrapper	BD ton	237.60	216.00	338.40	183.60	291.60	280.80	1548.00	
Fibreloss from PM1 to effluent	ton	114.60	318.40	199.00	150.30	131.10	93.90	1007.30	
Scrap Baling Wire	kg	4800.00	1750.00	2250.00	500.00	3400.00	4200.00	16900.00	Scrap Metal Removed From Site, Technical Report, Page
PM2									
PM2 saleble production	ton	14117.00	13915.00	19378.00	15040.00	19760.00	16131.00	98341.00	PM 2 - Monthly Operating Report - KraftLiner Machine
PM2 product moisture content	%							7.50	
PM2 total production	BD ton	13058.23	12871.38	17924.65	13912.00	18278.00	14921.18	90965.43	
PM2 deckle loss	ton	1088.00	630.00	1453.00	1293.00	1027.00	845.00	6336.00	
PM2 deckle loss	BD ton	1006.40	582.75	1344.03	1196.03	949.98	781.63	5860.80	
PM2 Broke to repulper	ton	1634.00	2166.00	2245.00	1954.00	1770.00	1214.00	10983.00	

PM2 Broke to repulper	BD ton	1511.45	2003.55	2076.63	1807.45	1637.25	1122.95	10159.28
PM2 gross production	BD ton	15576.08	15457.68	21345.30	16915.48	20865.23	16825.75	106985.50
PM2 fibre loss	BD ton	763.9	482.7	536.7	164.6	179.6	316.3	2443.8
VOC	kg							9100
water	m^3							**2765490.0**
effluent	m^3	189336	180180	261345	161252	254485	168140	1214738.00
WCC PM ret.	m^3	280168	318976	282415	267876	222705	178612	1550752.00

unbleached pulp to PM2	BD kg/s	BD ton
mar	33.28	71953.83
apr	27.40	57448.03
may	23.78	53551.21
jun	25.46	55290.83
jul	28.25	59203.74
aug	25.12	62892.16
		360339.80

Appendix Thirteen

Energy Balance Calculations

For the production of Baycel

Power supplied to *Recovery Process*	2.488	MWh
Energy supplied to *Power* plant from *Recovery*	8.24297	GJ

1 MWh = 3.6 GJ………..Eskom information

therefore:

Energy supplied to Recovery Process	8.9568	GJ

For the production of Baywhite

Power supplied to *Recovery Process*	2.40325	MWh
Energy supplied to *Power* plant from *Recovery*	7.96077	GJ

1 MWh = 3.6 GJ………..Eskom information

therefore:

Energy supplied to Recovery Process	8.6517	GJ

Appendix Fourteen

Effluent Plant

EFFLUENT

INPUT

Weeks		11--14	15--18	19--23	24--27	28--32	33--36		Source
Description	unit	march	april	may	june	july	august	total	
waste, water	m^3								
effluent to sea	m^3/adt	55	62	48	58	55	50	328	Effluent discharged to sea, Technical Monthly Production Reports

OUTPUT

Weeks		11--14	15--18	19--23	24--27	28--32	33--36		Source
Description	unit	march	april	may	june	july	august	total	
BOD	mg/l	241	282	567	347	467	450	2354	
Iron as Fe	mg/l	1.68	0.95	0.73	1.57	1.25	0.9	7.08	
Magnesium as Mg	mg/l	37	20	22	29	23	29	160	
Mangenese as Mn	mg/l	2.65	1.63	1.75	2.11	1.92	1.89	11.95	
Sulphate as SO4	mg/l	416	464	473	388.2	334	254	2329.2	
Sulphide as S	mg/l	2.34	3.74	0.48	5.52	14.7	112	138.78	
TDS	mg/l	3746	3688	3517	3520	3338	3310	21119.00	Effluent Analysis Report. Na4, Ciska, Mhlatuzi water effluent report
Zinc as Zn	mg/l	0.21	0.16	0.36	0.19	0.05	0.16	1.13	Effluent Analysis Report. Na4, Ciska, Mhlatuzi water effluent report
TSS	kg/adt	14.8	16.7	9.4	12	19	12	83.90	Effluent discharged to sea, Technical Monthly Production Reports
COD	kg/adt	112	121	72	118	126	68	617.00	Effluent discharged to sea, Technical Monthly Production Reports
AOX: classic	kg/adt	1.4	1.8	1.7	1.4	0.76	1.412	8.47	Effluent discharged to sea, Technical Monthly Production Reports
AOX: ECF	kg/adt	1.1	0.8	0.7	0.9	0.56	0.812	4.87	Effluent discharged to sea, Technical Monthly Production Reports
$NaClO_3$	mg/l	110	103.3	223	118.9	80.7	120.6	756.50	Effluent discharged to sea, Technical Monthly Production Reports
PO_4	mg/l	1.2	1.3	1.5	1.7	1.6	0.9	8.20	Effluent discharged to sea, Technical Monthly Production Reports
chromium as Cr	mg/l	0.6575	0.4	0.828	0.6051	0.27	0.87	3.6306	