AN INVESTIGATION OF CLEANER PRODUCTION OPPORTUNITIES IN THE SOUTH AFRICAN COAL MINING INDUSTRY

By

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SYNOPSIS

The coal mining and processing industry in South Africa is responsible for significant local and regional environmental impacts, most notably those on water quality. As a result, legislation is becoming more stringent, public concerns are increasing and mine rehabilitation costs, which are incurred by the mining companies, are increasing. In response to this, the coal mining industry is recognising the importance of proper environmental management. However, the focus is still largely on end-of-pipe solutions. Cleaner Production (CP), which is a continuous preventative approach to environmental issues, has been demonstrated to be a cost-effective means of reducing wastes, increasing process efficiencies and improving the resource utilisation of coal mines in several countries, as well as of certain South African industries. It is therefore expected that Cleaner Production can provide the South African coal mining industry with an efficient, cost-effective approach to minimising its environmental footprint, and to meeting present and future legislation. This thesis aims to investigate whether this is in fact the case, by investigating and proposing feasible CP interventions for the coal mining industry. As part of the Water Research Commission initiated project to introduce Cleaner Production to the mining industry, the thesis ultimately seeks to promote the adoption of CP in this sector by providing examples of Cleaner Production opportunities.

To this end, CP assessments were carried out at three representative case study collieries. The procedure utilised followed the five generally accepted phases: *planning and organisation, pre-assessment, detailed assessment, feasibility assessment* and *implementation and monitoring*. In the planning and organisation phase a small project team was set up to ensure the continuation of CP after the completion of this thesis. The outcome of the pre-assessment phase, designed to identify the wastes on which to focus in the remainder of the assessment, is that at all three collieries the slurry, discards and energy wastages should constitute the focus areas. There were, however, significant differences in performance of the three collieries in terms of waste generation and resource utilisation. There are therefore opportunities for the mines to learn from, and benchmark against each other. This points towards the value of Cleaner Production Forums, which provide a framework in which knowledge sharing can occur.

In the detailed assessment phase, more comprehensive analyses where conducted through literature surveys, sampling and laboratory test-work, walk-through audits and brainstorming sessions in order to generate potential Cleaner Production ideas to reduce the three focus wastes. These ideas were then submitted to feasibility assessments to eliminate any options that are not environmentally preferable *and* financially favourable *and* technologically viable. Through this process, feasible Cleaner Production interventions could be identified for the case study collieries. The final phase, which involves the actual implementation and monitoring of the progress, is largely the responsibility of the mines concerned. However, methods are suggested to overcome the

various barriers that are likely to hinder the implementation of Cleaner Production interventions in the coal mining industry.

The assessments identified numerous feasible Cleaner Production opportunities available to reduce the amount of slurry, discards and energy wasted at the three case study collieries. Many of these options are expected to reduce the mines' impacts on the quality of the water in the region. None of the options proposed involves the use of unproven technologies. For the options that require high capital investments (i.e. investments in excess of R1 million), payback times were found to be less than one year, and the 10-year net present values ranged between R10 million and R200 million.

Most of the proposed options are applicable to all three collieries. Since the case study collieries are relatively representative of the industry, it can be concluded that there are in fact opportunities available to implement cost-effective Cleaner Production interventions in the South African coal mining industry. More specifically, it can be concluded that there are opportunities to implement Cleaner Production interventions also in other collieries, combining jointly to a significant potential to reduce the industry's impacts on the quality of water. However, the industry will only be able to fully embrace the Cleaner Production approach once several economic, technological, managerial and legislative barriers have been overcome. Co-operation, a change of company policies and innovation are required by the coal mining industry, coal utilisation industries, government and minerals tertiary institutions to overcome these barriers.

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LIST OF ABBREVIATIONS

AMD	Acid Mine Drainage
CP	Cleaner Production
CPF	Cleaner Production Forum
CSIR	Council for Scientific and Industrial Research
CV	Calorific Value
CWS / CWF / CWM	Coal-Water Slurry / -Fuel / -Mixture
DMC	Dense Medium Cyclone
DME	Department of Minerals and Energy (South Africa)
DWA	Digby Wells and Associates
EC	Electrical Conductivity
FOB	Free-on-Board
FTP	Feed-to-Plant
HVAC	Heating, Ventilation and Air Conditioning
IM	Inherent Moisture
ISO	International Standards Organisation
LCA	Life-Cycle Assessment
LSF	Low Smoke Fuel
NAR	Net-as-Received
NPV	Net Present Value
R	Rand (South African currency [ZAR])
ROM	Run-of-Mine
SA	South Africa
TDS	Total Dissolved Solids
TM	Total Moisture
UCT	University of Cape Town
UKZN	University of KwaZulu-Natal
VSD	Variable Speed Drive
WERM	Waste Energy Recovery and Management
WRC	Water Research Commission

GLOSSARY

Air-dry	Excludes surface moisture but includes inherent moisture
As-Received CV	The calorific value of coal as is, and includes total moisture
Ash	Incombustible matter found in coal
Beneficiation	Washing the coal to remove the ash
Calorific Value	Specific energy content of the coal
Classification Cyclone	Gravity separation unit that classifies coal based on size
Coal-washing Plant	The section of the mine where the coal is washed
Coarse Coal	The largest size fraction of coal, often > 25mm
Co-disposal	Disposing the slurry in a dam built from discards, also referred to as a slurry dam
Dense Medium Drum	Coarse coal washing unit
Dense Medium Cyclone	Intermediate coal washing unit
Discards	The high ash coal waste that is separated from the product coal in the coal-washing plant
Eskom	South Africa's main electricity supplier
Feed-to-plant	Crushed coal that is fed to the washing plant
Fine Coal	Coal that is often between 0.15 and 1 mm in diameter
Flotation	A separation technique that separates the valuable carbon-rich particles from the ash-rich particles based on their differing surface properties.
Free-on-Board Price	The price as at the port before being loaded for shipment
Inherent Moisture	The natural inherent or bed moisture of coal
Intermediate Coal	Coal that is typically between 1 and 25 mm in diameter
ISO 14000	A series of standards covering a number of environmental issues ISO 14001 is related to environmental management systems
Run-of-Mine	Mined coal that has not yet been crushed, processed or treated
Seam	A bed of coal lying between a roof and floor of rock
Slurry	A mixture of process water and ultra-fine coal
Spirals	Fine coal washing units
Total Moisture	Inherent moisture plus water adhering to the coal surface (surface moisture)
Ultra-fine Coal	Coal that is typically smaller than 0.15 mm in diameter
Variable Speed Drive	Device used to regulate the speed of motors
Waste	Any solid, liquid or gaseous substance that is perceived to have no value by those who produce it
Yield	The percentage of feed coal that is sold as product (where product includes any coal by-products)

CHAPTER 1

INTRODUCTION

1.1. Background

The South African economy depends heavily on coal, both as a source of foreign income and as a primary energy source. This dependence, coupled with South Africa's extensive coal reserves, indicates that the coal mining industry is likely to continue to be prominent in the near future. The industry, however, impacts significantly on the environment, particularly on the quality of water. In response to this, legislation is becoming more stringent, public concerns are increasing and mine rehabilitation costs, which are incurred by the mining companies, are increasing. This indicates a need for the industry to improve production efficiencies, reduce resource consumption and reduce waste generation. The potential for using Cleaner Production (CP) to achieve this is investigated in this thesis.

1.1.1 Cleaner Production in the context of the mining industry

Since the coal mining industry involves certain processes that will unavoidably cause environmental degradation, such as erosion, deforestation and sedimentation, and since their location is based upon geologically fixed ore deposits, rather than on the sensitivity of the environment, it is necessary to clarify the term Cleaner Production for the mining industry. Hilson (2003) argues that, despite not being able to completely eliminate environmental impacts, the mining industry can achieve Cleaner Production by continuously implementing physical, managerial and policy-making changes to minimise its impacts until complete reclamation of the mine. Hilson (2000) proposes that Cleaner Production practices in the mining context are those that reduce the quantity of wastes generated, improve production efficiency or put the mine into a better position to achieve the aforementioned practices. The latter includes training, improved management practices, monitoring, etc. Since improving production efficiency and reducing raw material consumption both bring about a reduction in wastes, Cleaner Production in the context of the mining industry can therefore be viewed as a continuous preventative environmental approach with the ultimate goal of reducing wastes at source. This definition of Cleaner Production, which can be applied to processes, products and services (www.uneptie.org) and therefore differentiates itself from 'waste minimisation', has been used in this thesis as it relates specifically to the mining industry. There are many other, albeit similar, definitions of Cleaner Production but it is outside the scope of this thesis to undertake a comprehensive analysis of Cleaner Production terminology. Similarly, there are many definitions of the term 'waste'. For the purposes of this thesis, 'waste' refers to any solid, liquid or gaseous emission that is considered to have no value by those who produce it.

Cleaner Production can be achieved at physical, managerial and legislative levels (Hilson, 2003) via 5 techniques that are shown in the following figure:

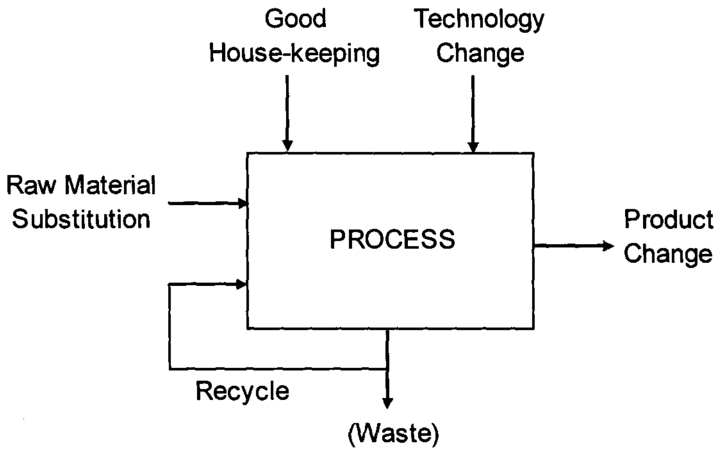

Figure 1: The 5 key CP techniques; *Source: UNEP, 1994*

Good house-keeping, raw material substitution, technology change, product change and internal recycling are the five generally accepted techniques of achieving Cleaner Production. Product change incorporates resource use optimisation (van Berkel, 2004) or any modifications to the products. Good house-keeping involves improvements in operational procedures and management, such as training and monitoring. Technology changes include improved process automation and substitution. Internal recycling includes any raw material re-use or recycling that occurs on-site. Since the concept of Cleaner Production seeks to reduce waste emissions, the costs associated with the waste (i.e. disposal, raw materials, energy, labour, water, transport, clean-up, storage, management time, etc.) are also reduced. Thus, Cleaner Production brings about reductions in costs, as well as environmental impacts.

Several other authors agree that Cleaner Production is considered the 'latest in a series of successive environmental management paradigms' (Hilson, 2003). The development of these waste management strategies is shown in the following figure.

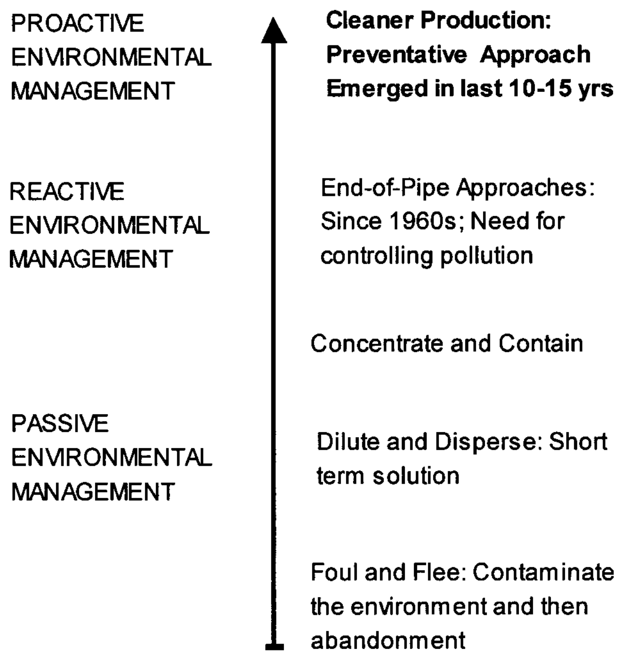

Figure 2: History and evolution of CP; *Source: Modified from EEA (2002)*

Cleaner Production is viewed as a proactive strategy, focusing on prevention, rather than 'end of pipe' waste management.

1.1.2 Status of Cleaner Production in SA mining industry

There are some documented examples of implemented Cleaner Production interventions in the coal mining industry in South Africa. However, there is little evidence to suggest that systematic, intentional Cleaner Production assessments have been conducted extensively in the South African coal mining industry.

A study conducted by Marr et al. (2004), involving interviews with 62 engineers from the South African mining sector, determined that the concept of Cleaner Technology, i.e. the technological aspect of Cleaner Production, 'has not yet been well disseminated to process designers of minerals processing and metals refining plants'. However, a 'widespread recognition of the importance of environmental considerations in design' was noted. These engineers also assert that the focus of waste disposal in this industry has been on 'end of pipe' treatment, but that this is changing. Another perspective that emerged from this study is that the mining industry does not wish to 'be the guinea pig' for new technologies, thereby hindering the acceptance of newer Cleaner Technologies in the industry.

According to another study, (Dama et al., 2005) surveying SA mining industry environmental representatives, 'the mining industry is improving its practices and taking the environmental impacts into consideration in project decisions and for operations'. However, South African mining company decisions are based primarily on capital and operating costs, followed by other criteria such as health, safety and the environment (Dama et al., 2005). Therefore, Cleaner Production interventions that bring about financial as well as environmental benefits are more likely to be implemented than those without financial benefits. It was also noted that distinct differences between small and larger mining corporations exist. The larger companies generally seek to obtain ISO 14001 status, and their environmental awareness is driven by their own policies. The awareness of the smaller companies, however, is driven by government legislation (Dama et al., 2005).

1.1.3 Cleaner Production in practice

This section describes the experiences of Cleaner Production in other industries in South Africa, as well as experiences in the mining industry in other countries.

1.1.3.1 Cleaner Production successes

Cleaner Production has been successfully introduced to a number of manufacturing and processing industries in South Africa (e.g. Barclay, 2001; Buckley, 2006a; Hanks and Janisch, 2003; Kothuis, 2006a;). Most notable are the successes of the metal finishing and textiles industries. The Cleaner Production in the Metal Finishing Industry (CPMFI) Project, funded by the Royal Danish Ministry of Foreign Affairs (DANIDA) has achieved total annual savings in excess of R 3 million from 14 sites through the implementation of Cleaner Production interventions (Koefoed, 2004). Most of the sites are small and medium enterprises. The successful implementation of Cleaner Production interventions in the metal finishing industry is attributed to a number of factors, including awareness raising, financial subsidies, the financial benefits of implementing Cleaner Production, evidence of savings through case study examples, the encouragement of openness amongst the companies and the formation of a representative body for the industry, i.e. the South African Metal Finishing Association (van der Spuy, 2006).

In 1999 a waste minimisation club was launched in Hammarsdale, which is an industrial area located in KwaZulu-Natal, South Africa. The club comprised 8 companies, most of which are involved in the textiles industry. During the life of this club over 100 waste minimisation options were generated and proposed, of which 40 options are known to have been implemented by 2001 (Barclay, 2001). As a result, the companies achieved annual savings in excess of R10 million with a further R10 million identified but not implemented at the time of review (Barclay, 2001). Reductions in water and electricity consumption accounted for most of the savings. Therefore, the adoption of waste minimisation (an aspect of Cleaner Production) enabled the textiles industry to reduce its environmental impact as well as its costs. There are a number of factors that lead to the successful adoption of waste minimisation by the companies in the club. The introduction of new regulations, the training of the companies and the cost savings were some of the main contributors (Barclay, 2001).

In Australia the Cooperative Research Centre (CRC) has established the Cooperative Research Centre for Coal in Sustainable Development (CCSD). The vision of the venture is 'to optimise the contribution of coal to a sustainable future' (www.ccsd.biz). One of the project goals is to apply Cleaner Production principles and tools to the coal industry. Cleaner Production practices have been implemented at several mining and minerals processing companies (including collieries) in Australia that have resulted in both environmental and financial benefits (van Berkel, 2000b). Interventions at coal mines, such as mine methane mitigation, coal recovery optimisation and fuel efficiency improvements have been documented (van Berkel, 2004).

1.1.3.2 Cleaner Production Barriers for the mining industry

According to Hilson (2000), there are three types of barriers hindering the implementation of Cleaner Production in the mining industry: economic, technological and legislative.

Economic: There is often a lack of availability, or a difficultly in gaining access, to funds and generally only short-term goals are considered, especially in the smaller companies. There is a preference to implement end-of pipe technologies as they meet legislation and are often regarded as lower capital expenses compared with cleaner technologies. Environmental budgets are often relatively small, therefore obtaining project approval for environmental ventures, especially those requiring large capital investments, is often difficult.

Technological Problems: There is a lack of knowledge of Cleaner Technologies, as well as a lack of knowledgeable people to operate and maintain the Cleaner Technologies. Managers and staff personnel often have limited time to pinpoint areas in need of Cleaner Production, let alone identify possible interventions.

Legislation: The lack of relevant legislation and its continual changing hinders the implementation of Cleaner Production in the mining industry.

Another barrier, discussed by van Berkel (2000b), is the minerals processing profession's general lack of training with regards to incorporating environmental issues and Cleaner Production into their designs and processes.

1.1.4 Context in which the research is carried out

This thesis forms a part of a larger project commissioned by the Water Research Commission (WRC) entitled 'Introducing Cleaner Production technologies in the mining industry'. The project is lead by Digby Wells and Associates (DWA), and is conducted together with the University of Cape Town (UCT) Chemical Engineering Department, the University of KwaZulu-Natal (UKZN) Pollution Research Group, BECO -Institute for Sustainable Business, Andrew Barker - Development Consultant, Susan Barclay and Claire Jänisch. The project commenced in 2004 and has already conducted the scoping study of Cleaner Production in the mining industry (Dama et al., 2005).

The objectives of the WRC project are as follows:

- Conduct a scoping study of the mining industry to determine the level of implementation of Cleaner Production techniques.
- Identify the water-related threats on the environment by the mining industry.
- Introduce the concept of Cleaner Production Forums (CPF), which are groups of companies that meet and discuss any relevant Cleaner Production developments and information.
- Conduct Life-Cycle Assessments (LCA), which will be used as a tool to evaluate areas where Cleaner Production techniques are required.
- Raise awareness of the benefits of using Cleaner Production in the mining industry.
- Ensure future viability and sustainability of Cleaner Production initiatives.

This thesis fits in with the Cleaner Production Forums as well as the awareness raising aspect, aiming to provide examples of Cleaner Production opportunities that can be used to promote Cleaner Production both within the Forums, and in the mining industry as a whole. As part of this WRC project, a Cleaner Production Forum for the coal mining industry has been initiated and is facilitated by *BECO – Institute for Sustainable Business.* The Forum comprises environmental specialists from several of the coal mining companies in the Witbank region. Through this Forum, in which the author is actively involved, an increased understanding of the problems and barriers facing the coal mining industry has been gained and applied to this thesis where relevant.

1.2. Problem statement

The coal mining and processing industry in South Africa is responsible for significant environmental impacts, most notably its impacts on water quality. As a result, legislation is becoming more stringent, public concerns are increasing and mine rehabilitation costs, which are incurred by the mining companies, are increasing. In response to this, the coal mining industry is recognising the importance of environmental considerations in both design and operations. However, the focus is still largely on end-of-pipe solutions. Cleaner Production, which is a continuous preventative approach to environmental issues, has been demonstrated to be a cost-effective means of reducing wastes, increasing process efficiencies and improving the resource utilisation of coal mines in several countries, and of certain South African industries. There is therefore an opportunity to investigate the application of the Cleaner Production approach to the coal mining industry in South Africa.

1.3. *Objectives*

The objectives of this thesis are:

- To propose feasible Cleaner Production techniques that can be adopted by the South African coal mining industry
- To identify feasible Cleaner Production methods to reduce water consumption and contamination by the SA coal mining industry
- To identify the barriers that may hinder the adoption of Cleaner Production in the coal mining industry and to propose methods of overcoming these barriers
- To promote Cleaner Production in the coal mining industry by providing evidence that Cleaner Production interventions have the potential to be both environmentally and financially beneficial.

1.4. *Key Questions*

The key questions that this thesis shall address are:

- *Are there opportunities to implement economically feasible Cleaner Production interventions in the SA coal mining industry?*
- *If so, what is the nature of these options?*
- *What are the barriers that will hinder the adoption of Cleaner Production in the coal mining industry, and how can they be overcome?*

Based on the successful implementation of cost-effective Cleaner Production interventions in various industries in South Africa (Dama et al., 2005), and on the successful implementation of Cleaner Production at several collieries in various countries, such as Australia (e.g. van Berkel, 2004), it is hypothesised that there are several economically feasible Cleaner Production interventions that can be implemented in the South African coal mining industry. It is expected that several economic, technical and legislative barriers, as outlined in Section 1.1.3.2, will need to be overcome before Cleaner Production is extensively adopted by the industry.

1.5. *Scope and limitations*

The evidence gathered for this thesis is centred on three case study collieries. If these case study collieries are found to be typical of the industry, then the findings of the case studies can be assumed to be relevant to the industry as a whole.

In order to propose Cleaner Production interventions to implement in the SA coal mining industry, Cleaner Production assessments were carried out at the three case study collieries. The assessments were conducted at a level that allowed feasible opportunities to be identified, but it is not within the scope of this thesis to provide the detailed site-specific technological specifications that are often required prior to the implementation of highly sophisticated, complex technologies. Further in-depth investigations are therefore recommended where appropriate.

Options are only proposed if they are identified as being environmentally preferable *and* technically *and* economically feasible. Because the South African mining industry bases its decisions predominantly on capital and operating costs (Dama et al., 2005) it is unrealistic to assume that the industry will implement Cleaner Production interventions that are not economically feasible. For this reason economic feasibility has been included as a criterion for the proposed Cleaner Production options. The decision as to whether an option is environmentally preferable or not, is based on a general and informed understanding of the environmental impacts of an option throughout its life-cycle, rather than on detailed Life-Cycle Assessments (LCA). However, since Life-Cycle Assessments are a project unto themselves, they are considered outside the scope of this research.

The scope of the assessments is limited to the boundaries of the case study collieries. All mining operations, on-site coal preparation plants, offices, stores, garages and workshops that are within the colliery borders are considered within the scope of the Cleaner Production assessment. Transportation and utilisation of coal outside the collieries are therefore considered outside the scope of this thesis. However, external wastes that are a direct result of the coal mining industry, such as power station emissions caused by electricity consumed by the collieries, are also considered to some extent within this thesis. Cleaner Production incorporates the reduction of wastes generated during the life-cycle of a product (van Berkel, 2000a). However, since this thesis is limited to the colliery boundaries, this aspect of Cleaner Production is addressed to a limited extent. The decision as to whether an option is environmentally preferable, however, is determined by the impacts on the environment both within and outside the colliery borders.

The Cleaner Production assessments are limited to currently operating collieries. Since the wastes are generated during the operational lifetime of the collieries, prevention is most important during this phase. Abandoned mines have therefore not been considered in this thesis but it is understood that by preventing wastes in the operational phase the environmental impacts upon abandonments are greatly reduced.

1.6. Thesis structure

The structure of this thesis is outlined in Figure 3.

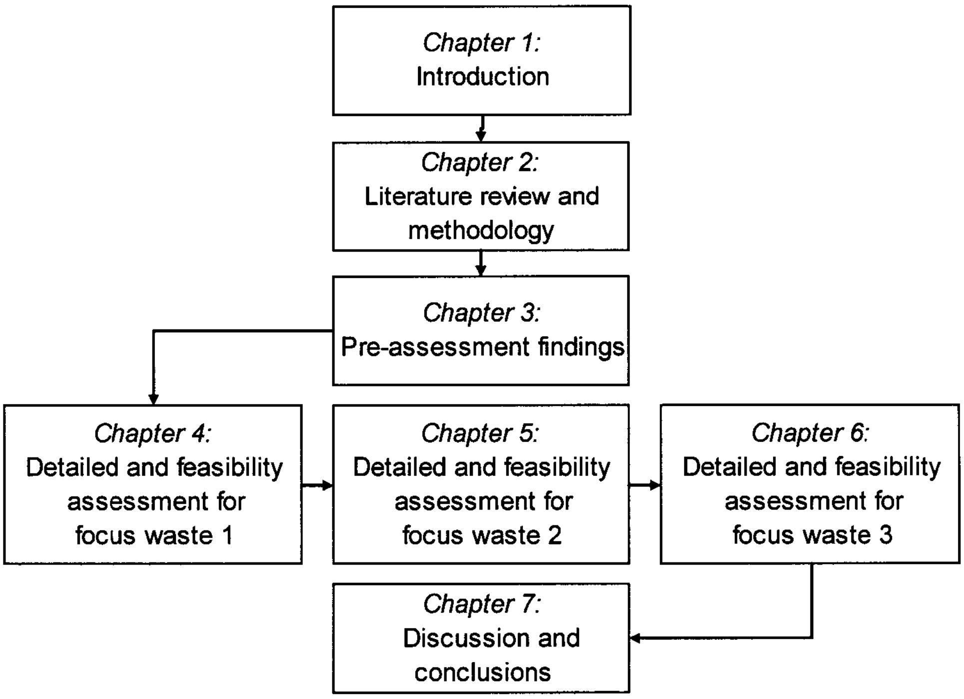

Figure 3: Thesis structure

Chapter 1 introduces the thesis and Chapter 2 is a review of relevant literature and ends with the details of the methodology used in this thesis. Chapter 3 presents the findings of the Cleaner Production pre-assessments, in which three focus colliery wastes are identified. In Chapters 4, 5 and 6 feasible Cleaner Production options are investigated for the respective focus wastes. The findings of the preceding chapters are discussed and conclusions are drawn in Chapter 7. References and appendices follow Chapter 7.

CHAPTER 2

LITERATURE REVIEW AND METHODOLOGY

This chapter presents a review of the South African coal mining industry, its environmental impacts and Cleaner Production initiatives related to this industry that have been undertaken to date. A description of the methodology used in this thesis is also discussed.

2.1. An overview of the SA coal mining industry

This section presents a brief overview of the South African coal mining industry.

2.1.1 The importance of coal to South Africa

Producing nearly 250 Mt of saleable coal a year, South Africa is the fifth largest producer and fourth largest exporter of coal in the world (IEA, 2005). Production of coal in South Africa has increased over the last 10 years, as is shown in Table 1. Approximately 50 % of this coal originates from open-cast operations with the remainder provided by underground collieries (www.info.gov.co.za).

Table 1: Production and sales statistics for SA coal (1995-2005); ***Source: DME, 2005c***

Year	Production (Mt)
1995	206.2
1996	206.4
1997	218.6
1998	224.9
1999	222.3
2000	224.1
2001	223.5
2002	220.2
2003	239.3
2004	242.8

South Africa relies heavily on coal as a source of energy, as over 60 % of the primary energy supply is coal (DME, 2005a), and roughly 90 % of electricity is generated from coal (Eskom, 2003). Owing to South Africa's growing electricity demands, the national electricity provider, Eskom, is de-mothballing three of its coal-fired power stations to increase its nominal capacity by 3800 MW, and is therefore in need of additional coal (www.miningweekly.co.za). Due to the increase in production and to its importance as an energy source, it is likely that coal mining will continue to be a prominent industry in South Africa in the near future.

2.1.2 Distribution of coal in South Africa

Up until recently, the country's coal reserves were estimated to be nearly 59 000 Mt. However, an investigation into the actual size of the coal reserves has revealed that around 29 000 Mt, or approximately half the original figure, is more realistic. These reserves are now expected to last until about 2050, which is significantly shorter than the original estimate of 250 years (Prevost, 2004). This places South Africa as the country with the sixth largest coal reserves in the world (BP, 2005). The reserves are predominantly distributed in the north-east of the country. The following figure displays the location of the various coalfields in South Africa.

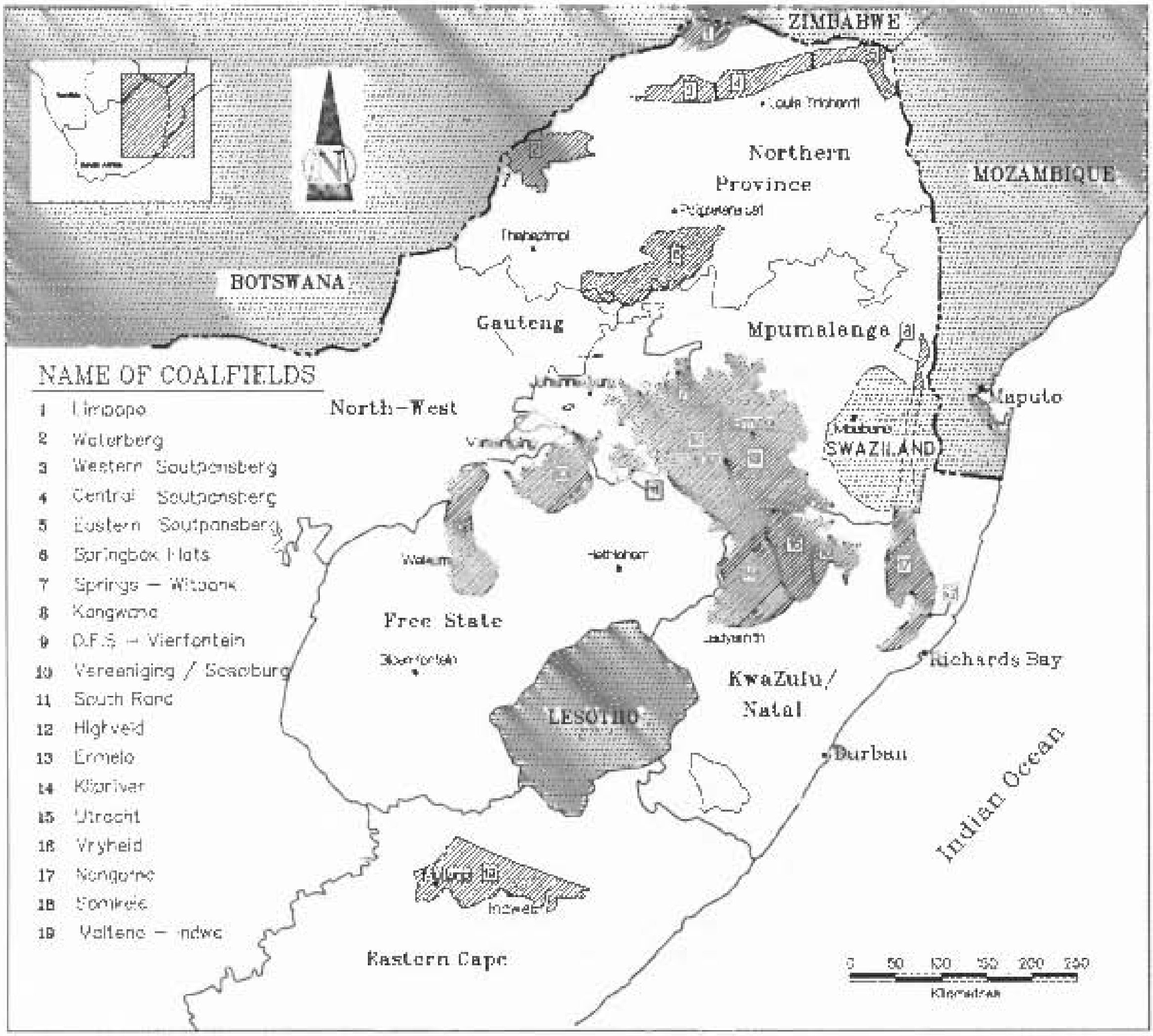

Figure 4: Coalfields of South Africa

The combined Witbank and Highveld coalfields produce more than 80 % of the total coal mined in South Africa (coaltech.csir.co.za). In this area there are 5 recognised coal seams, named 1-5, where 5 is the youngest. Seams 2 and 4 are most commonly mined at present, while seam 3 is rarely mined (DME, 2006). The characteristics of the coal differ from seam to seam. Seam 4 coal contains more near-density material than seam 2 coal, rendering it more difficult to process (de Korte, 2004a). The average calorific value of South African ROM coal lies between 18 and 26 MJ/kg (de Korte, 2000b).

2.1.3 Coal preparation in South Africa

Run-of-mine (ROM) coal, which refers to the unprocessed raw coal that is mined, is typically processed to increase its value. There are two types of processing that are used in South Africa. The first is screening, which involves separating the coal into various size fractions and selling the appropriate size fractions demanded by the market. Large foreign objects, such as metals and wood, are also removed. The second, more complex, processing type is 'coal washing'. Coal is washed in order to reduce the ash-content of the coal, where ash refers to the valueless, incombustible material that is found in coal. Therefore, decreasing the ash content increases the energy content, or calorific value, of the coal. Washing is required to increase the calorific value of the coal in order to meet product specifications that screening alone cannot achieve. The coal is typically washed using density separation techniques because of the differences in density of the ash and the valuable carbon in the coal. Washing also serves to reduce the sulphur content of the coal. South African unwashed coal is characteristically low in sulphur but high in ash. It is the ash and sulphur content that is required by the coal buyers that dictates the degree of washing, and therefore the amount of waste that is generated, in the process. The following figure illustrates the relative proportions of coal that are screened and washed, as well as the destinations of the run-of-mine (ROM) coal in 2002.

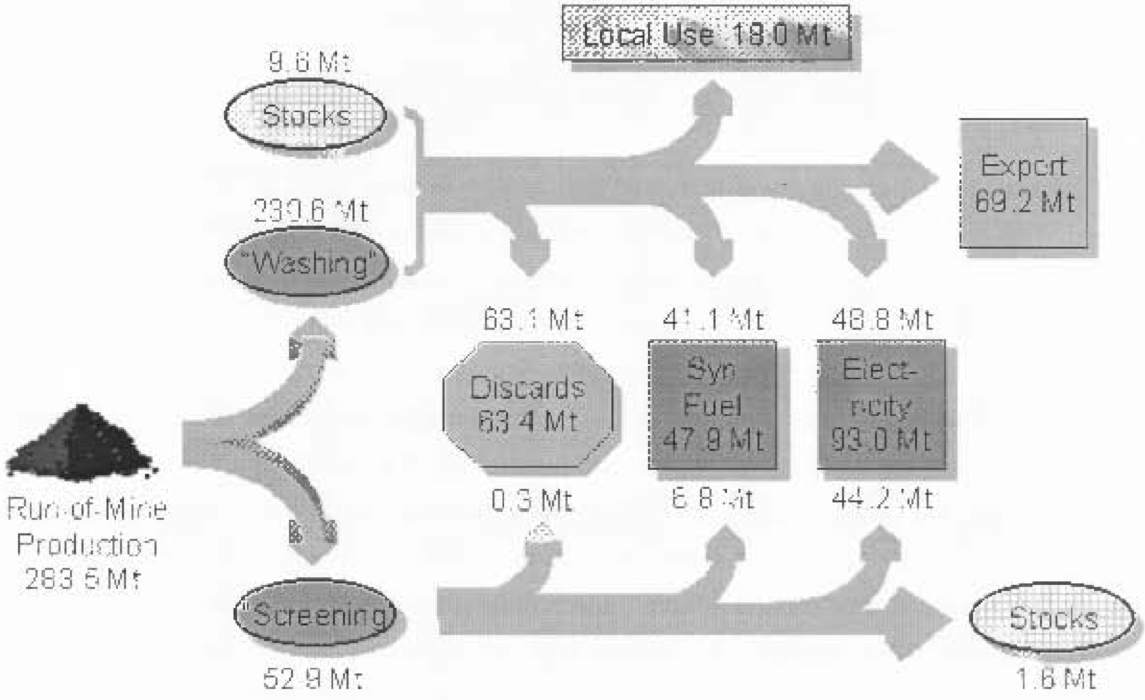

Figure 5: South African coal chain (2002); *Source: www.dme.gov.za*

Figure 5 illustrates that more than 80 % of the ROM coal is washed. This is because the value of the coal increases with increasing energy content. Coal washing is a water-based process that requires large quantities of water to operate. The washing typically takes place on-site in a coal washing plant and is therefore considered to be part of the mine. Based on information provided by de Korte (2000c), the following figure gives a generalised overview of the coal flows in a washing plant at a typical South African colliery.

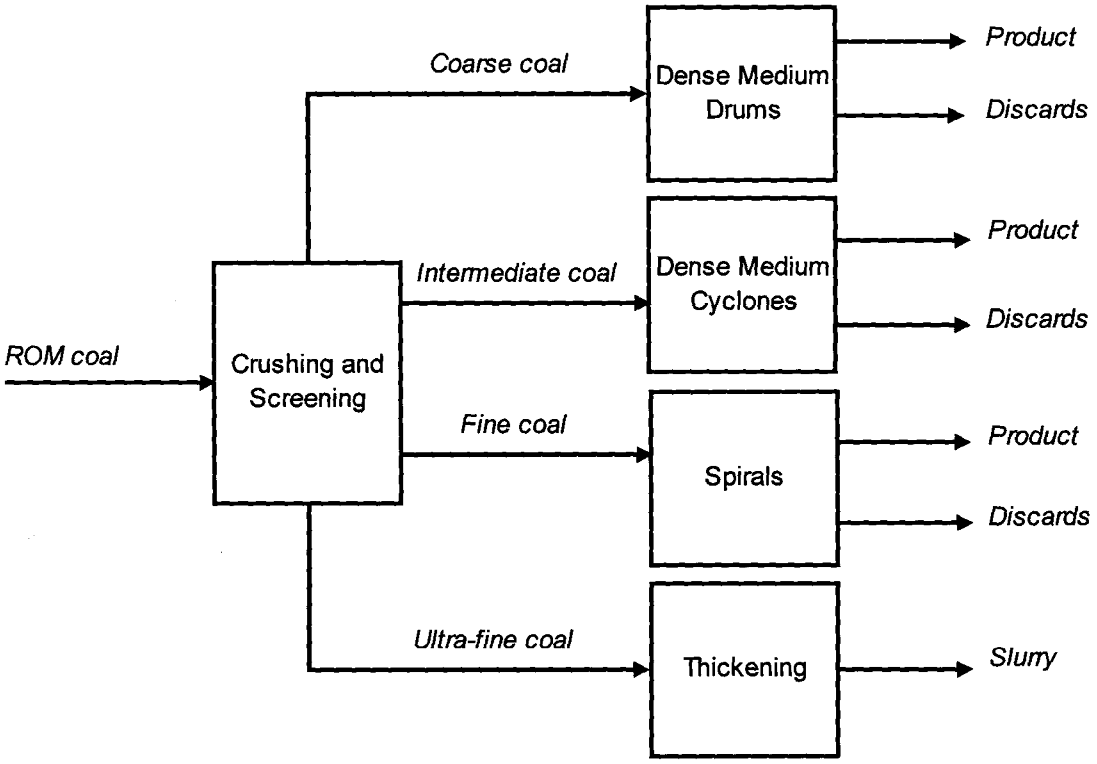

Figure 6: Block flow diagram of the coal washing process

The ROM coal is first crushed and screened and foreign objects, such as wood and metal, are removed. The coal is then separated into various size fractions. The specified size fractions vary from colliery to colliery. The coarse coal, which is often specified as coal larger than around 25 mm, is typically washed in dense medium drums, which separate the coal into a low ash product coal and a high ash discard coal using density separation techniques. The intermediate coal, which is also referred to as small coal is often specified between approximately 1 - 25 mm, is typically washed in dense medium cyclones using density separation techniques. The fine (0.15 - 1 mm) and ultra-fine (< 0.15 mm) coal are typically separated by classifying cyclones, rather than screens, as shown in Figure 7. The classifying cyclone separates coal based on size and should not be confused with the dense medium cyclone that separates coal based on density. The fine coal is sent to the spirals where it is washed. The ultra-fine coal, which cannot be effectively beneficiated in spirals (Nicol, 1992), is typically sent to the thickener, where some of the process water is recovered via the overflow and is sent back to the plant. The ultra-fines, together with un-recovered process water, then exit the thickener as a thickened slurry.

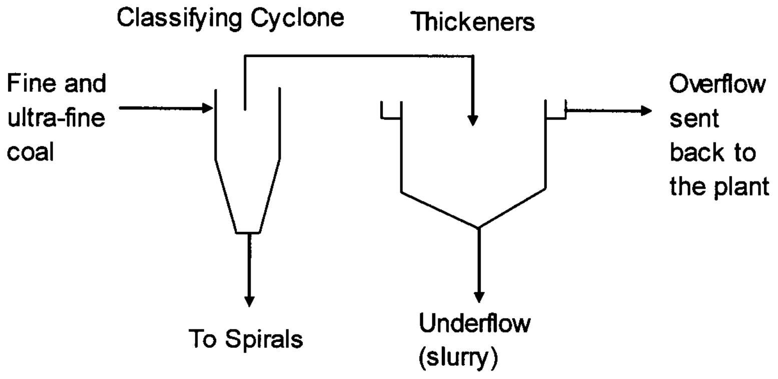

Figure 7: Schematic diagram of typical fine and ultra-fine coal processing

The various sized products are either sold separately, or they are combined and sold as a single product either locally or on the export market. Figure 5 indicates that most of the washed coal products, also referred to as clean coal products, are sold locally (most of which is utilised to generate electricity). Product specifications are typically expressed as a net-as-received (NAR) calorific value. A NAR calorific value export specification of 25.1 MJ/kg, or 6000 kcal/kg as it is more commonly expressed in the industry, is most common (SACR, 2006). An 'as received' calorific value (CV) takes into account the moisture content of the coal, such that a sample of air-dried coal will have a higher 'as received' calorific value than its moist counterpart. Therefore product moisture is of concern to the industry. The finer the coal, the greater the ratio of surface area to volume, and hence the greater the amount of moisture retained by the coal. Thus fine and ultra-fine coal requires additional dewatering, and hence additional costs, to achieve the product specifications. It is for this reason that the slurry, and in some cases the fine coal, is generally disposed of, rather than washed. The industry generally perceives that the high cost of dewatering the ultra-fine coal exceeds its value. The following table illustrates a typical distribution of moisture in product coal, assuming that the ultra-fine coal is also washed.

Table 2: Typical product moisture breakdown; *Source: Hand, 2000*

Coal Size	Product breakdown (%)	Moisture content (%)	Water distribution (%)
Coarse	61	5	40
Small	28	9	34
Fine	7	13	13
Ultra-fine	4	27	13
Total	100	7.5	100

The table illustrates that the fine and ultra-fine coal products have far higher moisture contents than the coarser products. However, owing to the sheer quantity of coarser coal, the bulk of the moisture actually originates from the coarser products. Due to environmental and economic pressures, local research in recent years has focused on fine and ultra-fine coal processing and dewatering (de Korte, 2006), rather than on the dewatering of the coarser sized coal.

Washability characteristics represent the maximum yield of product that can be achieved by density separation techniques for a specified product calorific value. Since dense-medium drums and cyclones are density separation units, this information can be used as an indicator of their performance. The following figure displays typical washability characteristics of the some of the coal seams found in South Africa. As mentioned in Section 2.1.2, seams 1, 2, 4 and 5 correspond to the Witbank-Highveld coalfield and account for the almost 80 % of coal mined in South Africa, while the Waterberg coalfield accounts for roughly 11 % of the coal mined (DME, 2005c).

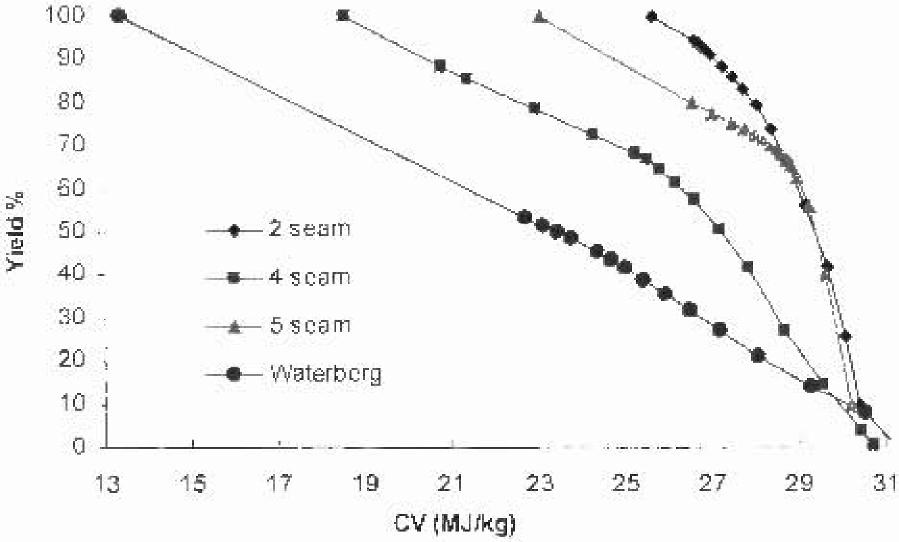

Figure 8: Washability characteristics for the 1-50 mm coal of various seams; ***Source: de Korte, 2000b***

The figure indicates that the different seams have differing washability characteristics. For a product air-dry calorific value of 27 MJ/kg, a 90 % yield of the 2-seam coal is possible, but only a 30 % yield of the Waterberg coal is possible. Thus, the amount of coal that is discarded depends heavily on the seam type and the product quality specifications.

2.1.4 Coal waste disposal practices in South Africa

As Figure 6 indicates, there are two types of coal waste generated on a coal mine, the discards and the slurry. In Figure 5 the term 'discards' refers to the combination of these two wastes. The discards are disposed of due to their high ash content, while the slurry is disposed of due to its high moisture content. According to a national survey of discard and slurry facilities, the air-dry calorific value of the slurry solids, i.e. ultra-fines, discarded in South Africa is typically between 20-27 MJ/kg, while the air-dry sulphur content is typically between 0-2 % (DME, 2001). The quality of the ultra-fines is therefore roughly equivalent to that of the unwashed ROM coal. The air-dry calorific value of the discards is typically between 11-14 MJ/kg (DME, 2001), while the air-dry sulphur content is typically between 2-3 %. Although the practice has almost ceased completely in the industry, some collieries continue to discard the fine coal instead of washing it in the spirals (DME, 2001). According to Figure

5, a combined amount of over 60 Mt of slurry and discards are being produced each year. An accumulated mass of over 1 billion tons of slurry and discards are estimated to have been dumped over the years (DME, 2001). The discards are typically disposed of on discards dumps; while the slurry is usually disposed of underground in old mine workings, in open-cast voids or on surface slurry dams together with the discards (DME, 2001). Co-disposal is when the slurry is pumped into the centre of a dam constructed from compacted discards. Integrated disposal is when the slurry is pumped onto un-compacted discards forming a matrix that is non-oxidising. Both of these disposal methods are practised in South Africa (DME, 2001). In the case of the former method, the slurry solids can be reclaimed.

2.1.5 Resource consumption

The two major resources consumed at the collieries are water and energy. These resources are discussed in this section.

2.1.5.1 Energy consumption

The South African mining industry consumes roughly 8 % of the total energy consumed in the country (DME, 2005a). In the absence of a breakdown of energy types consumed on SA collieries, Figure 9 shows a breakdown of the energy types consumed in the SA mining industry.

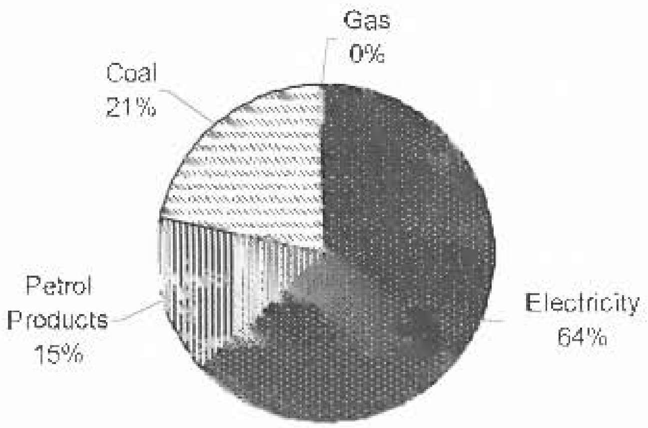

Figure 9: Breakdown of energy type consumed in the mining industry; *Source: DME, 2005a*

The figure indicates that electricity is the dominant energy source in the mining industry. It is likely that the same applies to the coal mining industry, particularly since coal is not used directly as an energy source on coal mines. According to Eskom (2003), coal mines consume roughly 1.5 % of the total electricity produced from coal-fired power stations. Figure 10 indicates an estimation of the breakdown of electricity consumers, or end-users, on a coal mine. Appendix 1 describes the origin of this information.

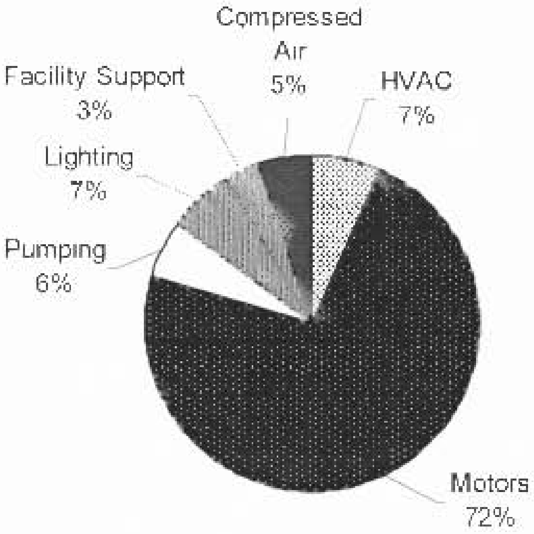

Figure 10: Breakdown of electricity usage in coal mining

Facility support refers to any non-process electricity end-use excluding heating, ventilation, air conditioning (*HVAC*) and lighting. The hot water heaters used in the laundries and change houses represent the bulk of this category. *Motors* include all motor-driven activities, including materials handling and coal processing, but exclude any motor-driven activities that are listed as other end-users, such as compressors and pumps.

2.1.5.2 *Water consumption*

It has been estimated that an average SA colliery (which takes into account those with and without washing plants) consumes roughly 133 litres of water per ton of ROM coal mined (Pulles et al., 2001). Collieries with on-site washing plants tend to consume more water than those without. This is because washing plants are the largest consumers of water and account for roughly 36 % of the total water consumed (Pulles et al., 2001). The slurry is the main source of water losses in the washing plant. On average, one third of the slurry water is recovered from the slurry dams, while the remainder is lost to evaporation and seepage (Pulles et al., 2001). The state of water balances in the coal mining industry is generally poor (Pulles et al., 2001). It has been observed that colliery water balances tend to lack detail and omit important information such as the influence of rain water, seepage and evaporation.

Most of the collieries are situated in the Olifants River Basin (Ashton et al., 2001). The distribution of rainfall in the Olifants Basin is uneven, as the southerly upper reaches receive far more rainfall (1000 mm p.a.) than the north-easterly lower reaches (400 mm p.a.) (Ashton et al., 2001). The demands on the water supply are high, and 75 % is consumed by industry, mining and agriculture. As competition for water in this region increases, tensions between the regional water consumers for the rights to the resource have arisen (Ashton, 2000) and the situation is likely to worsen in the future. Additional water from the Vaal, Usutu and Komati systems is used to supplement the water requirements of the 6 base-load power stations in this region (Notten, 2001).

2.2. *Environmental impacts of coal mining in SA*

The South African coal mining industry has been the cause of major environmental degradation (Van Horen, 1996). This section describes the various environmental impacts of the coal mining industry.

2.2.1 Water-related impacts

The environmental impacts of the coal mining industry are predominantly water-related. This section outlines the various water-related impacts of the industry. Since the amount of precipitation exceeds the amount of water evaporated in the Witbank region (Ashton et al., 2001), contaminated water produced by the mine can be expected to 'move' away from the source and show distinctive contributions to water quality in the region (Ashton et al., 2001).

2.2.1.1 Acid Mine Drainage (AMD)

Acid mine drainage (AMD) is the most widespread and persistent impact in the Olifants catchment (Ashton et al., 2001). There is evidence of AMD, represented in changes in the sulphate to chloride ratio, as far as 200km downstream of the Witbank and Highveld coalfields (Ashton et al., 2001). pH values as low as 1.8 have been reported from the Blesbokspruit, a tributary of the Olifants in the Witbank region (Bell et al., 2001). Water quality data gathered by Bell et al. (2001) from the same tributary is shown in the following table. The South African Water Quality Guidelines, Domestic Use (1993) are included in the table.

Table 3: Water Quality Data for the Blesbokspruit and SA Water Quality Guidelines;
Source: Bell et al., 2001

Determinand (mg/l)	*Average May 1990- Aug 1996*	*Recommended limit (no risk)*	*Crisis Limit (max limit for low risk)*
TDS	3092		
EC (mS/m)	398	70	400
pH	2	6-9	>4 or <11
Sulphate	2293	20	1200
Calcium	135	150	400
Magnesium	62	70	200
Iron	163	0.1	2
Manganese	14	0.05	2
Aluminium	105	0.15	1

This table indicates that this water is far from potable and in several cases, notably iron, sulphate and pH, the crisis limit is exceeded. Similar results have been noted at other sampling points in the Witbank region (Bell et al., 2001). This information verifies the occurrence of acid mine drainage in the Witbank region. The coal mining operations in the sulphur-containing coalfields and the abundance of water in the region are the main contributors to this problem. Exposed sulphurous coal and waste-rock on stockpiles, slurry dams, discard dumps and in the mined out area, are the main sources of AMD on a coal mine. More than 4000 hectares of land are occupied by discarded coal and slurry facilities in South Africa (DME, 2001). Due to their elevated pyrite content, these facilities are potential causes of acid mine drainage, especially when they are inappropriately located too close to water systems.

2.2.1.2 Other sources of water contamination

Failure of tailings dams is considered the greatest global mine problem. Around 75 % of all major mining-related environmental hazards around the world can be contributed to failure of tailings facilities (IIED, 2002). The Vaal river system in South Africa, for example, is estimated to receive over 50 000 t of salt from tailings stockpiles each year (Booth, 1994). The main reason that these facilities fail is because they are built continuously over time so that the original dimensions are long forgotten and are consequently exceeded (IIED, 2002). Chemical and fuel spillages that occur at the collieries are other sources of water contamination.

2.2.2 Air-related impacts

This section describes the various air-related impacts of coal mining.

2.2.2.1 Methane emissions

Roughly 8 % of the world's anthropogenic methane emissions originate from coal mines around the globe (US EPA, 2003). Coal mining in South Africa accounts for 2 % of the global coal mine methane emissions (www.methanetomarkets.org). Considering that South Africa produces roughly 5.2 % of the worlds coal (IEA, 2005), the mine methane emissions are relatively low compared with other countries. In South Africa, the methane that is emitted from underground mines is typically released into the atmosphere instead of being captured and utilised as an energy source.

2.2.2.2 Coal dust release

Coal fines that are stockpiled can be blown into the atmosphere, thereby creating air pollution. The fines can be carried off-site and therefore pose health problems for the surrounding communities. These airborne fines can threaten aquatic life if they end up in rivers. These threats include reduced light, so that plants cannot photosynthesise, and the clogging of fish gills. Water is generally used to suppress dust at the collieries, thereby increasing the likelihood of the dust ending up in rivers, and increasing the water consumption at the collieries.

2.2.2.3 Spontaneous combustion of coal

Under certain conditions coal dust may explode in the presence of air, and coal exposed to air in mined out areas, stockpiles and discard dumps may spontaneously combust. As a result, several noxious gases including sulphur dioxide and carbon monoxide are emitted together with carbon dioxide.

An explosion has the potential to completely destroy an underground mine. This has occurred twice in South Africa, first in 1926 and then later in 1972 (www.dme.gov.za). As the industry tends more and more towards using mechanised mining methods, the occurrence of these explosions has increased globally. This is because these machines produce large amounts of dust, and the friction caused by these machines is a potential ignition source. Other factors that increase the risk of coal explosions are increased temperature, surface area exposed, moisture content and pyrite content.

Exposed coal in the mined out areas, stockpiles and discard dumps are the high risk areas for spontaneous combustion. A typical abandoned coal mine in the Witbank region was investigated by Bell et al. (2001) and it was determined that spontaneous combustion had been occurring in this mine for over 50 years. An estimated area of between 150 and 200 hectares, situated only 2 km from a town, had been affected by this burning.

2.2.2.4 Air pollution resulting from energy use

The use of energy directly or indirectly results in several atmospheric emissions. Diesel and petrol consumption result in exhaust fumes being released into the workplace and/or the larger atmosphere. Electricity consumption results in flue gas emissions and resource consumption at the power plant (and ultimately back at the mine). According to Eskom (2005), the emissions and resource consumption per kiloWatt hour of electricity sent out are as follows:

Table 4: Eskom's emissions and water consumption per kWh sent out; *Source: Eskom, 2005*

Category	*Quantity per kWh sent out*	*Unit*
Water Used	1.3	*l*
Particulate Emissions	0.28	g
Ash Produced	160	g
NO_x Emissions	3.9	g
SO_2 Emissions	8.8	g
CO_2 Emissions	0.96	kg

Although these wastes are generated off-site, they are a direct result of the electricity consumed at the collieries. As Figure 5 indicates, roughly half of the coal supplied for electricity is unwashed and is therefore cheaper to produce, but is higher in ash and sulphur content than washed coal. This is one reason why South African electricity is extremely inexpensive, but it comes with the cost of increased sulphur dioxide and dust emissions. On average, Eskom combusts coal with an air-dry calorific value of 19 MJ/kg (Eskom, 2005).

2.2.3 Other impacts

Coal mining has had little lasting effect on the natural ecosystems in the Mpumalanga - eastern Gauteng - northern Free State region, where most of the collieries are situated, partly because natural ecosystems in this region have been strongly altered due to extensive farming prior to and during mining operations. The surface disruptions that are unavoidable in open-cast mining are usually able to be rehabilitated to an acceptable state (Wells et al., 1992). There are other impacts to the mining environment, such as noise pollution, surface subsidence, increased erosion, etc. The impacts resulting from either off-site or on-site disposal of the general and hazardous wastes, produced at the collieries are also an environmental concern. There are also other indirect environmental impacts caused by coal mining, such as the contamination of the river systems by garbage and sewage dumping from the informal settlements that have developed around the coal mines.

2.3. Cleaner production initiatives in the coal mining industry

This section describes some of the Cleaner Production initiatives that have been undertaken in the South African coal mining industry. Infrastructure promoting Cleaner Production is also discussed, because it puts the industry into a better position to reduce wastes and to optimise processes, and is therefore a Cleaner Production initiative in itself.

2.3.1 Infrastructure promoting Cleaner Production in South Africa

Aside from this project, some of the mechanisms that promote Cleaner Production in the South African coal mining industry are discussed in this section.

2.3.1.1 Legislation and regulation

There is currently no legislation that explicitly dictates that Cleaner Production techniques should be implemented on coal mines, or any industry for that matter. However, Section 63 of the Regulations document of the *Minerals and Petroleum Resources Development Act 28 of 2002* states:

'...A holder of a mining right, prospecting right or mining permit in terms of the Act must-

c. avoid the generation and production of pollution, waste and mine residue at source; or

d. where the generation and production of pollution, waste and mine residue cannot altogether be avoided, it must be minimised, re-used or recycled;'

According to the *Energy Efficiency Strategy of the Republic of South Africa* (DME, 2005b), the South African Department of Minerals and Energy (DME) aims to reduce the industry and mining sector's energy demand by 15 % by 2015. This will be achieved by introducing compulsory energy audits, imposing a series of mandatory standards and promoting energy efficient practices.

2.3.1.2 Coaltech 2020

COALTECH 2020 is a collaborative research programme that was formed to develop solutions to the problems facing the South African coal mining industry. Although not specifically aimed at Cleaner Production solutions, many of the research projects involve the prevention of problems, such as acid mine drainage and the improvement of process efficiencies. Amongst other topics, dry coal beneficiation, i.e. waterless coal 'washing', is being investigated as a potential solution to the large quantities of water consumed in coal washing plants. The programme is a collaboration of governmental departments, coal mine representatives, engineers, academics and local authorities (www.coaltech.csir.co.za).

2.3.1.3 Company collaboration

There are several representative bodies in place for the coal mining industry. The South African Colliery Managers' Association (SACMA), comprising colliery managers from many of the mining houses, aims to create a forum in which, amongst other agendas, best practices are shared (www.sacollierymanagers.org.za). Another representative body, the South African Colliery Environmental Practitioners Association (SACEPA), aims to ensure the knowledge transfer of safety, health and environment related matters, and to become actively involved in making sure that these three aspects are properly represented and addressed in the industry.

2.3.1.4 Environmental Management Systems

The ISO 14001 series of standards for environmental management systems prescribes the continual setting of targets to achieve reduced environmental and social impacts. Although not enforced by law, some collieries, typically from the larger mining houses, have implemented an environmental management system compliant with this standard (Dama et al., 2005).

2.3.2 Cleaner Production opportunities in the SA coal industry

This section describes some of the Cleaner Production opportunities for the SA coal mining industry that have been identified through research initiatives. Some of these options have already been implemented at various collieries.

2.3.2.1 Conversion of the slurry into a useful product

Considering the resources that are spent on mining the ultra-fine coal and considering its relatively high quality, it is a considerable waste that significant quantities of slurry are discarded annually. With this in mind, and the water contamination problems that the slurry disposal facilities pose, some

South African collieries have implemented Cleaner Production interventions to convert the ultra-fine coal, either as it arises or from existing disposal sites, into a valuable product. These interventions are discussed in this section.

Beneficiate, dewater and export the ultra-fines

One method of converting the ultra-fine coal into a valuable product that is practised in South Africa is to beneficiate the ultra-fines followed by dewatering of the high quality product. Flotation is the most effective method of beneficiating ultra-fine coal that is commercially available (Laskowski, 2001), and many major coal producing countries, such as Australia, commonly operate flotation plants. In South Africa, the technical feasibility of using flotation to beneficiate the ultra-fines from the Witbank coalfield has been confirmed since the early 1990s (Hand, 2000). However, in 2000 roughly only 12 % of the SA coal washing plants utilised flotation to beneficiate the ultra-fines (de Korte, 2000c).

The product is dewatered for several reasons, including reducing transport and port costs and improving the calorific value of the coal to increase revenue. There are several equipment types that can be utilised, including screen-bowl centrifuges, horizontal belt filters and thermal driers. For ultra-fine coal, mechanical dewatering can only reduce the moisture content to roughly 25 % (de Korte and Mangena, 2004). Thermal drying is therefore required to reduce the moisture content below this (de Korte and Mangena, 2004). In Canada and the USA thermal drying is commonly used but it is not popular in South Africa (de Korte and Mangena, 2004). This is due to a number of factors including a resistance to change, differences in operation compared with conventional drying equipment and the perceived safety risks of the unit due to the potential for coal dust explosions (de Korte, 2006). de Korte and Mangena (2004), however, argue that the risk of coal dust explosions can be sufficiently reduced provided that appropriate safety precautions are factored into the design and operation of the unit. If the flotation product is dewatered such that the final net-as-received (NAR) CV is higher than the export specifications, adding this coal to the coarse coal for export will serve to increase the overall NAR CV of the exported coal. To compensate for this increase in quality, and to satisfy product specifications, a poorer quality coarse product can be produced at a higher yield. Hence, decreasing the moisture of the flotation product increases the amount of coarser coal product, thereby increasing the quantity of product sold. Flotation results in an estimated 75 % conversion of the ultra-fines into a valuable product (de Korte, 2000a). This conversion, however, will vary from mine to mine.

The Coaltech 2020 programme conducted a study to predict the financial feasibility of washing the ultra-fines using flotation, followed by product dewatering to 1 % surface moisture using thermal drying for a typical SA colliery. By adding the dried product to the coarser coal product for export, the resulting 10-year net present values (compared with the scenario of discarding the ultra-fines) were in the order of R100 million, with payback times of less than one year (de Korte, 2000a). The feasibility of this option is heavily dependant on the fact that there is no minimum size limit for the coal that is exported at this particular colliery. At some collieries however, contracts will not permit ultra-fine coal to be added to the coarse coal.

Dewater and sell the existing ultra-fines on slurry dams

Another option to improve resource efficiency that is practised in South Africa involves the dewatering of existing ultra-fines on slurry dams to sell as a low quality coal for electricity generation. Thermal drying of unwashed coal is unlikely to be economically feasible due to the low value of the coal. Therefore a more cost-effective drying method has been considered. A local private company, Waste Energy Recovery and Management (WERM), has patented a process of drying and recovering ultra-fines from co-disposed slurry dams using solar energy. Every 2-3 days the top 300 mm layer of the dam is ploughed and stockpiled. The ultra-fines are dried to between 12 % and 18 % moisture because they become difficult to handle above or below this range. Once dry, the coal is not easily re-wet if it is stockpiled. This enables the drying process to occur during the rainy season; although a 30-40 % decrease in yield is experienced (Blenkinsop, 2005). WERM also re-washes the arising and existing coarse discards in a portable washing plant to produce a higher grade middlings product typically at a 50 % yield. The dried ultra-fine material is blended with the middling product and is sold to either Hendrina or Majuba power stations, as other power stations are not equipped to handle the fine material (Blenkinsop, 2005). The purpose of blending the discards with the ultra-fines is to lower the overall moisture content. This process converts all of the ultra-fines into a valuable product, as WERM operates until the slurry dam is empty, typically up to 5 years per mine (Blenkinsop, 2005). This is therefore a short-term option that utilises the slurry that is already discarded on the dams. By 2005, less than 10 collieries had contracted WERM to recover their coal wastes (WERM, 2005). A Life-Cycle Assessment might be needed to confirm that such a use of ultra-fine coal for power generation is indeed a Cleaner Production intervention, although it is likely that the environmental benefits outweigh the negative environmental impacts such as increased air emissions.

2.3.2.2 *Other possible opportunities to utilise the slurry*

Although not implemented in South Africa on a commercial level, there are additional opportunities to convert the slurry into a useful product that have been investigated by research initiatives.

Convert the ultra-fines to a low smoke fuel

This Cleaner Production option entails converting the ultra-fine coal to a low smoke fuel. Low smoke fuels (LSF) are fuels that release low levels of smoke emissions when burnt. They are widely used in many countries, including the United Kingdom, Poland and India. LSF could provide a solution to the significant quantities of air pollution brought about by the burning of coal for domestic usage, particularly in informal settlements. In order to convert ultra-fine coal into a low smoke fuel, the coal should first be agglomerated to improve its ability to be handled. Various methods of agglomeration are available, including pelletising, extrusion, binder and binderless briquetting. Research by Coaltech 2020 established that binderless briquetting is the most economically viable method of agglomeration (England, 2000). To convert the coal into a low smoke fuel, the briquettes are devolatised at high temperatures. Pilot and laboratory tests have been conducted locally at Kleinkopje Colliery by Coaltech 2020 to establish the technical feasibility of the production of low smoke fuels from ultra-fines in South Africa. The tests established that the process is technically feasible with South African coal (Mangena and de Korte, 2005). A study by England (2000), concluded that the briquetting costs compared with the selling price of D-grade coal, suggests that it is unlikely, particularly in the informal settlement sector, that low smoke fuels will be adopted by the domestic sector unless subsidised or mandated by law.

Solubilise the ultra-fines to produce methane and polymers

Coal solubilisation is the process whereby coal is converted by micro-organisms and enzymes into a solution of coal macromolecules that can be converted into various products, such as methane or polymers (Catcheside and Ralph, 1999). Low rank coals are more susceptible to solubilisation because of their higher moisture content, more suitable structure, smaller pores, softness and susceptibility to weathering (Faison, 1993). However, certain micro-organisms can solubilise higher rank coal (Klein, 1999), such as that found in the Witbank coalfield. The lack of standardisation of research work in this field has hindered the progress and development of this process. In South Africa this technology is not commercially available at present. Research work undertaken at local universities aims to optimise and commercialise this process.

Produce a coal-water fuel from the slurry

Coal-water fuels (CWF), also known as coal-water slurries (CWS) or coal-water mixtures (CWM), are concentrated suspensions of highly beneficiated ultra-fine coal in water. The CWF must be between 65 and 70 % solids and 3-4 % ash. The CWF can be produced by upgrading the slurry using flotation so that the low ash requirements can be met (Laskowski, 2001). The CWF is pipelined directly to power stations where it is burned as a heavy oil rather than adding it to the coarse coal. Coal-water fuels have several advantages over traditional dry coal. The problems of spontaneous combustion and dust generation during the storage and transportation of dry coal are eliminated. The cost of drying and dewatering are significantly reduced. Unlike dry coal, coal-water fuels are more easily handled and do not require large transportation or handling facilities because they are aqueous (Laskowski, 2001). Despite these benefits, there are currently no power stations in South Africa that can utilise coal-water fuels as they are limited to handling dry coal.

Combust the slurry in a fluidised bed combustor

A fluidised bed reactor is a combustor in which the coal particles are suspended in a bed by updrafts of gas that keep the coal in a turbulent state (www.worldcoal.org). Research by the CSIR has established that it is technically feasible to combust South African ultra-fine coal slurries of 63 % moisture in a fluidised bed combustion boiler (North, 1990). Conventional pulverised fuel boilers require that the feed coal contains at most 10 % moisture. Therefore the cost of dewatering the ultra-fine coal is greatly reduced for the fluidised bed reactor. Although a relatively low thermal efficiency of 67 % is achieved, the costs of obtaining this waste coal are also low. Transport, other than via pipelines, is not feasible as the slurry is not sufficiently stable (North, 1990). There are, however, currently no commercial fluidised bed combustion power stations in South Africa that run on coal, although Eskom plans to operate them in the unspecified future (North, 2006).

2.3.2.3 Methane capture and utilisation

In several countries, coal mine methane is recovered and utilised as an energy source, thereby reducing the amount of greenhouse gases emitted into the atmosphere. In South Africa, there are two coal bed methane projects that are being proposed: one near Musina and the other in the Waterberg coalfield (www.miningmx.com). Although still in the planning stages, these projects have the potential to reduce the industry's greenhouse gas emissions and to provide the country with an additional source of energy. As mentioned in Section 2.2.2.1, South African methane emissions per ton of coal mined are relatively low compared with the world average. Some international mining companies, including Xstrata, are therefore investing in methane capture and utilisation technologies in their foreign operations before considering their South African mines (e.g. www.xstrata.com).

2.3.2.4 Reductions in energy consumption

Research has been undertaken to establish the possibilities of reducing electricity consumption in the South African coal mining industry. It has been estimated that the industry has the potential to save at least 380 GWh of electricity (Howells, 2006), which equates to a 13 % decrease in electricity consumption. These savings can be achieved by implementing energy saving measures, such as installing energy efficient motors and lighting, and reducing compressed air wastages. Many collieries have used their own initiatives to reduce energy consumption, and as a consequence have benefited both environmentally and financially.

2.4. Methodology

As stated in Chapter 1, the objectives of this thesis are to propose cost-effective Cleaner Production techniques to reduce the environmental impacts of the South African coal mining industry. A methodology of identifying and proposing feasible Cleaner Production interventions is therefore required. The United Nations Environment Programme (UNEP) recognises *Cleaner Production assessments* to be an effective method of systematically applying Cleaner Production to a site (www.uneptie.org). The United States Environmental Protection Agency (USEPA), which refers to the assessments as *industrial assessments*, recognises this methodology to be 'instrumental to systematically identifying opportunities to increase energy efficiency and decrease waste generation' (USEPA, 2001). Many companies have successfully identified feasible CP interventions through this methodology (www.uneptie.org). Therefore, the Cleaner Production assessment approach has been used in this thesis to address its objectives. Three typical case study collieries were selected on which to conduct the Cleaner Production assessments. This section describes the methodology of the Cleaner Production assessments in detail.

2.4.1 Cleaner Production assessment procedure

There are five generally accepted phases of a Cleaner Production assessment. The following figure depicts these phases which are then discussed.

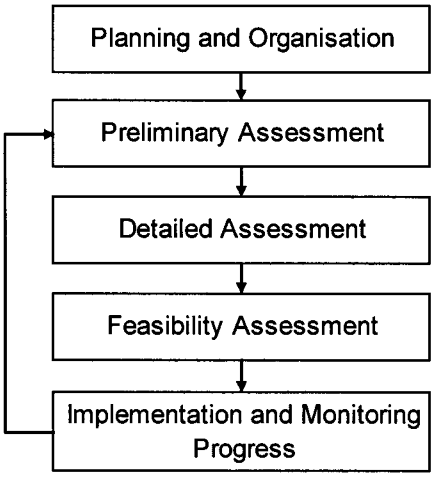

Figure 11: Phases of a Cleaner Production assessment; *Source: van Berkel, 1996*

2.4.1.1 *Planning and Organisation Phase*

The first phase of a Cleaner Production assessment involves obtaining management support and setting up a project team. A small project team, consisting of colliery employees, was set up at each colliery to assist in the assessment and to learn about Cleaner Production so as to ensure its continuation after the completion of this thesis.

2.4.1.2 Preliminary Assessment Phase

The purpose of the preliminary assessment is to gain an understanding of the processes at each site, to identify the major inputs and outputs, to quantify the wastes and then to compare the wastes. The wastes are compared in order to determine on which wastes to focus in the *detailed* and *feasibility* phases. The waste comparison carried out in this thesis is a 'quick and dirty' preliminary analysis that was used to refine the focus of the Cleaner Production assessment so that the detailed analysis is limited to the wastes most in need of further investigation. Therefore, the comparison was predominantly based on educated estimates rather than on detailed and precise calculations. According to the comparison method described by BECO (2000) that was used in this thesis, the wastes are rated from 1-5 (5 being the most wasteful) in five different categories. The total points for each waste are compared, so that the three wastes with the most points (i.e. the most wasteful) can be identified. The five different categories are:

- Quantity
- Cost
- Environmental impact/ Hazardous nature
- Potential for Cleaner Production interventions (rated 1-3)
- Other (rated -1 to 2)

Quantity refers to the quantity of waste produced. Mass balancing, site surveys, reports, meter readings, and invoices were consulted to estimate the quantity of each waste produced. Points were allocated according to the following table.

Table 5: Allocation of points for quantity of waste generated (t/year); ***Source: BECO, 2000***

Quantity (t/year)	*Point*	*Description*
>1,000,000	5	very high
250,000-1,000,000	4	high
50,000-250,000	3	medium
10,000-50,000	2	low
0-10,000	1	very low

Energy consumption is included as a source of waste. This is because wastes associated with the consumption of energy are either generated off-site, as in the case of electricity, or are difficult to quantify, e.g. vehicle emissions. The points for quantity of energy consumed are based on electricity consumption since this is the dominant energy source consumed in the mining industry (DME, 2005a), and were allocated as shown in Table 6.

Table 6: Allocation of points for energy consumed; *Source: BECO, 2000*

Quantity of Electricity Consumed (kWh/year)	*Rating*	*Description*
>15,000,000	4	very high
10,000,000 -15,000,000	3	high
5,000,000 -10,000,000	2	medium
0 - 5,000,000	1	low

The *cost* category refers to the total costs associated with producing the waste stream and therefore includes the cost of any raw materials discarded with the waste, labour costs, disposal costs, the cost of energy consumed to produce the waste, etc. Costs were estimated qualitatively, relative to the most expensive waste stream, where 5 represents a very high cost stream and 1 represents a low cost stream.

The *environmental impact* category reflects the toxicity or potential for environmental harm of each waste. The points were allocated from 1-5, where 5 reflects a waste that is hazardous in nature or is likely to impact significantly on the environment.

The *potential for Cleaner Production interventions* category reflects the potential of each waste to be reduced by implementing Cleaner Production interventions. Each waste stream was rated based on the answer to the following question (BECO, 2000):

'Does the assessment team believe that there is potential for Cleaner Production, based on a good knowledge of Cleaner Production options for the process?'

No ideas:	*1*
Low Potential:	*2*
High Potential:	*3*

Other includes the mine's compliance with present or known future regulations and any safety or health hazards it poses to the mine employees and surrounding areas. The ratings for *other* are allocated as follows:

- Compliance with present or known future regulations? *Yes: 0; No: 1*
- Safety hazards to employees and surrounding areas? *Yes: 1; No: 0*
- Existing reuse/recycle? *Yes: -1; No: 0*

Once all the points had been allocated for each category, these were totalled for each waste and were compared. The three wastes with the most points at each colliery represent those that should be focused on in the Cleaner Production assessment.

2.4.1.3 Detailed Assessment Phase

In this phase Cleaner Production ideas are generated to reduce, either directly or indirectly, the quantity and toxicity of the three focus waste streams. More detailed knowledge of the processes that generate the focus wastes is required. Therefore sampling, laboratory test-work and site walk-through audits were conducted. Cleaner Production ideas were generated from literature, interviews with experts in the field and at colliery brainstorming sessions. The brainstorming sessions, which were conducted in conjunction with *BECO – Institute for Sustainable Business*, were meetings where various employees from all aspects of the colliery operations came together and collectively suggested potential Cleaner Production ideas to reduce the focus wastes. Apart from the benefits of obtaining ideas from employees who are experienced and familiar with the various processes at the collieries, these sessions are believed to promote ownership of the ideas which increases the potential for implementation (Kothuis, 2006b). Ideas were also generated from the case study collieries, where one colliery is implementing Cleaner Production interventions that the others are not implementing.

2.4.1.4 Feasibility Assessment Phase

The options that were generated in the detailed assessment were then submitted to a feasibility assessment to determine their technical, environmental and economic feasibility. This assessment procedure is illustrated in the following figure, the ovals indicating the tasks that were conducted.

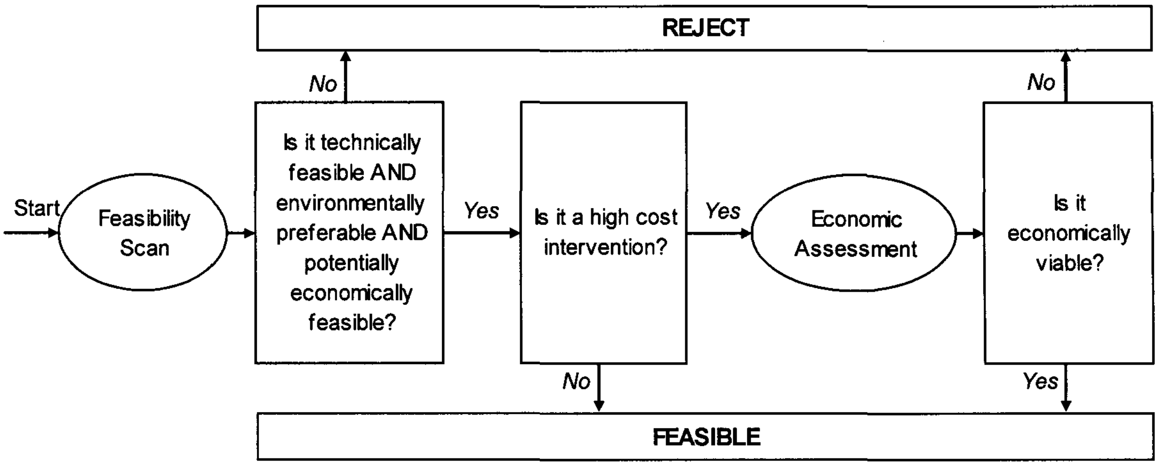

Figure 12: Feasibility assessment procedure

As depicted in the figure, the options were first submitted to a scan to assess their technological and environmental feasibility and potential economic feasibility. The environmental assessment is based on a general and informed understanding of the environmental impacts of an option rather than on detailed life-cycle assessments (LCA). Since life-cycle assessments are a project unto themselves, they are considered outside the scope of this thesis.

The successful options of the scan that do not require high capital investments (<R1,000,000) were considered feasible, whilst the successful options that require high capital investments (>R1,000,000) were then submitted to an economic assessment. This involved estimating financial indicators, such as Net Present Values and payback times, as well as conducting sensitivity analyses to determine the influence of certain parameters on the financial indicators. If two mutually exclusive options were deemed viable, the more profitable option took preference. Through this process, feasible Cleaner Production interventions could be identified for the case study collieries and potentially for the industry as a whole. This feasibility assessment can be considered as a preliminary evaluation as in many cases more detailed techno-economic evaluations, which are outside the scope of this thesis, are required prior to the implementation of an option.

2.4.1.5 Implementation and Monitoring Phase

This phase involves the actual implementation of the Cleaner Production options, the continuation of its application and the monitoring of progress. The assessment can then return to the preliminary phase thereby ensuring the continual execution of Cleaner Production. Although briefly mentioned in this thesis, this phase will not be discussed in detail, because it is largely the responsibility of the mines. However, methods are suggested to overcome the various barriers that hinder the implementation of the Cleaner Production interventions in the coal mining industry.

2.4.2 Profile of the case study collieries

Three case study collieries, referred to as A, B and C, were selected for this thesis. The collieries were selected based on their representation of the far larger arm of the industry that 'washes' the coal (refer to Figure 5), on their willingness to disclose colliery information, and on their acceptance of this project. The profile of the three collieries is listed in Table 7, while Appendix 2 provides more detailed information about the collieries and includes block flow diagrams of the coal washing operations.

Table 7: Profile of the three case study collieries

Colliery	*A*	*B*	*C*
Coalfield	Witbank	Witbank	Highveld
Seams mined	2 and 4	4	2
Coal type	Bituminous	Bituminous	Bituminous
Mining method	Underground	Underground	Underground
On-site washing plant	Yes	Yes	Yes
Coal tonnage mined (tpa)	2,900,000	3,900,000	970,000
Coarse coal washing unit	Drums	Drums	Drums
Small coal washing unit	Cyclone	Cyclone	Cyclone
Fine coal washing unit	None	Spirals	Spirals
Ultra-fine coal washing unit	None	None	None
Exported products	Coarse + small	Small + fines	Small + fines
Export specifications (NAR)	6000 kcal/kg	6000 kcal/kg	6000 kcal/kg
Locally sold products	None	Coarse + brick duff + raw duff	Coarse
Slurry disposal method	Underground	Co-disposal	Co-disposal
Discards disposal method	Surface dump	Co-disposal	Co-disposal
Expected remaining life of mine	>20 years	>15 years	>20 years

The facts that the three collieries have on-site coal washing plants, are located in the Witbank-Highveld coalfield, mine seam 4 and/or seam 2 coal, export a 6000 kcal/kg product, utilise drums, cyclones and spirals to wash the coarse, small and fine coal respectively and dispose of the ultra-fine coal, render these three case study collieries relatively representative of the industry.

Although spirals are installed at colliery A, the fine coal is discarded instead of being washed due (so it is claimed) to the costs of dewatering the spiral product. Colliery B sells the spiral discards, known as brick duff, to a local brick manufacturing company. Colliery B also sells raw duff (unwashed <10 mm coal) as the quantity of coal that is mined exceeds the capacity of the washing plant.

CHAPTER 3

PRELIMINARY ASSESSMENT

This chapter presents the findings of the pre-assessments conducted at each case study colliery. The purpose of the pre-assessment is to gain an understanding of the nature and origin of the wastes at the collieries, and to determine which wastes to focus on in the Cleaner Production assessment. By conducting pre-assessments at the three representative case studies, a general qualitative understanding of the wastes generated at South African collieries can be gained. This is necessary before Cleaner Production interventions can be proposed and the key questions of the research answered.

3.1. Background

Systematic Cleaner Production assessments had not previously been conducted at any of the three collieries or at any other collieries belonging to the same mining companies. Driven predominantly by legislation and company image, the collieries are seeking to reduce their environmental impacts. However, management strategies tend to be largely focused on end-of-pipe waste treatment, rather than on prevention. The reason for the environmental management systems still largely being end-of-pipe focused is because there are several barriers in place that hinder the adoption of Cleaner Production at these collieries. Many of these barriers correspond to those noted in the mining industry as a whole that were discussed in Section 1.1.3.2. Firstly, a general lack of awareness of the concept and value of Cleaner Production, even by the environmental managers, was noted at the three collieries. Secondly, as discussed in Section 2.3.1.1, legislation does not provide incentives to implement Cleaner Production interventions over end-of-pipe solutions. Thirdly, no-one is allocated the responsibility of investigating Cleaner Production interventions at the case study collieries. Environmental managers have limited time and limited expertise to take on this task as their focus is largely on keeping up with the ever-changing legislation, while production management is primarily focused on achieving tonnage targets.

Decision-making is based primarily on financial concerns. Budget limitations, the risk associated with high capital expenditure and expected profits are all significant factors that influence decisions and project approval. Obtaining access to large capital sums is made difficult by the policies and bureaucracies of the mining companies. This is therefore a barrier to implementing high capital Cleaner Production investments.

Colliery C dedicates a few minutes each day to informing its mine workers of certain environmental issues. Monthly topics, such as 'reducing oil spillages', are used as themes for these brief meetings.

Collieries A and B do not have environmental awareness or training programmes in place for their employees.

3.2. Wastes produced by the collieries

Based on the site visits and colliery documentation, the following significant wastes have been identified at the case study collieries. As indicated in Section 1.1.1, the term 'waste' refers to any solid, liquid or gaseous substance that is not regarded as having any value by those who produce it. All wastes apply to all three collieries. These wastes are:

- Methane
- Dust
- Slurry
- Discards
- Sewage
- Oil leakages and spillages
- Other leakages
- Excess energy use (source of waste)
- Reclaimed oil
- General waste
- Hazardous waste

These wastes are described and discussed in more detail in the following section. As mentioned in Section 2.4.1.2, energy consumption is included in this list because wastes brought about by energy consumption are either generated off-site, as in the case of electricity, or are difficult to quantify, e.g. vehicle emissions.

3.3. Discussion of the wastes

This section discusses the various wastes in more detail and compares the relative quantities of waste generated at each mine. The quantities are expressed per ton of mined coal so that they can be compared between the collieries. The lowest relative quantity for each waste can be viewed as a benchmark for the other two collieries because it represents a lower, achievable waste production rate. Options to reduce wastes can be arrived at by establishing why one colliery produces less waste than another. Therefore, comparing the quantities of wastes generated at each mine, and establishing the reasons for the differences, is a meaningful exercise.

Difficulties in obtaining the quantities of waste produced were experienced at all three collieries. This is due to a number of factors. Firstly, there is minimal monitoring of resources and wastes at the collieries, resulting in a shortage of information. Besides water balances at collieries A and C, no mass or energy balances have been conducted for the washing plants or for the colliery as a whole. In the case of colliery A, accurate process flow diagrams of the washing plant were not available. Secondly, the information that is available is not necessarily documented or consolidated in a single document. Water-meter readings, equipment specification sheets, interviews with employees, daily and monthly reports and invoices were therefore resorted to in order to obtain the relevant information. Thirdly, the available information is not made easily accessible to the various employees of the respective collieries. In some cases, such as the coal flows at colliery A, contradictions in reported values were noted. These difficulties in obtaining useful information reduce the effectiveness of the Cleaner Production assessment because a waste cannot be managed if little is known about it. Appendix 2 provides a detailed breakdown of the quantities of wastes produced at each colliery, together with the sources of the information.

3.3.1 Methane

The methane contents of the seams that are mined at the various collieries are listed in Table 8. The average methane content of South African coal seams in general is also included in the table (IT ASCA Africa, 2005).

Table 8: Comparison of the seam methane content

COLLIERY	*A*	*B*	*C*	*SA*
Average methane content (m^3/t coal)	0.03	0.02	0.3	0.6

The table indicates that the seam methane contents are well below the South African average, especially in the case of collieries A and B. These emissions are particularly low considering that South African mine methane emissions are relatively low in relation to the rest of the world. Due to the low methane emissions, none of the case study collieries captures or drains the methane prior to excavation. Instead the methane is emitted into the atmosphere with the ventilation air. Thus, the methane emissions are not being used as an energy source by the collieries.

3.3.2 Dust

The case study collieries are all underground mines, where dust is less of a problem than in open cast mines. Dust particles located on stockpiles and roads become airborne predominantly due to disturbances by the weather or by vehicles. Front-end loaders and pre-wet crushers are also responsible for releasing fine coal particles into the atmosphere. Dust is prevented from becoming airborne by spraying water on the various exposed surfaces, particularly roads. Significant quantities of water are consumed suppressing dust regardless of the weather conditions. Table 9 indicates these quantities per ton of ROM mined.

Table 9: Water consumed to suppress dust

COLLIERY	*A*	*B*	*C*
Water consumed to suppress dust (m^3/t ROM)	0.009	0.008	0.01

Colliery A uses depressurised fire-hydrant water to suppress the dust. This is both an environmental and safety hazard, as a pressurised fire water supply is not readily available in the case of an emergency. Colliery B utilises chemical dust suppressants to assist with the dust suppression, thereby reducing water requirements. Mine B also covered the ROM stockpile so that it is no longer exposed to the atmosphere. Collieries A and B utilise product silos, rather than stockpiles, thereby preventing the fine particles from becoming airborne.

Due to its complex nature, dust generation has not been quantified. However, even in the worst case scenario, i.e. a 'very heavy' dust fallout rate of 1200 mg/m^2/day (Jonanti, 2005), the dust produced would be less than 10,000 tpa.

3.3.3 Slurry

As mentioned in Chapter 2, the ultra-fine coal is discarded because the collieries perceive that the high cost of dewatering the ultra-fine coal exceeds its value. Hence, the ultra-fines are discarded together with process water in the form of a slurry. Mine A disposes of the slurry underground in old mine shafts. Boreholes are located at a deeper level so that some of the seeping slurry water can be recovered. Mines B and C dispose of the slurry on co-disposal discard dumps, which allow roughly 40% of the water to be recovered. Prior to dumping, the slurry is partially dewatered at all three plants in a thickener. The water thus recovered is recycled back into the plant. An efficiently operated thickener is capable of reducing the water content to roughly 75 % (Reddy, 2005). However, at all three collieries, the thickened slurry is approximately 85 % process water, therefore excess water is being unnecessarily being disposed of in the slurry.

Because it is viewed as a waste, very little information is available regarding the slurry. The quantities of slurry produced were obtained from the plant mass balances in Appendix 2 and are shown in Table 10.

Table 10: Comparison of slurry generation

COLLIERY	*A*	*B*	*C*
Slurry produced (t / t ROM)	0.32	0.27	0.27

The table indicates that colliery A disposes of more slurry than the other collieries. As indicated in Section 2.4.2, mine B sells part of the unwashed <10 mm ROM coal. Since this coal contains ultra-fines, less ultra-fines are available to be purged in the slurry. Colliery C crushes the coal to a top size of 80 mm, compared with 40 mm and 50 mm at mines A and B respectively, resulting in fewer ultra-fine material being produced. It is therefore expected that colliery A will produce more ultra-fine material and, therefore, slurry.

None of the collieries samples and monitors the quality of the ultra-fine coal, and are therefore unaware of the quality of the coal they are discarding. To obtain the coal quality data, samples were taken at each mine and were analysed for calorific value and ash content. The results of the analyses are shown in Table 11 together with the results of the error analysis.

Table 11: Comparison of the slurry quality

COLLIERY	*A*	*B*	*C*
Air-dry calorific value of slurry solids (MJ/kg)	22.7 ± 0.7	23.7 ± 0.8	22.1 ± 2.2
Air-dry ash content of the slurry solids (%)	27.2 ± 2.3	23.9 ± 1.2	29.2 ± 4.2

The table indicates that valuable coal is being discarded on the grounds that the costs of dewatering this coal are perceived to exceed its worth. Since the mines are unaware of the quality of this coal, the decision to discard it appears unjustified. As mentioned in Section 2.1.3, it is a common practice throughout the SA coal mining industry to discard the ultra-fine coal, and is therefore not limited to the case study collieries.

3.3.4 Discards

The discarded coarse rock, referred to as the discards, is disposed of because of its high ash content, i.e. poor quality. At mine A, the discards are disposed of on a discard dump, and at mines B and C they are disposed of together with the slurry on a co-disposal tailings dam. None of the case study collieries has conducted a study to predict or quantify the environmental impacts caused by the discard dumps. Table 12 indicates the quantities and qualities of the discards at each colliery.

Table 12: Comparison of discards quantity and quality

COLLIERY	*A*	*B*	*C*
Discards disposed of (t / t ROM)	0.39	0.29	0.19
Discard air-dry calorific value (MJ/kg)	13	13	10
Discard air-dry ash content (%)	50	52	61

Table 12 indicates that there are considerable differences in the quantity of discards generated at each mine. Almost 40 % of the mined coal at colliery A is discarded, while only 19 % is discarded at colliery C. The coal seam type is largely responsible for these differences. As explained in Section 2.1.3, the different coal seams have differing washability characteristics. Washability characteristics represent the maximum yield of product that can be achieved by density separation techniques for a specified product calorific value. In the absence of site-specific data, Figure 13 displays the assumed washability characteristics of the coal mined at the three collieries. The characteristics for collieries B and C, which mine 2-seam and 4-seam coal respectively, were obtained from research by de Korte (2000b) and reflect typical washability characteristics for these seams. Since colliery A mines 2-seam and 4-seam coal in equal parts, and since there is no site specific data available, the washability characteristics for this mine were predicted by averaging the 4-seam and 2-seam characteristics. Also shown on the figure are the operating points that reflect the yields and calorific values that the mines are currently achieving respectively. The characteristics in this figure hold for coal sized between 1-50 mm, i.e. that washed by the drums and cyclones and not incorporating the yields of the finer-sized coal.

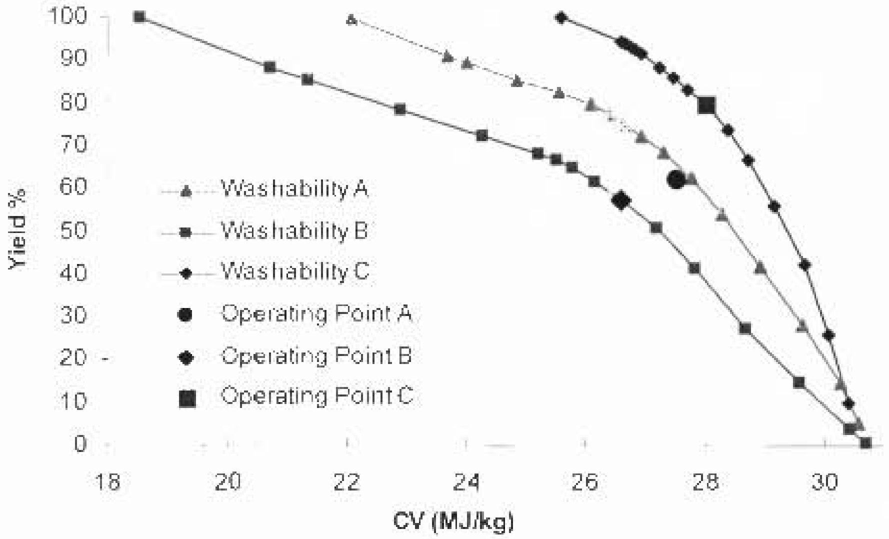

Figure 13: Washability characteristics and operating points of the coal mined at the case study collieries

The first observation from the figure is that, if all three collieries were required to produce the same quality 1-50 mm product, colliery C would inherently be able to achieve the highest yield and hence produce the least discards. Observing the operating points, colliery B has partly compensated for the low yields by producing a poorer quality product than the other two mines. However, the quality is not low enough that it produces less 1-50 mm discards than mine A. The information in Table 12, however, indicates that colliery B generates less discards than colliery A despite the washability characteristics. This is because colliery B sells just over 20 % of the unwashed –10 mm ROM coal as is, such that no discards are generated on account of this mined coal. Colliery B also sells the spiral discards to a local brick manufacturing company, thereby converting it to a by-product, rather than a waste. Colliery A is also not achieving the maximum possible yield in the drums and cyclones dictated by the washability characteristics. It is therefore expected that colliery B generates less discards overall than colliery A. Since colliery A discards all of the fine coal, the overall plant yield is lower than that for the 1-50 mm size fraction shown in Figure 13.

The pyrite content of the discards, which is the sulphurous component that contributes to acid mine drainage, is not monitored at any of the three collieries.

3.3.5 Sewage

At collieries A and B the sewage is treated in an on-site sewage treatment plant. At colliery A, the treated solids are used in a responsible manner as fertiliser to assist with the rehabilitation of the mine. Since the solids add value to the mine, they are not considered a waste. Half of the treated water is recycled back into the mine, while the other half is released into a nearby river. At colliery B, the treated liquid is recycled back to the plant and the solid waste is collected by outside contractors. Colliery C, which is situated near a small town, pipelines the combined untreated sewage waste to the local municipality treatment plant. Thus, 'sewage waste' refers to the half of the treated liquid effluent that is released into the river for colliery A, the solid material for colliery B, and the untreated liquid-solid waste for colliery C.

Table 13: Comparison of sewage quantities

COLLIERY	*A*	*B*	*C*
Sewage (g / t ROM)	14000	1.2	44000

The table indicates that treating the waste on-site and recycling the treated water back into the mining operations, significantly reduces the amount of sewage disposed of. During the cold months at colliery C, the underground mine workers open the shower hot taps to generate steam to heat up the rooms prior to showering. This accounts for a significant portion of the sewage water that is generated at this colliery.

3.3.6 Oil spillages and recovery

Oil that is consumed at the collieries is burnt in the vehicle engines, recovered and recycled, or wasted due to spillages and leakages (mostly pipe bursts). The percentage of used oil that is recovered and then recycled by an outside contractor is indicated in Table 14 for each mine. This oil is recovered from vehicle oil sumps.

Table 14: Comparison of quantities of recovered oil

COLLIERY	*A*	*B*	*C*
Recovery of oil (%)	8	3	3.5

The table indicates that less than 8 % of the total oil consumed is recovered, while the remainder is combusted in engines, spilt or leaked. Based on discussions within the coal Cleaner Production Forum (see Section 1.1.4), these figures appear to be typical of the industry. Although generally unknown, some of the causes of oil spillages have been identified, such as the overfilling of oil into the various components and into the storage tanks, resulting in oil spilling onto the ground. The underground workers then leave the empty oil drums on the surface, where the drums are no longer their responsibility. Residual oil may drain out onto the ground as the drums are not necessarily placed upright. Another identified source, more difficult to address, is the problem of pipe bursts of hydraulic equipment. It is estimated by the mine workers that pipe bursts are the largest cause of oil losses. The quantity of oil that is wasted due to spillages and leakages is unknown. However, the total quantity of oil consumed at each colliery does not exceed 10,000 tpa, which means that the amount lost as leakages will also be less than 10,000 tpa. Spilt oil, especially after use, is however known to be highly toxic to the receiving environment (Rwodzi, 2000).

3.3.7 *Other leakages*

'Other leakages' refers to any aqueous leakages that are not recovered and recycled back into the mining processes. Such leakages may originate from leaking taps, overflowing equipment or burst pipes. Leakages that occur within the washing plants are recovered by sump pumps located on the bottom floor. Leakages that occur outside the plant, such as dripping taps and leaking hoses, are recovered by a network of canals that redirect the flows to storage dams. However, some of these canals are simply dug-out trenches that allow water to pass through them into the ground. As this contaminated water is not recovered and re-used, it is considered a waste. Although the quantities of water lost in this manner are unknown, it is estimated that the losses are not likely to exceed 10,000 tpa. This is partly due to the relatively small amounts of water that are leaked, and partly due to the canal systems effectively recovering most of the leaks. The canal system also serves to keep clean surface run-off water separate from the coal-contaminated water used on the mine, thereby preventing further contamination of water.

3.3.8 *Energy consumption*

The energy sources utilised at the collieries are petrol, diesel, oil and electricity. At all three mines only the total consumptions of each energy source are recorded. None of the mines has an electricity monitoring system in place to monitor the end-user consumptions, and none has conducted liquid fuel balances. The oil, diesel and electricity consumptions, shown in Appendix 2, have been converted to energy consumed per ton of ROM mined (MJ/t), assuming an energy content of 38.4 MJ/l, 36.4 MJ/l and 3.6 MJ/kWh respectively (bioenergy.ornl.gov). Figure 14 summarises this data, together with the total energy consumed per ton of ROM coal, at each mine. Petrol consumption at all three collieries is negligible. Only energy consumed on-site is considered, as energy used to transport the coal to its final destination is outside the scope of this assessment.

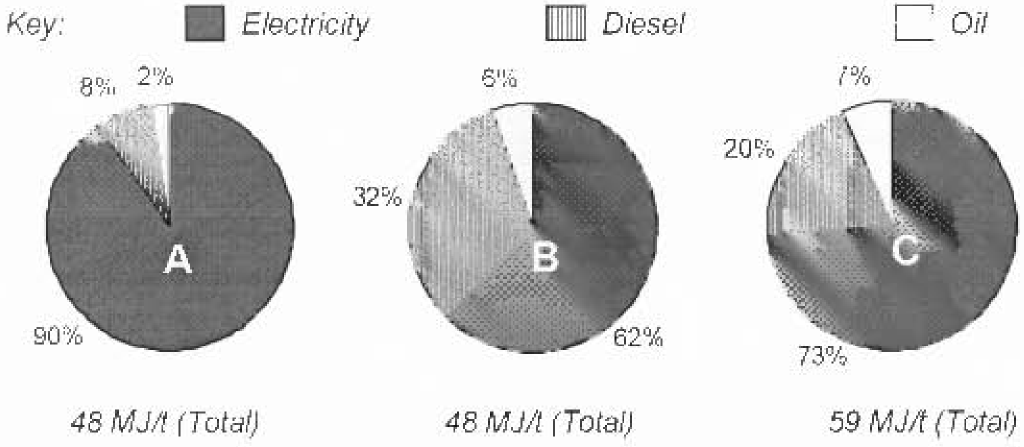

Figure 14: Energy consumption comparison

The figure indicates that electricity is the principal energy source, accounting for more than 60 % of the total energy consumed at all three collieries. The figure also indicates that colliery C consumes notably more energy than the other two. Colliery C transfers its product coal to stockpiles via conveyor belts and employs front-end loaders to transfer the coal from the stockpile to the transport vehicles. The other two collieries transfer the coal via conveyor belts to the product bins from where they drop via gravity into the trains. The product handling at collieries A and B is therefore less energy consuming. Colliery C mines at roughly 80 m below the surface, which is at a greater depth than mines A and B (40 m and 60 m respectively) and is located where the coal seam is particularly thin (1.5 m compared with 3.6 m and 3.5 m at A and B respectively). Hence excavation at mine C is more energy intensive than at the other mines. Considering the product handling, excavation practices and economies of scale at colliery C, it is expected that the energy consumption will be higher than that of the other two mines.

3.3.9 General and hazardous waste

Outside companies are contracted to remove and dispose of the general and hazardous wastes produced by the collieries. Colour-coded containers designated to the different waste types are distributed around the collieries and are collected on a weekly basis. If hazardous waste is found in the incorrect bins, the colliery is financially penalised by the disposal companies. If general waste is disposed of in the hazardous waste bins, the colliery pays unnecessarily high disposal costs for its disposal. From the information given in Appendix 2, Table 15 compares the general, hazardous and combined wastes for the three different collieries per ton of ROM mined.

Table 15: Comparison of general and hazardous waste generation

COLLIERY	*A*	*B*	*C*
General Waste (kg/t ROM)	0.11	0.076	0.028
Hazardous Waste (kg/ t ROM)	0.009	0.004	0.023
Total (kg/t ROM)	*0.11*	*0.080*	*0.051*

Table 15 indicates that colliery A generates the largest quantities of general waste. Although colliery C generates the least amount of combined waste, the quantities of hazardous and general waste collected are fairly similar. Since it is unlikely that the amount of hazardous waste produced is similar to that of the general waste, this suggests that there may be a waste separation problem at colliery C. The mine workers are responsible for separating and placing the wastes in the correct bins.

3.4. Waste comparison

In order to determine on which three wastes to focus in the Cleaner Production assessment, a waste comparison was carried out for each colliery. A waste comparison is a 'quick and dirty' preliminary analysis that is used to refine the focus of a Cleaner Production assessment. Therefore, the comparison is predominantly based on educated estimates, rather than on detailed and precise calculations. This process allows the focus wastes to be identified at each colliery, so that the detailed Cleaner Production analysis is limited to the wastes most in need of further investigation. Section 2.4.1.2 describes in detail the method of conducting the waste comparison analysis. The wastes are rated from 1-5 (5 being the most wasteful) in five different categories:

- Quantity
- Cost
- Environmental impact
- Potential for Cleaner Production interventions (rated 1-3)
- Other

Other includes the mine's compliance with present or known future regulations and any safety or health hazards it poses to the mine employees and surrounding areas. At all three mines, methane, dust and hazardous wastes were allocated a score of 1 for the *other* category due to the health risks that these wastes pose. Recycled oil was allocated a score of -1 in the *other* category because it is recycled off-site. The waste quantities presented in this chapter and in Appendix 2 were converted to a rating via Tables 5 and 6 in Section 2.4.1.2. Owing to the lack of information regarding the exact composition of the wastes and the inputs required to produce the wastes, qualitative, rather than quantitative, costs were estimated. These were relative to the highest costing waste, i.e. the discards. The environmental impact ratings were estimated from the information in Section 2.2. Appendix 3 describes in more detail the decisions behind the point allocation for the various criteria.

Figure 15 displays the results of the waste comparison. The radar diagrams together with the 'key' indicate the individual rating that each waste at each mine was allocated. The bar chart displays the total scores for each waste at each colliery.

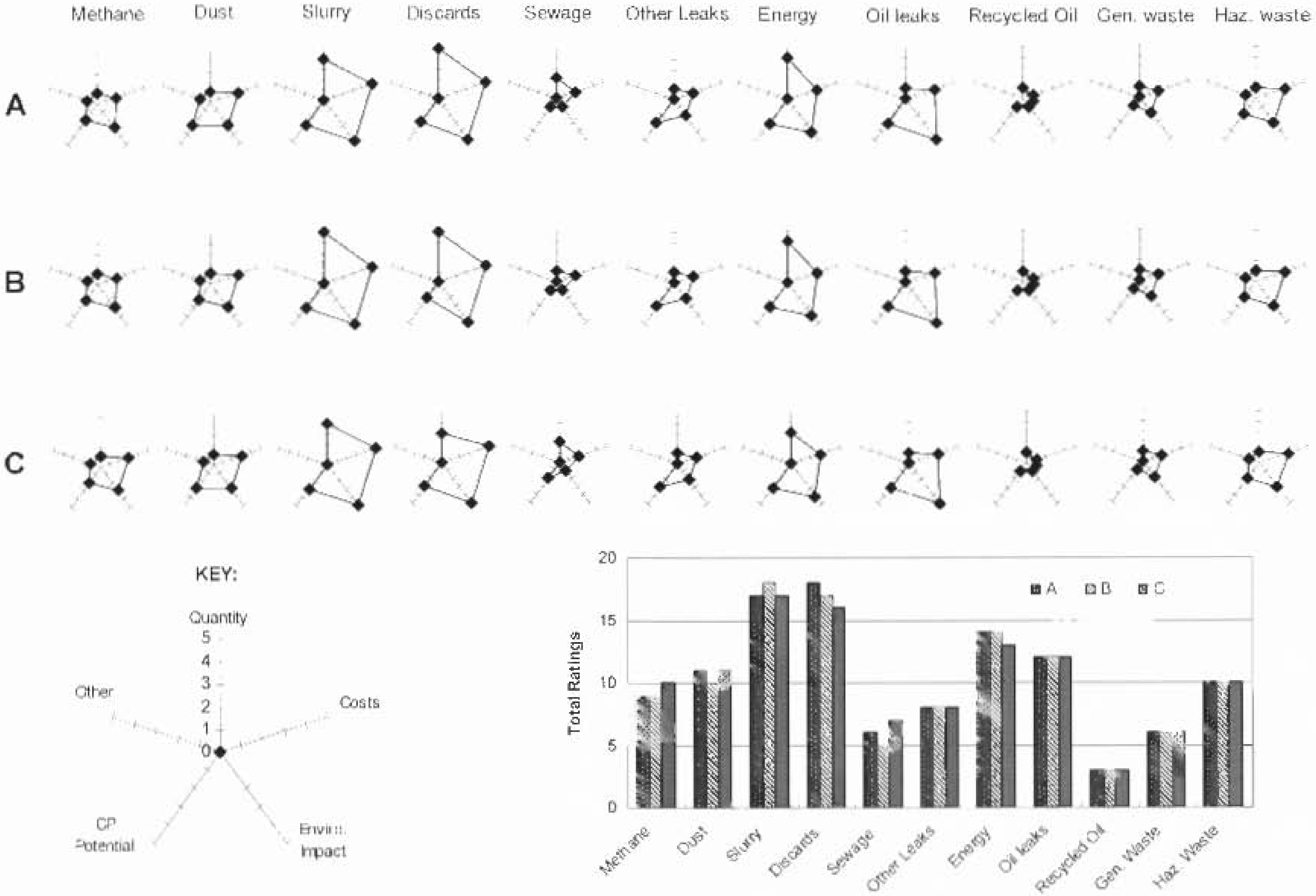

Figure 15: Waste comparison results

The comparison results shown in Figure 15 indicate that the three wastes with the highest total ratings at all three collieries are:

- Slurry
- Discards
- Wastes resulting from energy consumption

Therefore, these three wastes will be the focus of the Cleaner Production assessment and will be investigated in detail in Chapters 4, 5 and 6 respectively. Despite the high environmental impacts of oil leakages and hazardous wastes, energy consumption takes preference due to the sheer quantities of energy consumed at the mines. Although they will not be considered further in this assessment, oil leakages and spillages have been identified as a waste that requires more attention in the future.

The bar-chart indicates that for each colliery, the ranking of the wastes is similar. This shows that the three collieries are producing wastes of a similar nature. This is not unexpected as the process operations and locations of the collieries are similar. Since the majority of the South African collieries are located densely in the same coalfields as the case study mines, and since coal processing operations in South Africa are relatively consistent, it is likely that the findings of the waste comparison are applicable, or at least consequential, to the industry as a whole in its current state.

The radial diagrams in Figure 15 indicate that the ratings are identical for the oil leakages, other leakages, recycled oil and hazardous and general wastes for all three collieries. This again highlights the similarity in the nature of the wastes produced.

3.5. Summary of pre-assessment findings

This section summarises and discusses the findings of this chapter. Driven predominantly by legislation and company image, the collieries are seeking to improve their environmental performance. However, management strategies tend to be largely focused on end-of-pipe waste treatment, rather than on prevention. There are several reasons for this, including a general lack of awareness of the concept and value of Cleaner Production, the fact that legislation does not provide incentives to implement Cleaner Production, and that no-one is allocated the responsibility of investigating Cleaner Production at the case study collieries. Other barriers were noted, such as a difficultly in obtaining approval for projects that require large capital investments.

A difficulty in obtaining colliery performance data was experienced at all three collieries. This is due to a number of factors. Firstly, there is minimal monitoring of resources and wastes at the collieries. Besides water balances at collieries A and C, no mass or fuel balances have been conducted for the washing plants or for the collieries as a whole. The compositions of the waste streams are also generally not monitored and more than 90 % of oil consumption is unaccounted for. Secondly, the information that is available is not necessarily documented or compiled into a single document. Water-meter readings, equipment specification sheets, invoices and interviews were therefore resorted to so as to obtain the relevant information. Thirdly, the available information is not made easily accessible to the various employees of the colliery, such that the knowledge is not distributed around the colliery. This difficulty in obtaining information, and the lack thereof, reduces the effectiveness of the Cleaner Production assessment. As the saying goes, 'You can't manage what you can't measure'.

The information provided in this chapter suggests that there are several opportunities to implement Cleaner Production interventions at all three collieries for many of the wastes. Some of the wastes are managed differently at the three collieries. In some cases one colliery is implementing a Cleaner Production intervention which is not being implemented at the other two. The covering of the ROM stockpile at colliery B, which prevents dust from being released into the atmosphere, is an example of such an intervention. There are therefore opportunities for the mines to learn from each other. Cleaner Production Forums, such as the one that has been established for the coal mining industry in South Africa (see Section 1.1.4), can provide a valuable framework through which knowledge sharing can occur.

The waste comparison determined that the slurry, discards and energy consumption should be the foci of the Cleaner Production assessment at all three collieries. Owing to the similarity of the process operations and locations of the majority of South African coal mines to the case study collieries, it is likely that these findings will be relevant to the industry as a whole. Chapters 4, 5 and 6 investigate in more detail the slurry, discards and energy consumption respectively.

CHAPTER 4

SLURRY ASSESSMENT

Chapter 3 identified the slurry as being a waste in need of a detailed Cleaner Production investigation at all three mines. In response to this finding, this chapter aims to identify feasible Cleaner Production opportunities to reduce the amount of slurry that is discarded by presenting the findings of the detailed and feasibility stages of the assessment for the slurry. Since the slurry comprises both water and solids (ultra-fine coal), both of these aspects were investigated. Section 2.2 described that the ultra-fine slurry solids are the source of several significant environmental problems, including acid mine drainage, dust release and spontaneous combustion. Therefore, by reducing the quantity of slurry that is disposed of, these impacts on the environment can be reduced. As mentioned in Section 2.1.5.2, most of the water consumed in the coal washing plants is lost via the slurry. By recovering and recycling this slurry water, and hence reducing the quantity of slurry disposed of, the amount of water consumed in the plant is reduced.

4.1. Slurry volume reduction options

Based on the information given in Chapter 3, the following general methods ultimately bring about a reduction in the amount of slurry that is discarded:

- Prevent the unnecessary generation of ultra-fine coal
- Prevent coarser coal from being discarded with the slurry
- Prevent water from being unnecessarily included in the slurry
- Convert the remaining slurry into a useful product

These methods are discussed in detail in this section.

4.1.1 Prevent the unnecessary generation of ultra-fine coal

Extraction of coal underground is one of the main causes of ultra-fine coal generation. Modern mechanised mining methods result in the production of more ultra-fine coal than manual mining methods. It is, however, highly unlikely that the industry would be willing to revert back to manual mining methods because of the significant financial benefits of mechanisation. Crushing is the other main cause of ultra-fine generation whilst other causes, such as material handling, are negligible by comparison. Increasing the top or maximum size to which the coal is crushed would serve to decrease the amount of ultra-fines and increase the proportion of coarser coal produced. On the downside, larger crush sizes might result in less liberation of coal from ash, and therefore more discards due to less effective separation in drums and cyclones. The mined coal is crushed to a top size of 40, 50 and 80 mm at collieries A, B and C respectively. The dense-medium drums are designed to handle coal up to 100 mm in size. Therefore, there is a potential to increase the crushing top size while still remaining within the equipment's operating size range. Since colliery C is currently crushing to a large top size, this option is more applicable to collieries A and B. Plant trials should be conducted to determine the optimum crusher top size.

In summary, a Cleaner Production option to reduce the amount of slurry that is discarded is:

- *Increase the crusher top size to reduce the proportion of ultra-fines that are generated.*

4.1.2 Prevent coarser coal from being discarded in the slurry

Coal that is larger than 150 µm should not be purged in the slurry with the ultra-fines as it can easily be upgraded and dewatered in the washing plants at each of the mines. Therefore, it is considered an unnecessary waste if +150 µm coal is discarded with the ultra-fine coal in the slurry. Preventing this from happening will reduce the amount of coal that is wasted. Samples were therefore taken and analysed using a Malvern Mastersizer X to determine whether coarser particles are being sent to the slurry. Figure 16 displays the particle size distribution of the coal discarded in the slurry for the case study collieries (with the 95 % confidence limits shown).

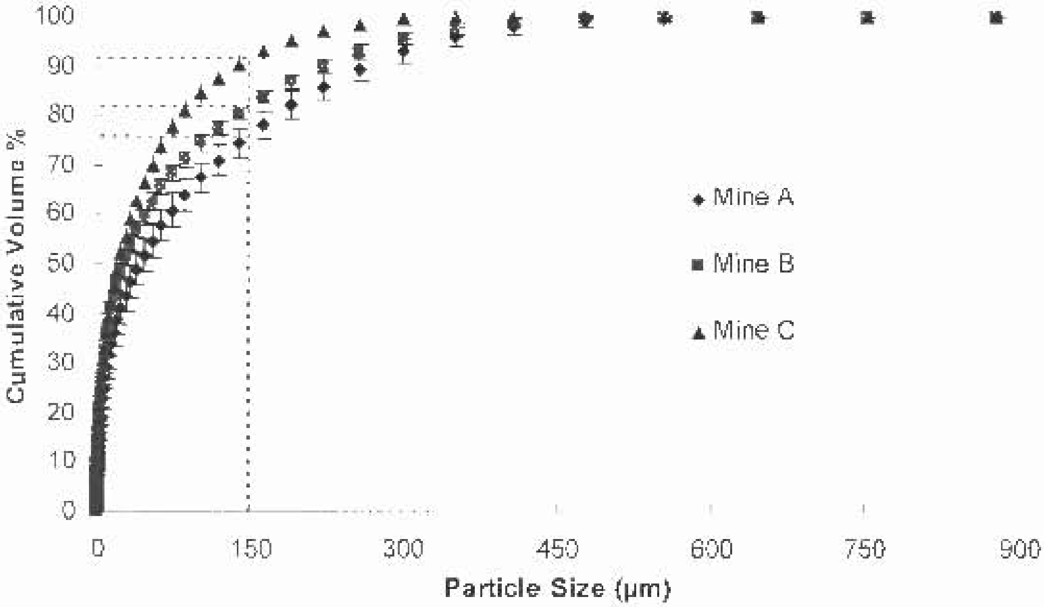

Figure 16: Particle size distribution of the slurry solids

Based on this information, Table 16 lists the percentage of coal coarser than 150 µm that is discarded, to within 95 % confidence.

Table 16: Volume fraction of the slurry solids coarser than 150 µm

Colliery	*A*	*B*	*C*
Volume % coarser than 150 µm	24 ± 3	18 ± 1.3	8 ± 1.4

The information indicates that roughly one quarter of the slurry solids at colliery A should not be discarded in the first place. Although not as significant, there is also a notable wastage at the other mines. These findings serve to partially account for the differing quantities of slurry produced at each mine (see Section 3.3.3).

Figure 7 indicates that the classifying cyclones are responsible for separating the coal into the fine and ultra-fine coal size fractions. Thus, it can be concluded that the cyclones, particularly at colliery A, are not operating effectively. A detailed study should therefore be conducted to optimise these classifying cyclones to perform sharper, more precise separations.

In summary, a Cleaner Production option to reduce the amount of slurry that is discarded is:

- *Optimise the classifying cyclones to perform sharper, more precise separations*

4.1.3 Prevent water from being unnecessarily sent to the slurry

There are two general methods of reducing these water losses. The first is to ensure that the maximum amount of water is being recycled back into the plant, and the second is to prevent the ultra-fines from coming into contact with water by replacing the current wet washing method with dry coal beneficiation. These are both discussed in this section.

4.1.3.1 Maximise recycling of water back into the plant

Currently, slurry densities of around 1.08 S.G., corresponding to 15 % solids, are experienced at the three mines. This means that 85 % of the slurry is water that is being discarded with the ultra-fines. Although some of this water is recovered via slurry dam penstocks or by boreholes, it would be more efficient if it were recovered prior to dumping. Since the thickener is responsible for recycling the slurry water back into the plant (see Figure 7), ensuring that it is operating efficiently will serve to reduce the amount of water lost to the slurry. In an efficiently operated coal thickener, slurry densities of around 1.13 S.G., or roughly 23 % solids, are easily achievable (Reddy, 2005), and less water is lost to the slurry.

There are several reasons why thickeners operate inefficiently, most of which are related to flocculent type, dosage and mixing (Waters, 1992). An outside company specialising in thickeners was called in to assess the thickeners at mine A. The assessment established that the current flocculent mixing and dosing system is the cause of the inefficiencies (Reddy, 2004). Currently, the flocculent is mixed manually at all three mines, causing inconsistencies in the dosage. If too much is added, the mixture becomes too thick to mix with the coal and inadequate flocculation takes place. If too little is added, insufficient flocculation takes place. The thickener specialists proposed that mine A install an automated flocculent make-up system that will ensure consistent and sufficient dosing is achieved, thereby reducing the amount of water lost in the underflow and solids exiting in the overflow. Automating the flocculent make-up system also has the added advantage of reducing the wastage of flocculent. This is therefore a Cleaner Production option that can potentially be implemented at all three collieries. At a cost of less than R300,000 (Jooste, 2005), this is considered a medium-cost investment. The savings associated with the reduction in flocculent wastage, increased water recovery and decreased labour and pumping requirements, are likely to pay off the capital expenditure.

4.1.3.2 Dry coal beneficiation

As mentioned in Section 2.3.1.2, another completely different method of reducing the amount of water that is lost via the slurry is to convert to dry beneficiation of coal, rather than wet beneficiation, so that no water is brought into contact with the ultra-fine coal. Currently, almost all of the coal washing plants in South Africa and the rest of the world utilise water to wash the coal (de Korte, 2000c). Due to the large quantities of water consumed and the problems with increased product moisture content, there is a renewed interest in dry coal beneficiation. The Pollution Research Group of the University of KwaZulu-Natal, funded by Coaltech 2020, is currently researching the feasibility of the dry beneficiation of South African coal. This research, however, is in its early stages so the technology is not yet ready to implement on a commercial scale (Buckley, 2006b).

In summary, Cleaner Production options to reduce the amount of slurry that is discarded are:

- *Install an automated flocculent make-up system*
- *Beneficiate the coal using dry methods*

4.1.4 Convert the remaining ultra-fine coal into a useful product

By utilising the slurry and converting it into a product, a waste is being reduced or even eliminated. As indicated in Chapter 2, there are several different methods of converting the slurry into a useful product. These are listed and then discussed:

- *Beneficiate, dewater and export the ultra-fines*
- *Dewater and sell the unwashed ultra-fines*
- *Convert the ultra-fines to a low smoke fuel*
- *Solubilise the ultra-fines to produce methane and polymers*
- *Produce a coal-water fuel from the slurry*
- *Combust the slurry in a fluidised bed combustor*

Owing to the ongoing developments of technologies for slurry utilisation world-wide, it is likely that several other options are currently available or will become viable in the future.

4.1.4.1 Beneficiate, dewater and export the ultra-fines

As discussed in Section 2.3.2.1, this option entails the upgrading of the ultra-fines by flotation and the dewatering of the high quality product. According to the colliery managers at the respective collieries, there is no minimum limit on the size fraction of the coal that can be exported by any of the three mines. Therefore the beneficiated and dewatered ultra-fines can be added to the coarse coal, and can be sold via the already established export market. In the case of colliery A, all of the product coal is exported but at the other two only a portion is exported. Flotation results in an estimated 75 % conversion of the ultra-fines to a valuable product (de Korte, 2000c). The economic assessment will determine whether centrifuging, belt filtering or a combination of belt filtering and thermal drying is the most economically feasible dewatering method. Apart from the reduction of transport costs and increase in product net-as-received calorific value, the dewatering of the flotation product has the added benefit that a significant portion of the slurry water is recovered. Hence, this option results in a decrease in both the slurry solids and the slurry water that are discarded. This option has the added attraction in that a contract has already been agreed upon into which the ultra-fine coal product can be sold.

4.1.4.2 Dewater and sell the existing ultra-fines on slurry dams

As discussed in Chapter 2, this option could be operationalised by the contracting of Waste Energy Recovery and Management (WERM) to solar dry and recover the existing ultra-fines on slurry dams to sell as a low quality coal for electricity generation. The ultra-fines are dried to between 12 % and 18 % moisture and are blended with rewashed discards. Thus this option reduces the amount of ultra-fines and discards that are dumped. This process converts all of the ultra-fines into a valuable product, as WERM operates until the slurry dam is empty, typically no longer than 5 years per mine. This is therefore a short-term option that utilises the slurry that is already discarded on the dams. Other options should be considered to utilise the arising slurry. Since colliery A disposes of the slurry underground, rather than on a slurry dam, and since coal that is disposed underground is considered un-reclaimable (DME, 2001), this option is not feasible at colliery A. It is estimated that the benefits of reducing the problem of acid mine drainage caused by discard dumps, and producing electricity from coal that is not required to be mined, render this option environmentally preferable to the current scenario. However, an in-depth Life-Cycle Assessment should be conducted to establish the environmental impacts caused by the combustion of ultra-fines and rewashed discards to generate electricity.

4.1.4.3 Convert the ultra-fines to a low smoke fuel

As discussed in Section 2.3.2.2, this Cleaner Production option entails converting the ultra-fine coal to a low smoke fuel (LSF). Despite the technical feasibility of the process, due to the high costs associated with producing the LSF and the intrinsically lower cost of normal D-grade coal, it is unlikely that this product will be economically viable, particularly in the domestic sector unless subsidised or mandated by law.

4.1.4.4 Solubilise the ultra-fines to produce methane and polymers

This option involves solubilising the ultra-fine coal into a useful product such as methane or polymers and is described in more detail in Section 2.3.2.2. In South Africa, this technology is not commercially available at present. Therefore this option is not feasible at present but may become so in the future as the research develops.

4.1.4.5 Produce a coal-water fuel from the slurry

This option (discussed in Section 2.3.2.2) involves converting the slurry into a coal-water fuel (CWF) which is a concentrated suspension of highly beneficiated ultra-fine coal in water. Although the process has been technologically proven, there are currently no power stations in South Africa that can utilise coal-water fuels as they are limited to handling dry coal. Therefore, until appropriate infrastructure is in place to utilise the CWF, this option is not economically feasible.

4.1.4.6 Combust the slurry in a fluidised bed combustor

This option involves combusting the slurry in a fluidised bed reactor to generate electricity and is discussed in more detail in Section 2.3.2.2. Despite the benefits of implementing this option, there are currently no commercial fluidised bed combustion power stations in South Africa that run on coal, although Eskom plans to install and operate them in the unspecified future (North, 2006). Therefore this option is not currently economically feasible but it may become so in the future. Another innovative idea, not considered in this thesis, is to set up smaller, decentralised fluidised bed combustors located close to the washing plants.

4.2. Feasibility of the slurry reduction options

The various Cleaner Production options that have been generated to reduce the amount of slurry disposed of at the case study collieries are summarised below.

1. Increase the crusher top size to reduce the proportion of ultra-fines that are generated
2. Optimise the classifying cyclones to perform sharper, more precise separations
3. Install an automated flocculent make-up system
4. Beneficiate the coal using dry methods
5. Beneficiate, dewater and export the arising ultra-fines
6. Solar dry and sell the unwashed existing ultra-fines to local power stations
7. Convert the ultra-fines to a low smoke fuel
8. Solubilise the ultra-fines to produce methane and polymers
9. Produce a coal-water fuel from the slurry
10. Combust the slurry in a fluidised bed combustor

All of these options are applicable to the three collieries, with the exception of option 6, which is not applicable to colliery A since it disposes of its slurry underground and is therefore un-reclaimable. As described in Section 2.4.1.4, each option is subjected to a feasibility assessment, commencing with the feasibility scan.

4.2.1 Feasibility scan

The purpose of the feasibility scan is to discard any options that do not meet certain criteria. The criteria are shown in the left hand column of the following table. Negative answers (X) signify that the option is unsuitable and will not be considered any further. The option numbers in the table correspond to the option numbers listed above. The information provided earlier in this chapter and in Section 2.3.1 was used to complete this scan. The results, shown in the following table, are identical for all three mines with the exception that option 6 was not considered for colliery A.

Table 17: Results of the feasibility scan

Option no.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Technical Feasibility										
Is it proven technology?	✓	✓	✓	X	✓	✓	✓	X	✓	✓
Is the technology currently useful to implement in SA?	✓	✓	✓	N/A	✓	✓	✓	N/A	X	X
Environmental Feasibility										
Is it likely to result in a net reduction of environmental impacts?	✓	✓	✓	?	✓	✓	✓	?	✓	✓
Does it decrease the amount of slurry discarded?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Economic Feasibility										
Is it likely to be financially feasible at present?	✓	✓	✓	X	✓	✓	X	X	X	X

Options 9 and 10 are unfeasible because there are currently no coal-water fuel compatible power stations or fluidised bed combustors available in South Africa that could utilise the products of options 9 and 10 respectively. Options 4 and 8 are unfeasible as the technologies are not yet sufficiently developed to implement on a commercial scale. As explained in Section 2.3.2.2, option 7 is unlikely to be economically feasible as it is not expected to be adopted by the market. The scan therefore indicates that options 4 and 7-10 are not feasible and will therefore not be considered further. These options may become more viable in the future and should therefore not be completely dismissed. The remaining options (1, 2, 3, 5 and 6) are all considered technically feasible and are estimated to be environmentally preferable as they have satisfied the criteria in the left hand column of Table 17. Owing to the fact that options 1, 2 and 3 are not high cost interventions, these options do not require an economic feasibility study as per the feasibility procedure outlined in the Section 2.4.1.4. Options 5 and 6 are both high cost options and are therefore submitted to a generalised economic feasibility assessment.

4.2.2 Economic assessment

This section describes the economic assessment for each colliery for options 5 and 6. The economic assessments are approximate calculations to determine the 'order of magnitude' financial indicators for each option. It is therefore recommended that in-depth detailed assessments be conducted at each colliery before implementation, particularly as both of these options are complex in nature.

4.2.2.1 Beneficiate and dewater the ultra-fine coal

As mentioned in Section 4.1.4.1, the economic assessment determines the type of dewatering equipment used to dewater the flotation product. Seven dewatering options were considered and are listed below (TM refers to total moisture).

i. Dewater the ultra-fine product using a belt-filter
ii. Dewater the combined fine and ultra-fine products in a screen-bowl centrifuge to 20% TM
iii. Dewater the combined fine and ultra-fine products in a screen-bowl centrifuge to 16% TM
iv. Dewater the combined fine and ultra-fine products in a screen-bowl centrifuge to 12% TM
v. Belt filter the ultra-fine product, then thermal dry the combined fine and ultra-fine products to 8.5% TM
vi. Belt filter the ultra-fine product, then thermal dry the combined fine and ultra-fine products to 5.5% TM
vii. Belt filter the ultra-fine product, then thermal dry the combined fine and ultra-fine products to 3.5% TM

In the case of colliery A, which currently discards the fine coal, only the ultra-fine coal product is dewatered. Since ultra-fine coal alone can at best be mechanically dewatered to 25 % moisture (de Korte and Mangena, 2004), dewatering options ii-iv are not possible and are therefore not considered at this colliery. For each dewatering option, an assessment was conducted to determine the economic feasibility of beneficiating and dewatering the ultra-fines compared with the current scenario of simply dumping them. The approach to and results of the assessment, together with the assumptions are shown in Appendix 4, while Figure 17 summarises the results.

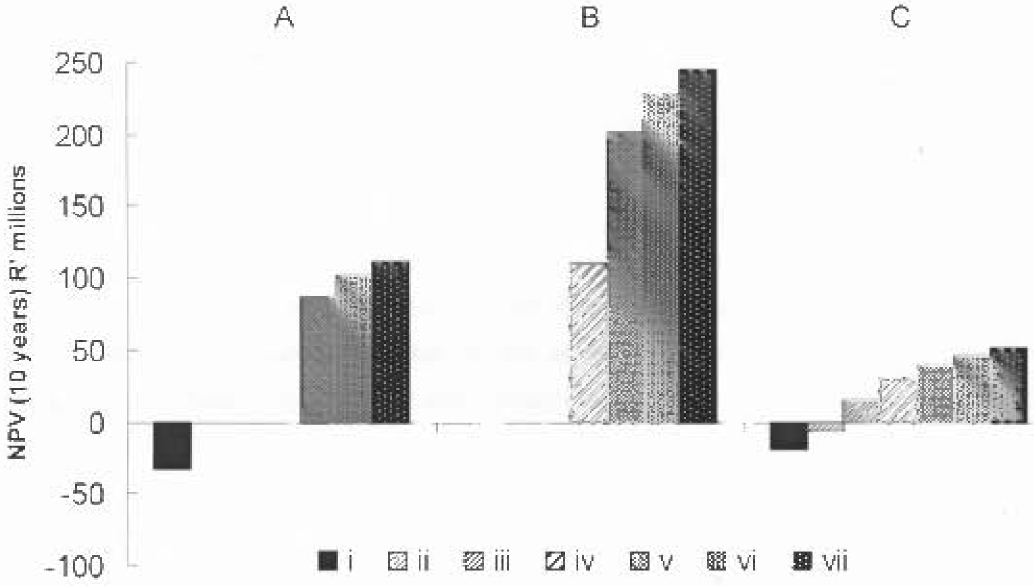

Figure 17: Financial assessment for option 5, relative to the current scenario of ultra-fine disposal*

*In the case where an option is not applicable to a certain colliery, an NPV of zero is indicated.

Although not clear in Figure 17, dewatering options i-iii are not possible at colliery B as the export coal is not able to meet its specifications. The results in Figure 17 indicate that at all three collieries, thermal drying the beneficiated product to 3.5 % total moisture (sub-option vii) is the most economically beneficial option. This is because the ultra-fine and fine coal product is dewatered to such a degree that the overall 'as-received' calorific value exceeds the export market specifications. Therefore, adding this coal to the coarser coal for export allows the coarser coal to be washed to a poorer quality and hence a higher yield, resulting in more saleable coal, less discards and hence more revenue. The results also indicate that beneficiating the ultra-fines followed by product dewatering is more economically beneficial than simply disposing of the ultra-fines, provided that belt filtering alone (or centrifuging to 20 % moisture at colliery C) is not used. Since thermal drying to 3.5 % TM (sub-option vii) is the most profitable at all three collieries, only this option is considered further. Table 18 expands on the financial indicators for this option to beneficiate and thermal dry the ultra-fines relative to the current scenario at each mine. As mentioned earlier, only the flotation product is thermally dried for this option for colliery A, as the fine coal is not washed at this colliery.

Table 18: Predicted financial indicators for option 5 (incorporating sub-option vii)

Colliery	*A*	*B*	*C*
NPV (10 years)	R 100,000,000	R 200,000,000	R 50,000,000
Capital	R 10,000,000	R 10,000,000	R 6,000,000
Payback (yrs)	0.4	0.3	0.5

The financial indicators shown in Table 18 are relative to the current situation of ultra-fine disposal at each mine. The reductions in rehabilitation costs that would be achieved if option 5 were to be implemented have not been factored into the economic assessment. With payback times of less than one year and significant Net Present Values (NPV) after 10 years, this option appears economically strongly beneficial at all three collieries. These findings are of a similar magnitude to those of Coaltech 2020 (see Section 2.3.2.1) and represent additional income of between 5 and 13 % of the annual turnover of the respective mines in 2005. Fluctuations in the export price of coal will have an influence on the economic predictions. In 2005 the coal price, as measured by the South African Coal Report spot price indicator, fluctuated between R256/t and R353/t (SACR, 2006; www.oanda.com). This equates to a 14 % decrease and a 19 % increase from the average for 2005. Although these fluctuations are relatively minor, a sensitivity analysis was conducted to determine the effect of varying the coal price on the 10-year NPV. Figure 18 displays the sensitivity of the NPV after 10 years to variations in the coal price.

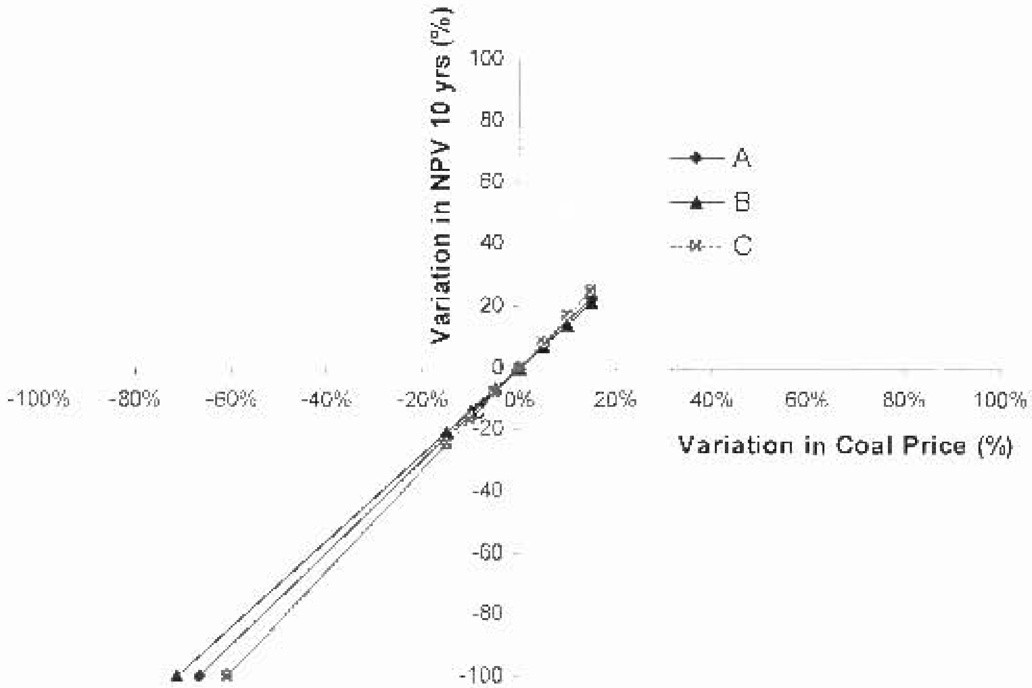

Figure 18: Sensitivity analysis for option 5

The figure indicates that the NPV is very sensitive to the coal price at all three collieries as a 5 % change in coal price translates to roughly an 8 % change in NPV. Because the NPV is relative to the current scenario, a decrease in NPV by 100 % would mean that there would be no difference, financially, between implementing option 5 and the current scenario of simply discarding the coal. As indicated in the figure, the NPV is predicted to decrease by 100 % if the coal price decreases by 60 - 70%, depending on the colliery. Therefore, this information suggests that if the coal price was to decrease by more than 60-70%, implementing option 5 is no longer financially feasible. Since the coal price is a relatively un-volatile commodity and since the export value of coal is predicted to increase over the next few years (DME, 2005c), it is an unlikely scenario that the coal price will decrease by more than 60 % and remain so for an extended period of time in the near future. Therefore, it appears from this 'order of magnitude' economic assessment that the option to beneficiate and thermally dry the ultra-fine coal is economically feasible, especially bearing in mind that the savings from reduced closure costs have not been factored into the assessment.

Considering its environmental and economic feasibility, this option is highly attractive to all three collieries. However, owing to the complex and site-specific nature of flotation, it is recommended that a detailed techno-economic study be conducted and a slurry monitoring system be put in place at each mine prior to implementation. It is important to note that the feasibility of this option is heavily dependant on the fact that there is no minimum size limit for the coal that is exported at the three collieries. Therefore, this option may not be applicable to all collieries in the industry. This option is also dependant upon the assumption that there is an export market for the additional coal that is produced if this option is implemented. Supported by interviews with the colliery managers of the three mines, and by the increase in sales of South African coal over the last 10 years (see Table 1), there is a global demand for coal at present such that any additional coal produced is likely to be readily purchased by foreign buyers. Should the demand for coal decrease in the future, it is recommended that market analyses be conducted prior to implementation of this option.

4.2.2.2 Solar dry and sell the unwashed existing ultra-fines to local power stations

This option is submitted to an economic feasibility assessment because of the associated high contractor costs. Table 19 summarises the profits for this option, while Appendix 5 contains the details of the economic assessment. The contract period for mine B is estimated to be 5 years, while the contract period for mine C is estimated to be roughly 2 years (Blenkinsop, 2005). As discussed in this Section 4.1.4.2, this option is not suitable for colliery A, so an economic assessment was not conducted here.

Table 19: Predicted net present values for option 6

Colliery	*B*	*C*
NPV (B: 5 years; C: 2 years)	R 50,000,000	R 15,000,000

Since the contractor incurs the capital costs, the payback time is irrelevant. The reductions in rehabilitation costs that would be achieved if this option is implemented have not been factored into the economic assessment. The results in Table 19 are based on non-binding quotes given by WERM. Since it is therefore probable that either or both the contractor cost and the selling price of the coal may vary, a sensitivity analysis was conducted. The results are shown in Figure 19 and are the same for both collieries.

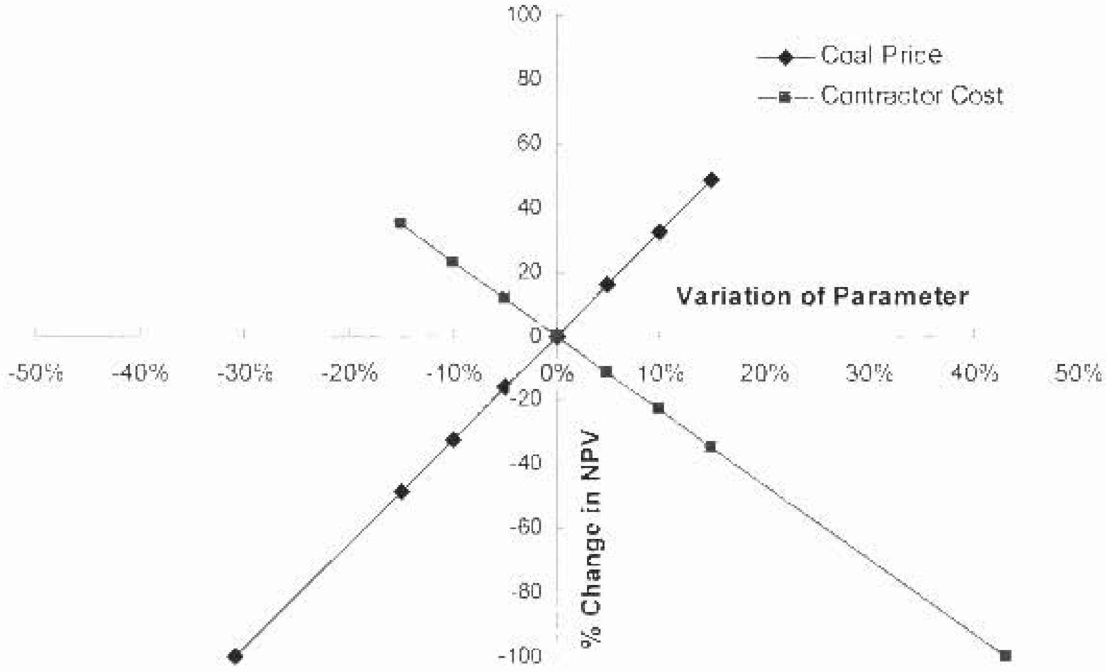

Figure 19: Sensitivity analysis for option 6

The figure indicates that the NPV is very sensitive to both the coal price and the contractor cost at both collieries as a 5 % change in coal price or contractor cost results in roughly a 12 % or 16 % change in NPV respectively. The results indicate that if the coal price used in the economic assessment decreases by 30 % or more, and the costs remain constant, then option 6 is no longer feasible. Similarly, if the contractor cost increases by more than 43 %, and the revenue remains the same, option 6 is no longer feasible. These results indicate that this option has the potential to be economically feasible, provided that a coal price that exceeds the contractor costs can be agreed upon. While it appears potentially environmentally and financially preferable, the feasibility of option 6 ultimately depends on whether the collieries are able to establish a contract agreement with the local electricity supplier, Eskom. However, since Eskom is in need of additional coal suppliers (www.miningweekly.co.za), this option may provide the collieries with an opportunity to meet these needs. Owing to the complex and site-specific nature of this option, it is recommended that a detailed techno-economic study be conducted and a slurry monitoring system be put in place at each mine prior to implementation.

The economic indicators shown in Tables 18 and 19 are also affected by other parameters such as the discount rate. However, since all of the indicators suggest that options 5 and 6 are highly financially viable, t is expected that the options will remain preferable despite minor changes to these parameters.

4.3. Summary of the slurry assessment findings

Several Cleaner Production options to reduce the amount of slurry that is wasted were identified in this chapter. The following options were identified as being feasible at all or some of the case study collieries. For each option, the type of Cleaner Production intervention referred to in Figure 1 is indicated in brackets.

- Increase the crusher top size to reduce the proportion of ultra-fines that are generated (Good house-keeping)
- Optimise the classifying cyclones to perform sharper, more precise separations (*Good house-keeping*)
- Install an automated flocculent make-up system *(Technology change, internal water recycling)*
- Beneficiate using flotation, thermal dry and export the arising ultra-fines *(Technology change, Product change, internal water recycling)*
- Solar dry and sell the unwashed existing ultra-fines to local power stations *(Product change: resource use optimisation)*

Since all five options are mutually exclusive, there is no need for further elimination. Owing to the complex, high-cost and site-specific nature of the last two options, it is recommended that detailed techno-economic studies be conducted and slurry monitoring systems be put in place at each mine prior to implementation. Of the five feasible options, two (or 40 %) are high cost and complex options, and one option requires establishing a contract agreement with an outside company (Eskom). None of the options involves the introduction of novel technologies because thermal drying and flotation are well established technologies that have been recognised as being effective on the South African Witbank and Highveld coals for many years.

Section 2.2 described that the discarded ultra-fine slurry solids are the source of several significant environmental problems, including acid mine drainage, dust release and spontaneous combustion. Therefore implementing the above options serves to reduce these impacts on the environment. As mentioned in Section 2.1.5.2, most of the water consumed in the coal washing plants is lost via the slurry. By recovering and recycling this slurry water, which can be achieved by installing the automatic flocculent make-up system and by dewatering the slurry product, the amount of water consumed in the plant is reduced.

There were several options that were eliminated because they are not feasible at present, these being:

- Convert the ultra-fines to a low smoke fuel
- Solubilise the ultra-fines to produce methane and polymers
- Produce a coal-water fuel from the slurry
- Combust the slurry in a fluidised bed combustor

These options should not be completely dismissed as technology, legislative and market changes may render them more feasible in the future.

CHAPTER 5

DISCARDS ASSESSMENT

The discarded coarse waste rock, referred to as the discards, was identified in Chapter 3 as a waste to be focused on in the Cleaner Production assessment. In response to this finding, Chapter 5 aims to identify feasible Cleaner Production options to reduce, eliminate or utilise this discard waste by presenting the findings of the detailed and feasibility phases of the assessment for the discards. Section 2.2.1.1 described that the discards are a source of acid mine drainage (AMD) and of air pollution through spontaneous combustion. Therefore, by reducing the quantity of discards that are disposed of, the extent to which AMD occurs can be reduced. As mentioned in Section 3.3.4, there is no site-specific data available quantifying the pyrite content and hence the potential for acid mine drainage of the discard dumps at any of the three mines. Therefore, reductions in environmental impacts brought about by decreasing the quantity of discards could not be quantified.

5.1. Discard Cleaner Production options

There are several general methods to reduce the amount of discards that are disposed of on a mine:

- Reduce the amount of waste rock that is mined
- Optimise the yield of the coal
- Reduce the quality of the product
- Convert the discards to a valuable product

These methods are discussed in more detail in this section.

5.1.1 Reduce the amount of waste rock that is being mined

Reducing the amount of waste rock that is mined with the coal reduces the amount of discard material that needs to be removed in the washing plant, and hence the amount of discards that are disposed of. This can be achieved by limiting excavation to the coal seams and avoiding the waste rock layers in between these seams. Prevention of roof collapse is a means of preventing the waste rock in the roof from contaminating the coal while it is still underground. However, waste material that is embedded within the coal seam is more difficult to avoid. The three case study collieries have already recognised the importance of avoiding waste rock during excavation. Geologists survey the seams and map out the areas suitable for excavation. Sections of seams that contain significant amounts of waste rock are avoided. Weak sections in the roofs are sought, tagged and reinforced.

Since Cleaner Production measures are already in place to prevent the amount of discard material that is mined to a considerable extent, these measures will not be discussed further. However, it is acknowledged that advances in precision mining may provide additional methods of reducing the amount of waste rock that is excavated.

5.1.2 Optimise the yield of the coal

This section describes the methods of optimising the processing of the different coal sizes in order to maximise the yield of product and thereby minimise the quantities of discards generated.

5.1.2.1 *Coarse and intermediate coal*

The washability characteristics discussed in Section 3.3.4 represent the maximum yield of product coal for a specified CV for the different seams. Figure 20 shows the assumed washability characteristics of the coal mined at the three collieries, as well as the operating points that reflect the yields and calorific values that the mines are currently achieving respectively.

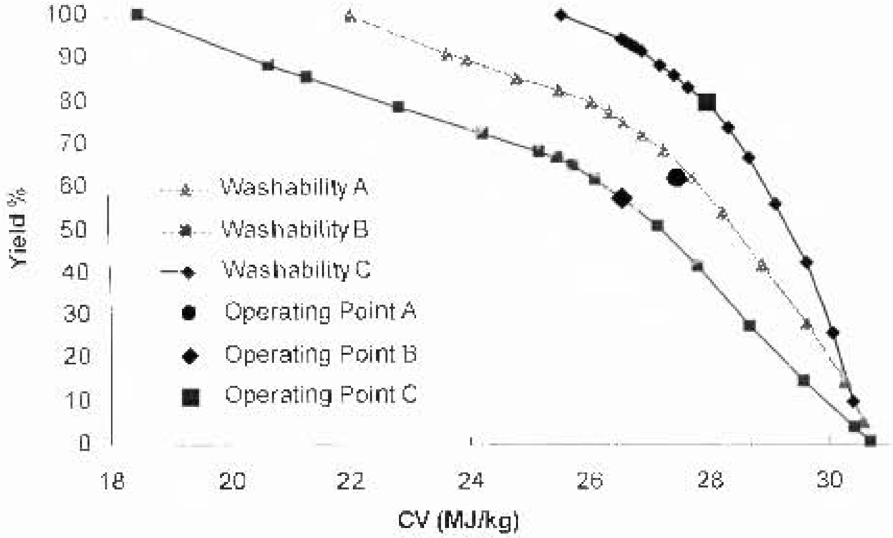

Figure 20: Washability characteristics and operating points of the coal mined at the case study collieries

These characteristics hold for gravity separating units, such as the dense-medium drums and cyclones used at all three mines, and for the 1 - 50 mm size range, i.e. that which is washed by the drums and cyclones. Observing the operating points, collieries B and C appear to be achieving the maximum yields dictated by the washabilities of the coal they are mining. This implies that the drum and cyclone units are operating at their maximum efficiency. Colliery A, however, appears to be achieving yields slightly lower than the maximum achievable. This could be due to a number of reasons including poor control of magnetite, damaged or incorrectly fitted equipment or variations in mined coal quality. A detailed investigation should be conducted to determine whether, and by what means, the yield of the clean coal can be improved by optimising the operation of the drum and cyclone washing units. As explained in Section 3.3.4, due to a lack of available data, the washability characteristics shown in Figure 20 are not site-specific: instead they represent typical characteristics for the appropriate seams. It is therefore recommended that regular detailed test-work be conducted at each colliery to determine the washability characteristics of the ROM coal specific to the respective collieries. This will ensure that the most accurate indication of the performance of the drums and cyclones can be obtained.

Another method of increasing the coarse coal yield is to decrease the product moisture content so that the 'as-received' quality of the coal increases. To compensate for this increase in quality, and to satisfy product specifications, a poorer quality product can then be produced at a higher yield. Hence decreasing the moisture of the coal decreases the amount of coal that is discarded. The coarse coal is currently mechanically dewatered to around 2 % surface moisture at the case study collieries and is therefore not in particular need of further dewatering. The intermediate coal product, however, is dewatered only to less than 6 % surface moisture at the collieries. Dewatering beyond this requires thermal drying. Thus, there is a Cleaner Production opportunity to thermally dry the cyclone product. An analysis was conducted to predict the outcome of implementing such an option. Table 20 indicates the estimated reductions in discards that can be achieved by thermally drying the intermediate coal product to 1% surface moisture, compared with the current scenario at each mine. Appendix 6 gives the full details of the analysis.

Table 20: Predicted reductions in discards from thermally drying the cyclone product

Colliery	*A*	*B*	*C*
Reduction in Discards (%)	28	12	49

Table 20 indicates that significant decreases in discards, particularly at colliery C, are potentially achievable by thermally drying the cyclone product. The economic assessment will decide whether this option is economically viable.

5.1.2.2 Fine coal

Due to the high moisture content of the spiral product, it is sometimes perceived to be financially preferable to discard all the fine coal rather than to beneficiate and dewater it. This is because the addition of the moist spiral product to the coarser coal lowers the overall calorific, and hence monetary, value of the combined coal. In order to compensate for this moisture, so as to meet the export specifications, the coarse coal needs to be beneficiated to a higher calorific value. This results in a lower yield of coarse coal, and hence more discards are produced. Thus, the practice of discarding fine coal may not necessarily result in larger quantities of discard material than the practice of washing the fine coal. Due to this uncertainty, an assessment was conducted to determine which fine coal management option results in the least amount of discards being generated, and which option is the most economically feasible. The options that were investigated are:

- Discard all the fine coal
- Add all the unwashed fines to the export coal
- Wash the fines using spirals and add the product to the export coal
- Wash the fines using dense-medium cyclones (DMC) and add the product to the export coal
- Wash the fine coal using spirals, thermally dry the product and add it to the export coal

For all the options except the last mentioned, the fines are assumed to be dewatered to 25 % total moisture by dewatering screens prior to their final destination at all three mines. The fines are also assumed to be beneficiated to 28 MJ/kg in both the dense-medium cyclones and the spirals at all three mines. Although these assumptions may not reflect the current situation at each mine, it allows the performance of each option to be evaluated relative to the three collieries and to the other options.

The last option investigates the influence of dewatering the spiral product further than the 25 % achieved using only dewatering screens. Thermal drying to 1 % surface moisture was chosen as it was found to be the most cost effective ultra-fine coal dewatering method in Chapter 4. Although the process is still being developed, using dense-medium cyclones to beneficiate fine coal is being increasingly considered as a possible alternative to spirals (de Korte, 2000b), and was therefore included as an option.

The details of the full assessment are shown in Appendix 7 while the results are summarised in Figures 21 and 22. Figure 21 compares the discards generated for each option for each mine *relative* to the option to *discard all of the fine coal*. Negative values therefore indicate that less discards are generated compared with the option to discard all the fines.

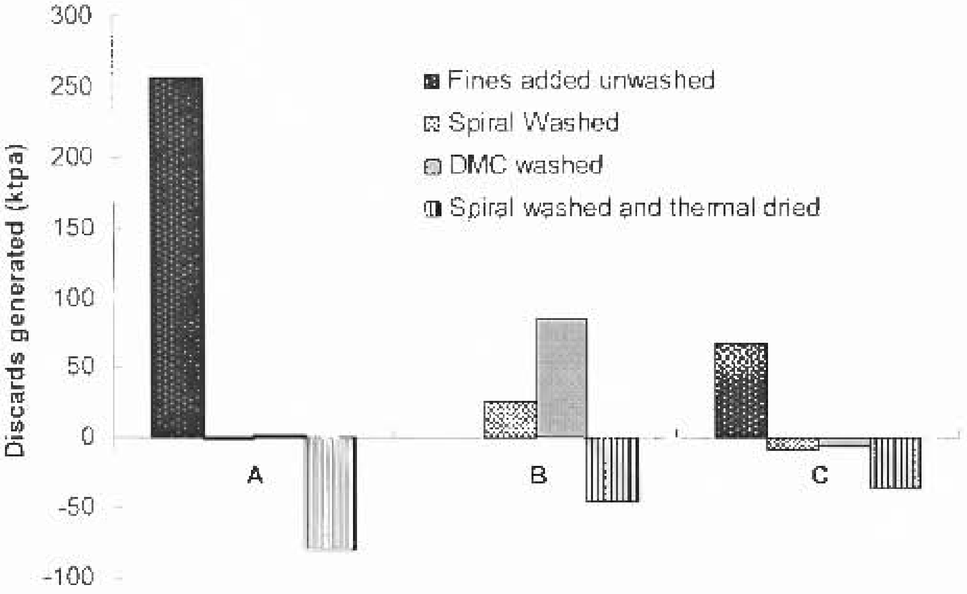

Figure 21: Predicted discards generation relative to the option to discard the fine coal

There are several conclusions that can be drawn from the information in Figure 21. At all three mines, the option to wash the fines using spirals and then to thermally dry the product results in considerably less discards being generated than with any of the other options. This is due to the addition of high quality fine coal to the coarse coal, allowing the coarse coal to be washed to a lower quality, and hence a higher yield. In all three cases, the spirals result in less discards than the dense-medium cyclones. Therefore dense-medium cyclones, even in conjunction with thermal drying, are not considered further.

The answer to the concern as to whether less discards are generated by washing the fines in spirals without thermal drying or by simply discarding all the fine coal, is different for each mine. For colliery A it makes no difference, for colliery B it is better to discard all the fine coal, and for colliery C it is better to operate the spirals. These differences are mainly due to the differing characteristics of the various coal seams. 4-seam coal has been found to be more difficult to beneficiate with spirals than 2-seam coal (de Korte, 2004b). Since colliery B only mines 4-seam coal, colliery A mines 2-seam and 4-seam coal in equal parts, and colliery C mines only 2-seam coal, these results are not unexpected.

Although not clear in Figure 21, colliery B cannot achieve the export specifications for the option of adding the unwashed fines to the export coal as the quality of the moist unwashed 4-seam fines is particularly poor.

The following figure indicates the Net Present Values (NPV) of implementing each option *relative* to the option to *discard all the fine coal*. Negative values indicate that the option is less economically feasible than the option to discard all the fines.

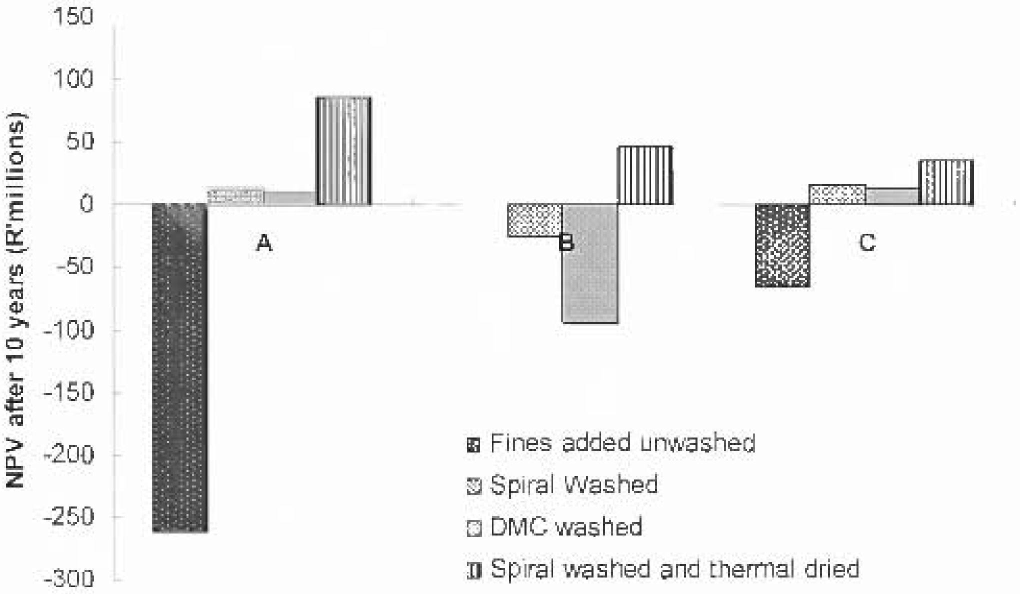

Figure 22: Predicted NPV relative to the option to discard the fine coal

The information in Figure 22 indicates that, for all three mines, the option to wash the fines with spirals followed by thermal drying to 1 % surface moisture is the most financially feasible option. This, coupled with the finding in Figure 21 that it generates the least discards, renders this fine coal management option the most favourable.

Colliery B is currently washing the coal with spirals without thermally drying the product. The results in Figures 21 and 22 indicate that this colliery would reduce the discards produced and increase their profits by discarding the fines. Whereas colliery C, which is also washing the coal with spirals without thermally drying the product, would not benefit from discarding all the fines.

Since the option to thermally dry the spiral product is convincingly the best fine coal management option to reduce discards generation, only this option will be considered further. The estimated reductions in discards that are potentially achievable if this option is implemented, compared with the option that is currently implemented at each mine, are listed in Table 21:

Table 21: Predicted reductions in discards from thermally drying the spiral product

Colliery	*A*	*B*	*C*
Reduction in Discards (%)	8	3	9

5.1.2.3 Ultra-fine coal

Chapter 4 investigates the methods of reducing ultra-fine coal waste. One of the feasible options discussed in Section 4.1.4.1 (option 5), involves using flotation to wash the ultra-fine coal followed by thermal drying the product together with the fine coal spiral product. This combined product can then be added to the coarser coal for exportation. By the same principle discussed in the previous section, this practice allows the coarse coal to be washed at a lower quality and hence less discards are produced. Thus implementing this option brings about a reduction in discards in addition to the reductions in slurry, and is therefore briefly discussed in this section. The estimated reductions in discards that can be achieved by implementing this option at each colliery are shown in Table 22.

Table 22: Predicted reductions in discards from thermally drying the spiral and flotation product

Colliery	*A*	*B*	*C*
Reduction in Discards (%)	15*	14	17

* This value assumes that the fine coal at colliery A is washed in spirals (like collieries B and C) instead of being discarded. Appendix 4 compares this scenario with the current scenario.

Differences in coal seam type, quantity of coal mined, and proportions of fine and ultra-fine coal in the feed, are responsible for the differing reductions in discards at the three mines. Comparing Tables 21 and 22, the option to dry both the fine and ultra-fine coal results in fewer discards being generated than the option to dry the fine coal alone. Thus, if this option is implemented there is no need to implement the option to thermally dry only the spiral product that is discussed earlier in this chapter in Section 5.1.2.2. and, since this option is discussed in detail in Chapter 4, it will no longer be discussed in this chapter.

In summary, Cleaner Production options to reduce the amount of discards are:

- *Improve the performance of the dense-medium drums and cyclones at colliery A*
- *Thermally dry the cyclone product*
- *Wash the fine coal using spirals, thermal dry the product and add it to the export coal*
- *Thermally dry the spiral and flotation products and add them to the export coal*

5.1.3 Reduce the quality of the product

Modifying the washing process to produce a product that is higher in ash results in less coal being discarded. Taking this concept to the extreme, the production of discards can be completely avoided by selling the unwashed ROM coal. This option has many environmental benefits, including the reduction of raw materials and electricity consumed in the washing plant and the reduction of a potential source of AMD (i.e. the discards). However, environmental problems due to the utilisation of coal that is higher in sulphur content need to be considered. Unwashed coal is not suitable to export due to its high ash content. After transportation costs, washed export coal fetches approximately R220/t (see Appendix 4) while Eskom, for example, paid R66/t for unwashed coal in 2005 (SACR, 2006). Therefore, it is unlikely that this option is economically feasible. Some collieries, however, sell part of their unwashed coal, such as at colliery B. This is typically either because they are tied to a contractual agreement or because the quantity of mined coal exceeds the plant capacity.

In summary, a Cleaner Production options to reduce discard waste is:

- *Sell unwashed ROM coal*

5.1.4 Convert the discards to a valuable product

There are two different methods of converting the discards into a useful product. These are listed and then discussed in the following section. By utilising and converting the discards into a product, a waste is being prevented or at least reduced.

- *Dewater and sell the discards*
- *Rewash and sell the discards*

Owing to the ongoing development of technologies for discards utilisation world-wide, it is likely that several other options will become viable in the future or are currently available.

5.1.4.1 Dewater and sell the discards

Colliery B currently dewaters and sells their arising spiral, i.e. fine coal, discards to a local brick manufacturing company. The spiral discards are dewatered using dewatering cyclones followed by dewatering screens. Since the coal needs to contain a certain amount of moisture to maintain its ability to be handled, further dewatering is not required. There are several brick manufacturing companies in the area surrounding the mines. There is a therefore a potential market into which collieries A and C may also be able to sell. Since spiral washing, followed by drying, has been identified as the optimum fine coal management strategy in Section 5.1.2.2, spiral discards are likely to be available for utilisation. Collieries A and C have already installed spirals and dewatering screens. Therefore this option requires no additional capital investment. According to their inland marketing manager, colliery B receives R23/t of spiral discard, but prices up to R30/t are known. This, coupled with the benefits of reducing the amount of coal that is discarded on the dumps, renders this option both financially and environmentally attractive. It should be noted, however, that this option might lead to increased air emissions during the brick-making process due to the elevated levels of sulphur in the discards compared with the ROM coal.

5.1.4.2 Rewash and sell the discards

This option is discussed in Chapter 4. Section 4.1.4.2 describes the option to blend rewashed discards with reclaimed slurry to form a product that can be sold to local power stations. Approximately 50 % of the arising and existing discards are recovered as a rewashed product. Therefore this option will potentially halve the amount of coal that is discarded. Since this option was discussed in Chapter 4, it will not be discussed further in this chapter.

5.2. Feasibility of the discard reduction options

The various Cleaner Production options that have been suggested to reduce discards generation at the case study collieries are summarised below. Only those options that have not already been discussed in other chapters are listed:

1. Improve the performance of the drums and cyclones
2. Thermally dry the cyclone product
3. Wash the fines using spirals and thermally dry the product
4. Sell the unwashed ROM coal
5. Dewater and sell the spiral discards

Option 1 is only applicable to colliery A, and options 4 and 5 are already implemented at colliery B and are therefore not applicable to this colliery. As described in Section 2.4.1.4, each option is subjected to a feasibility assessment, commencing with the feasibility scan.

5.2.1 Feasibility scan

The purpose of the feasibility scan is to eliminate any options that do not meet certain criteria. The criteria are shown in the left hand column of the following table. Negative answers (X) signify that the option is unsuitable and will not be considered any further. The option numbers in the table correspond to the option numbers listed above. The information provided earlier in this chapter was used to complete this scan. The results, shown in the following table, are identical for all three mines with the exception that options 4 and 5 were not included as an option for mine B, and option 1 is only applicable to mine A.

Table 23: Results of the feasibility scan

Option no.	*1*	*2*	*3*	*4*	*5*
Technical Feasibility					
Is it a proven technology?	✓	✓	✓	N/A	✓
Is the technology currently useful to implement in SA?	✓	✓	✓	N/A	✓
Environmental Feasibility					
Is it likely to result in a net reduction in environmental impacts?	✓	✓	✓	✓	✓
Does it decrease amount of coal discarded by the mines?	✓	✓	✓	✓	✓
Economic Feasibility					
Is it potentially financially feasible at present?	✓	✓	✓	×	✓

As explained in 5.1.3, option 4 is unlikely to be economically feasible and is therefore no longer considered. Options 1 and 5 do not require large capital investments and are therefore not required to be submitted to a detailed economic assessment, as per the feasibility procedure outlined in Section 2.4.1.4. Based on the analysis, and because neither of these options are mutually exclusive, options 1 and 5 have been identified as being feasible. However, the feasibility of option 5 ultimately depends on whether the collieries are able to establish a contract agreement with the local brick manufacturers. Options 2 and 3 involve the purchasing of thermal driers which are substantial financial investments. The type of thermal dryer that is required to dry the intermediate coal is different to that required to dry fine or ultra-fine coal, so a thermal drier must be purchased specifically for each coal type. Therefore options 2 and 3 are submitted to an economic feasibility assessment.

5.2.2 Economic assessment

This section provides rough estimates of the potential savings that can be achieved by implementing options 2 and 3. The reductions in rehabilitation and closure costs that would be achieved if these options are implemented have not been factored into the economic assessments.

Options 2 and 3 are both dependant upon the assumption that there is an export market for the additional coal that is produced if this option is implemented. Supported by interviews with the colliery managers of the three mines, and by the increase in sales of South African coal over the last 10 years (see Table 1), there is a global demand for coal at present such that any additional coal produced is likely to be readily purchased by foreign buyers. Should the demand for coal decrease in the future, it is recommended that market analyses be conducted prior to implementation of this option.

5.2.2.1 *Thermally dry the cyclone product*

The results of the economic assessment for the option to thermally dry the cyclone product are presented in this section. The details of this economic assessment are shown in Appendix 6, while Table 24 provides estimates of the financial indictors for this option.

Table 24: Predicted financial indictors for option 2

Colliery	*A*	*B*	*C*
NPV (10 years)	R 200,000,000	R 100,000,000	R 50,000,000
Capital	R 9,000,000	R 6,000,000	R 7,000,000
Payback (years)	0.2	0.2	0.7

The table indicates that this option is economically strongly beneficial at all three collieries with payback times of less than one year, and indicates additional income of between 5 and 20 % of the annual turnover of the respective mines in 2005. In order to determine the influence of fluctuations of the coal selling price on the 10-year Net Present Value predicted in Table 24, a sensitivity analysis was conducted. The results are shown in Figure 23.

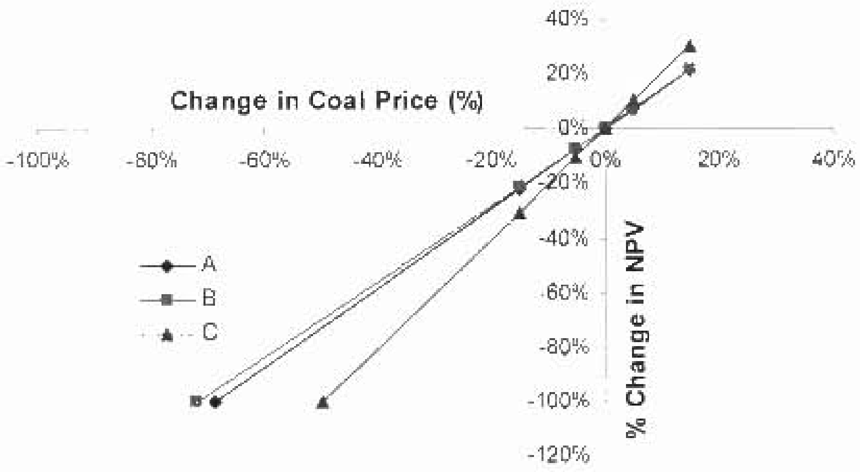

Figure 23: Sensitivity analysis for option 2

The sensitivity analysis indicates that the Net Present Values are strongly influenced by the coal price, particularly at colliery C. According to this assessment, the option to thermally dry the coarse coal remains more financially feasible than the current scenario, provided that the coal price does not decrease by more than 50 % for colliery C, and around 70 % for the other two collieries. In 2005 the coal price, as measured by the South African Coal Report spot price indicator, fluctuated between a minimum of R256/t and a maximum of R353/t (SACR, 2006; www.oanda.com) and is therefore relatively stable. The Department of Minerals and Energy (2005c) predicts that the export value of coal will increase over the next few years. If this is the case, this option is financially strongly beneficial, especially considering that the savings from reduced closure costs have not been factored into the economic assessment. Since it is not likely that transport costs and port fees will fluctuate significantly over the next few years, these parameters are not subjected to a sensitivity analysis.

This option is highly attractive, especially considering its potential to reduce the quantity of discarded coal, as shown in Table 20. With such significant benefits it is surprising that the SA coal industry has not yet adopted this idea. As discussed in Section 2.3.2.1 the perception that thermal drying is unsafe is a barrier hindering the adoption of this technology in the industry. Since there are methods of reducing the risk of coal dust explosions, and since coarse coal does not have a tendency to explode, the option to thermally dry the intermediate product is less of a risk than is commonly perceived. Due to the sheer mass of intermediate coal that is produced, compared with fine or ultra-fine coal, the bulk of the product moisture originates from the intermediate coal rather than from the finer coal. This appears to have been overlooked by the industry, as recent research has focused on processing and dewatering the high moisture-containing fine and ultra-fine products rather than on the coarser products (de Korte, 2006). It is therefore recommended that further research be conducted into coarse and intermediate coal dewatering methods.

5.2.2.2 Wash the fines in spirals and thermally dry and export the product

Earlier in this chapter Figure 22 indicated the estimated Net Present Values after 10 years of implementing option 3 relative to the option of discarding all the fines. In order to determine the feasibility of implementing option 3 in relation to the current situation, these profits are expressed in Table 25 relative to the fine coal management option that is currently in place at each mine respectively. Appendix 4 gives the financial details of the current scenario.

Table 25: Predicted financial indictors for option 3

Colliery	*A*	*B*	*C*
NPV (10 yrs)	R 90,000,000	R 30,000,000	R 10,000,000
Capital Investment	R 4,000,000	R 3,000,000	R 3,000,000
Payback time (years)	0.2	0.4	1.1

The information in Table 25 indicates that option 3 is economically strongly beneficial at all three mines. In order to determine the influence of fluctuations of the coal selling price on the Net Present Value predicted in Table 25, a sensitivity analysis was conducted. The results are shown in Figure 24.

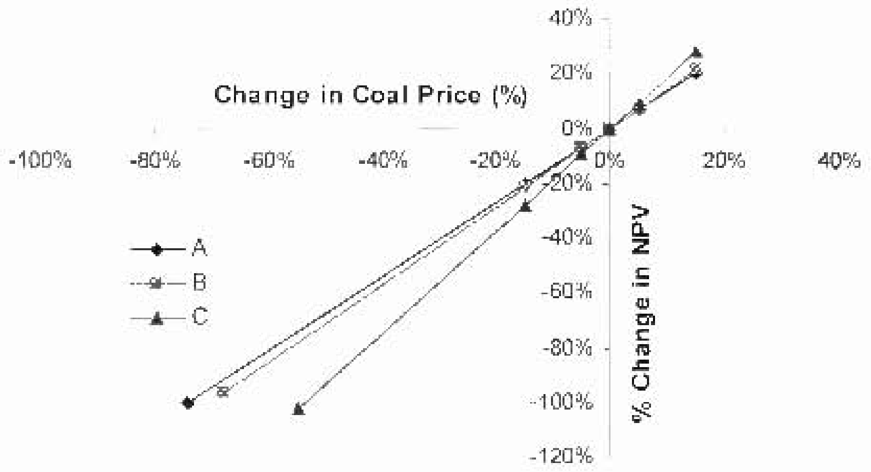

Figure 24: Sensitivity analysis for option 3

The results of the sensitivity analysis for this option are similar to those for option 2 (thermally dry the cyclone product). If the coal price decreases by more than 55 % for colliery C, and 70-75 % for collieries A and B, then this option is no longer feasible. Since the coal price remained relatively stable in 2005 and since the export value of coal is predicted to increase over the next few years (DME, 2005c), it is unlikely that the price will decrease by 50 % and remain so for an extended period of time in the near future.

The financial benefits, together with the facts that this option brings about significant reductions in discarded coal (see Table 21) and that the market into which the fine coal will be supplied (i.e. the export market that the coarser coal is currently supplying) has already been established, render this option extremely attractive. This option is incorporated into option 5 in Chapter 4 which is to thermally dry both the spiral and flotation products for exportation. The latter is preferred as fewer discards are generated (compare Tables 21 and 22) and higher profits are achievable (compare Tables 25 and 18). Therefore, option 3 in this chapter is only recommended if option 5 in Chapter 4 is not implemented.

The economic indicators shown in Tables 24 and 25 are also affected by other parameters such as the discount rate. However, since all of the indicators suggest that options 2 and 3 are highly financially viable, it is expected that the options will remain preferable despite minor changes to these parameters.

5.3. Summary of the discard assessment findings

Based on the analysis, the following options have been identified as being feasible Cleaner Production options to reduce the quantity of discarded coal material at the case study collieries. For each option, the type of Cleaner Production intervention, referred to in Figure 1, is indicated in brackets.

- Improve the performance of the drums and cyclones (*Good house-keeping*)
- Thermally dry the cyclone product (*Technology change, product change*)
- Wash the fines using spirals and thermally dry the product (*Technology change, product change*)
- Dewater and sell the spiral discards (*Product change: resource use optimisation*)

Of these options, half require high capital investments. One option requires establishing a contract agreement with an outside company (brick manufacturing company). None of the options involve the introduction of novel technologies, as thermal drying is a well-established technology that has been recognised as an effective means of dewatering coal for several years. All four options are relatively complex in nature, particularly those involving technology changes, and therefore require further technical and/or economic investigation. Detailed Life-Cycle Assessments should also be conducted to ensure that the net environmental impacts are reduced, particularly with regards to the impacts of the increased electricity consumed by the introduction of thermal driers. Since all four options are mutually exclusive, there is no need for further elimination. However, the option to thermally dry the spiral product is incorporated into the option to thermally dry the spiral and flotation products that is discussed in Chapter 4. Since the latter is predicted to result in lower discards generation and higher NPV, it is recommended that this option be implemented.

Section 2.2.1.1 described that the discards are a source of acid mine drainage. Therefore, by implementing the above options the extent to which AMD occurs can be reduced.

The following Cleaner Production options have been identified to reduce slurry waste in Chapter 4 but also happen to reduce the quantity of discards wasted.

- Wash the fines using spirals, wash the ultra-fines using flotation and thermally dry the combined products (*Technology change, product change*)
- Sell the rewashed discards (*Product change: resource use optimisation*)

CHAPTER 6

ENERGY ASSESSMENT

Chapter 3 identified that energy consumption and the reduction thereof should be one of the foci of the Cleaner Production assessment. In response to this finding, this chapter aims to identify feasible methods to reduce energy consumption at the three case study collieries by presenting the findings of the detailed and feasibility phases of the assessment for energy. As described in Section 2.3.1.1, the Department of Minerals and Energy aims to reduce the industry and mining sector's energy demand by 15 % by 2015. Based on international best practice, the DME estimates that savings of 11 % can be achieved by implementing low-cost or medium-cost interventions, and that a further 5-15% can be reduced using no-cost or low-cost interventions (DME, 2005b). The target of 15 % is therefore believed to be realistic and attainable, and can be used as a benchmark for energy reductions at the coal mines.

6.1. Energy reduction options

There are several general methods of reducing energy consumption, either directly or indirectly, on a mine:

- Monitor energy consumption
- Minimise energy consumption of the end-users
- Encourage mine workers to reduce and not waste energy consumption

Power factor correction and peak demand management are not included as they do not bring about a decrease in electricity consumed. Although reducing the impacts along a product's (i.e. energy's) life-cycle is within the scope of Cleaner Production, alternative energy sources such as solar power and renewable energy are not investigated in this chapter. This is because the purpose of this chapter is to reduce energy consumption rather than the wastes generated during the life-cycle of energy sources, and because the selection of the most appropriate energy source requires detailed Life-Cycle Assessments.

6.1.1 Monitor energy consumption

Before interventions can be proposed, it is necessary to identify the energy end-users, and how much they consume. None of the case study mines monitors the electricity, diesel or oil consumptions beyond the total colliery consumption. Thus there is no site-specific information available regarding the energy consumptions of each end-user. This lack of monitoring, common to all three mines, hinders the ability to benchmark and reduce energy consumption. Therefore, installing electricity meters and compiling detailed liquid fuel mass balances around the mines should be the first and foremost Cleaner Production interventions proposed, even though they do not directly result in energy reductions.

In summary, Cleaner Production options to reduce electricity consumption are:

- *Install electricity meters around the colliery*
- *Compile detailed liquid fuel balances*

6.1.2 Minimise energy consumption of the end-users

Energy consumption can be minimised by ensuring that the end-users are optimised to do so. Figure 14 in Chapter 3 indicates that, in all three cases, electricity accounts for more than 60 % of the total energy consumed on the mines. Since it is likely that the largest use category also represents the highest potential for savings, electricity will be the focus of discussion in this section.

Since there is no site-specific information regarding the quantities of electricity consumed by each end-user, general data from the South African coal mining industry as a whole, shown in Figure 10, is used as a rough approximation. By optimising the compressed air, motor-driven, HVAC, lighting and water heating systems, reductions in electricity consumption can be achieved. For each of these equipment systems there is a subset of options that brings about efficiency improvements. A list of such sub-options is provided in Table 26. Where available from the literature, the typical energy savings that can be achieved by implementing each such-option are also indicated in the table. While Table 26 provides a broad list of electricity saving opportunities for coal mining and processing operations, opportunities are not limited to this list.

The key to the references in Table 26 is:

1. US EPA (1998)
2. ERI (2000b)
3. www.bpa.gov
4. DETR (1996b)
5. www.osram.com
6. DETR (1996a)
7. ERI (2000a)
8. www.energystar.gov.ia

Table 26: Strategies to reduce end-user electricity consumption

	'Stand alone' Energy Savings*	*Reference*
Compressed Air Systems		
Detect and fix air leaks	> 30 %	1
Eliminate inappropriate users of air	10%	1
Replace air nozzles with energy efficient air nozzles		
Install control systems to regulate the load	10%	1
Replace throttle, poppet valve and turn-valve control with load-unload control		
Ensure the manual condensate drain traps are not jammed open		
Use cooler intake air	1% per 3°C	1
Ensure filters are clean	1% per 14 kPa	1
Ensure coolers are clean	1% per 6°C	
Replace rotary vane compressors with efficient screw types		
Regularly service the compressor every 1000 hrs (minor) and 6000 hrs (major)		
Install shut-off timer if there are long periods of zero capacity operation		
Motor Systems		
Replace standard V-belts with efficient belts	5%	2,3,4
Replace standard motors with efficient motors as they are required	3%	2,3,4
Install timers or load sensors to ensure motors are not running unnecessarily		
Undertake regular maintenance		
Match the motor with the load	2-6 %	3
Pumping		
Ensure pumps are correctly sized		
Replace throttle control with Variable Speed Drive (VSD)	<84 %	3
Replace bypass control with VSD	<84 %	3
Lighting		
Install occupancy or photoelectric sensors to reduce unnecessary lighting		
Replace incandescent lights with efficient T8 fluorescent lights and matching electronic ballasts	50%	3
Replace fluorescent lights with T8 fluorescent lights and electronic ballasts	35 - 45 %	3
Replace magnetic ballasts with electronic ballasts	14%	5
Heating, Ventilation and Air Conditioning		
Utilise compressor waste heat for space heating	30%	1,7
Ensure fans are operating at the optimum operating point and minimise operation time and air volume	5-15%	6
Hot water Heating		
Ensure electrical heater operates continuously.		2
Ensure adequate insulation of hot water		2
Install thermostats to regulate the temperature		
Replace the electric resistance heater with an efficient heat pump	10-50%	8
Continuous Miners		
Ensure that the picks are sharp and of the correct type		

* 'Stand alone' savings refer to the savings achieved if each option is implemented independently. If more than one option is implemented for an end-user, then the total savings for that end-user are iterative rather than additive.

In order to determine which sub-options in Table 26 have not already been implemented at each mine, a walk-through energy audit was conducted at each colliery. Maintenance Officers, Foremen, Engineers, Plant Supervisors, Occupational Hygienists, Mining Officers and Process Managers were among the mine employees that were consulted in order to complete the audits. The audit checklist, together with the results, can be viewed in Appendix 8. For each mine, a list was then drawn up, indicating the applicable options to reduce the various end-users' electricity consumption and totalling the known savings for each end-user. These lists can be viewed in Appendix 8. Table 27 summarises the results. The kilowatt-hour energy savings were estimated using the electricity breakdown information in Figure 10.

Table 27: Predicted annual electricity savings for the interventions identified in the audit

	Electricity Savings (%)			Electricity Savings (kWh/year)		
Colliery	*A*	*B*	*C*	*A*	*B*	*C*
Compressors	37	38	N/A	660,000	620,000	N/A
Motors	12	12	8	2,900,000	2,700,000	700,000
Pumping	unknown	unknown	0	unknown	unknown	0
Lighting	40	unknown	40	890,000	unknown	320,000
HVAC	30	30	0	690,000	630,000	0
Water Heating	30	30	30	340,000	310,000	120,000
Total	*16*	*13*	*10*	*5,480,000*	*4,260,000*	*1,140,000*

Note: N/A means *Not Applicable*

As Appendix 8 indicates, variable speed drives (VSD) have not been proposed as feasible energy saving interventions because the control philosophy adopted by the three collieries is that of manual control, rather than automatic control. Should these collieries wish to convert to automatic control, it is recommended that VSDs be installed rather than automatic control valves.

It is important to note that for several sub-options the potential savings were unknown. The savings in Table 27 are therefore conservative and are likely to be much higher in reality. The total electricity savings identified at the three collieries are in line with the total electricity savings identified for the SA coal mining industry as a whole (i.e. 13 %) that were discussed in Section 2.3.2.4.

Based on the information in Table 27, if each of the mines implements the appropriate options listed in Appendix 8, the target of 15 % total energy reduction set out by the DME will be almost within reach.

Based on Eskom's specific emissions to generate one kilo-watt of electricity, listed in Table 4, the following table indicates the predicted reduction in emissions and water consumption that are brought about by minimising the end-users' electricity consumption.

Table 28: Predicted reductions in environmental impact caused by reducing electricity consumption

Category	Unit	Annual Reductions		
Colliery		*A*	*B*	*C*
Water Used	k*l*	7000	5400	1400
Particulate Emissions	kg	1500	1200	320
Ash Produced	t	880	680	180
NO_x Emissions	t	21	17	4
SO_2 Emissions	t	48	37	10
CO_2 Emissions	t	5300	4100	1100

Table 28 indicates that significant atmospheric emissions, as well as water consumption, can be reduced by implementing the various end-user energy saving measures.

In summary, a Cleaner Production option to reduce electricity consumption is:

- *Minimise electricity consumption of the motor-driven, pumping, compressed air, HVAC, lighting and hot water heating systems*

6.1.3 Encourage mine workers to reduce energy consumption

As mentioned in Chapter 1, Cleaner Production opportunities include those that put the colliery into a better position to implement waste reduction interventions. Thus, motivating a company to adopt the Cleaner Production mind-set is considered a Cleaner Production opportunity. Mine workers who are aware of how to reduce energy consumptions and are motivated to do so, can impact significantly on energy reductions. An educational programme can be used to convey the importance and means to save energy. Monthly topics, such as 'The benefits of saving electricity', 'Fuel efficient driving' or 'What can you do to reduce diesel consumption?' can be used as themes for regular educational meetings. Truck and vehicle drivers should be trained to drive fuel-efficiently as it can result in significant fuel savings. Rewarding employee efforts to reduce energy consumption through incentives is a powerful means of achieving reductions.

In summary, Cleaner Production options to reduce energy consumption are:

- *Introduce an energy saving educational / training programme*
- *Introduce incentives to reward employee energy saving efforts*

6.2. Feasibility of the Energy Reduction Options

The various Cleaner Production options that have been generated to reduce energy consumption are summarised below:

1. Install electricity meters
2. Compile detailed liquid fuel and energy balances
3. Minimise the electricity consumption of the end-users
4. Introduce an educational / training programme
5. Introduce incentives to reward employee energy saving efforts

All of these options are applicable to the three mines with the exception of the educational programme which is already in place at mine C. As described in Section 2.4.1.4, each option is subjected to a feasibility assessment, commencing with the feasibility scan. The purpose of the scan is to discard any options that do not meet certain criteria. The criteria and the results are shown in the left hand column of the following table. Negative answers (X) signify that the option is unsuitable and will not be considered any further. The option numbers in the table correspond to the option numbers listed above. The results are identical for all three mines with the exception of option 4 (introducing an educational programme) which is not included as an option for mine C.

Table 29: Results of the feasibility scan

Option no.	*1*	*2*	*3*	*4*	*5*
Technical Feasibility					
Is it a proven technology?	✓	N/A	✓	N/A	N/A
Is the technology currently useful to implement in SA?	✓	N/A	✓	N/A	N/A
Environmental Feasibility					
Does it result in a net reduction in environmental impacts?	N/A	N/A	✓	✓	✓
Does it decrease the mine's electricity usage?	N/A	N/A	✓	✓	✓
Economic Feasibility					
Is it potentially financially feasible at present?	✓	✓	✓	✓	✓

Table 29 indicates that none of the options is unsuitable. The savings can be achieved through no-cost and low-cost interventions, especially when less efficient equipment is replaced with high efficiency equipment only when it needs replacing. Therefore, as indicated in the feasibility procedure in Figure 12, none of the options needs to undergo an economic feasibility assessment. However, converting the energy savings of option 3, i.e. reducing the electricity consumption of the end-users, into monetary terms will serve to strengthen its case for implementation. Table 30 provides estimates of the financial savings for option 3 based on the information in Table 27.

Table 30: Predicted annual savings of option 3

kWh Dependant Charge	*Rate (R/kWh)*	*A*	*B*	*C*
Energy Charge*	0.1214	R 665,000	R 517,000	-
Energy Charge‡	0.1379	-	-	R 158,000
Rate Rebalancing Levy*	0.0319	R 175,000	R 136,000	-
Total		R 840,000	R 653,000	R 158,000

* Applies to Eskom's *Nightsave Urban kVA Interval* tariff used by collieries A and B

‡ Applies to Eskom's *Nightsave Rural kVA Interval* tariff used by colliery C

The rates reflect Eskom's 2006/7 high demand season rates (Eskom, 2006). It is important to note that the financial as well as energy savings are rough estimates that are based on literature. Actual savings may differ slightly.

6.3. Summary of the energy assessment findings

Based on the analysis, and because none of these options is mutually exclusive, the following have been identified as being feasible Cleaner Production options to reduce energy consumption at the case study collieries:

- Install electricity meters (*Good-house keeping*)
- Compile detailed liquid fuel and energy balances (*Good house-keeping*)
- Minimise electricity consumption of the end-users (*Good house-keeping, Technology changes*)
- Introduce an educational / training programme (already implemented at mine C) (*Good house-keeping*)
- Introduce incentives to reward employee energy saving efforts (*Good house-keeping*)

The exact details of implementing option 3 at each colliery are listed in Appendix 8. Electricity end-user reductions were only considered for this option as electricity represents the majority of energy consumed at the collieries. However, savings can also be achieved by addressing the other energy types consumed.

Since all five options are mutually exclusive, there is no need for further elimination. Of the five feasible options, none is a high cost option. None of the options involves the introduction of novel technologies. Most of the energy savings can be achieved through improved house-keeping practices and are relatively simple to implement. Significant reductions of the environmental impacts caused by coal-fired power stations can be achieved by simply implementing low-cost, no-cost interventions.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This dissertation set out to determine whether, and by what means, Cleaner Production can be applied as a cost-effective approach to reducing the environmental impacts (particularly with regards to water quality) of the South African coal mining industry. In this chapter conclusions are drawn and recommendations are made based on the findings of the previous chapters.

The findings of Chapters 3 - 6 confirm that there are several Cleaner Production opportunities to implement Cleaner Production interventions in the case study collieries. Through a feasibility assessment, environmentally preferable, technically viable and economically beneficial options were identified for the slurry, discards and energy consumption. Chapter 3 demonstrated that the collieries are producing wastes of a similar nature, such that the environmental impacts experienced are also of a similar nature. It is therefore not surprising that the findings of Chapters 4-6 indicate that similar Cleaner Production interventions can be applied to all three collieries. Owing to the relative homogeny of the coal mining industry in South Africa, both in terms of location and processing operations, it is expected that the feasible Cleaner Production interventions identified in this thesis are relevant to the industry as a whole. However, the feasibility of the interventions did differ slightly among the case study collieries. This can be attributed to several factors, most notably differences in the management strategies of the different coal size fractions, waste disposal methods, the seam type that is mined and the house-keeping practices of the various mines. Therefore, while the options presented in this thesis may confirm the hypothesis that there are opportunities to implement Cleaner Production in the coal mining industry, site-specific assessments should be conducted at each colliery prior to implementation.

It is also likely that the opportunities for the focus wastes are not limited to those discussed in this thesis, especially as research into Cleaner Technologies develops and as Cleaner Production becomes more widely adopted. As Chapter 3 identified, there also appear to be several opportunities to implement Cleaner Production interventions for the wastes that were not focused on in this thesis.

7.1. Limitations on the findings

There are several limitations on the findings of the results. As mentioned in Section 1.5, the Cleaner Production assessments were conducted at a level that allowed feasible opportunities to be identified. It is not the aim of this thesis to provide the detailed site-specific technological specifications that are often required prior to the implementation of an option. Therefore further, more detailed techno-economic studies should be conducted before implementation of the complex options. Similarly, Life-Cycle Assessments, which are projects in their own right, were considered outside the scope of the thesis. The exclusion of this tool from the assessment means that the environmental preference of an option could only be knowledgably speculated rather than analytically determined. Therefore it is not implausible that an option proposed in this thesis results in a net increase in environmental impacts. For this reason it is recommended that detailed Life-Cycle Assessments be conducted for the more complex options.

Owing to a general lack of monitoring at the collieries that was mentioned in Chapter 3, several assumptions were made in order to predict the savings and reductions brought about by the Cleaner Production options. An example of such an assumption is the assumed breakdown of electricity consumption that is shown in Figure 10 or the assumed washability characteristics of the coal seams shown in Figure 13. As a consequence of these assumptions, actual savings may differ from those predicted in this thesis. Contradictions in values reported by the mines, which were occasionally noted, may also result in discrepancies. However, the options that underwent economic assessments were found to be strongly economically beneficial. It is therefore likely that these options will remain preferable despite minor changes to the performance data. All assumptions have been stated either in the main text or in the appendices.

Fluctuations in certain parameters, such as the coal price, will affect the results. For this reason sensitivity analyses were conducted. However, owing to the unpredictability of certain parameters, these fluctuations cannot be fully accounted for.

7.2. Nature of the identified improvement options

In order to identify and overcome the barriers that hinder the implementation of Cleaner Production interventions, it is first necessary to understand the nature of the proposed interventions. It is for this reason that this section discusses the nature of the feasible Cleaner Production options that are proposed in this thesis. For the exact details of the proposed options for the slurry, discards and energy consumption, refer to Chapters 4, 5 and 6 respectively.

As described in Section 1.5, an option was only proposed if it is financially preferable to the current situation. Therefore all the options proposed as feasible Cleaner Production interventions are cost-effective. More than 40 % of the feasible options proposed for the slurry and the discards are high cost options. Therefore significant capital investments will be required to implement Cleaner Production interventions for the discards and slurry. Technology and product changes play a significant role in reducing the quantities of slurry and discards disposed of, and are therefore relatively complex interventions. However, none of the technologies proposed is novel or unproven. The technical feasibility of using flotation to beneficiate the ultra-fines from the Witbank coalfield has been confirmed since the early 1990s (Hand, 2000). Similarly, thermal drying has been identified as an effective means of drying coal for several years and the risk of coal dust explosions can be sufficiently reduced provided that appropriate safety precautions are in place. Energy-saving Cleaner Production options, on the other hand, are generally low to no-cost interventions. Most of the energy saving options proposed involve improving house-keeping practices and are therefore relatively technologically simple to implement.

The Cleaner Production inventions for all three focus wastes result in a decrease in water consumed and/or a decrease in impacts on the quality of water. Reductions in water consumed are largely achieved by the options that involve recovering and recycling the slurry water and by reducing the amount of electricity consumed, and hence the amount of water required by the power stations. Water quality improvements are largely achieved by reducing the potential for acid mine drainage by reducing the amount of slurry and discards that are disposed of.

7.3. Overcoming Barriers

Based on the experience of other South African industries, on the experience of the mining industry in other countries, and on the findings of the case study collieries, it is expected that there will be several barriers hindering the adoption of Cleaner Production in the South African coal mining industry. The Australian mining industry is committed to addressing environmental issues and has made great strides towards adopting Cleaner Production in the industry. However, owing to the economic and social differences between the South Africa and Australia, it is expected that the process of adoption of Cleaner Production into South Africa will be more of a challenge. The expected barriers, and potential methods of overcoming them, are briefly discussed in this section.

7.3.1 Economic Barriers

An economic barrier in the mining industry that was noted by van Berkel (2000b), and was observed at the case study collieries, is the difficulty in getting approval for new ventures, especially those requiring large capital investments. Considering that many of the proposed Cleaner Production options for the slurry and the discards require large capital investments, it is likely that a difficulty in obtaining access to capital will be a barrier to the implementation of these options. Modifying company policies to facilitate, within reason, the approval of high capital Cleaner Production ventures needs to occur in order to encourage the adoption of Cleaner Production in the SA coal mining industry. However, since this thesis has demonstrated that cost-effective interventions are possible, and since decisions at the mines are predominantly based upon financial concerns, the likelihood of obtaining project approval is increased. Also, the financial benefits of reducing the closure and rehabilitation costs that result from reducing the quantities of wastes produced are an additional incentive.

7.3.2 Technological Barriers

As mentioned in Section 7.2, none of the technologies that are proposed as feasible Cleaner Production interventions in this thesis is novel or unproven. Despite the demonstrated benefits of using these technologies in South Africa, with particular reference to thermal drying and flotation, they have not been widely adopted in the South African coal mining industry. van Berkel (2000c) argues that significant changes in technology are not likely to occur unless significant changes in culture and structure occur. It is therefore expected that several behavioural and organisational changes will need to be made by the collieries. Also, as Marr et al. (2004) observed, the concept and value of Cleaner Technologies has not been fully disseminated into the SA mining industry. This problem is partially due to the fact that the minerals processing specialists have limited knowledge of how to incorporate environmental issues and Cleaner Production into their designs and processes. van Berkel (2000b) suggests that the minerals education system needs to incorporate environmental agendas into the fundamentals of the minerals tertiary curricula. A step towards addressing this problem could be to involve students in on-site Cleaner Production studies in the form of a series of vacation work projects. The benefits are two-fold. Firstly the students are able to gain an understanding of Cleaner Production and observe in practice its potential to improve process efficiencies, reduce environmental impacts and increase profits. Secondly, it provides the collieries with an additional taskforce to investigate Cleaner Production opportunities. Based on the findings of Chapters 4-6, suggested vacation work tasks for students, at the case study mines in particular, are:

- Compile detailed liquid fuel and energy balances
- Conduct audits to determine whether each motor matches its load and each pump is correctly sized
- Investigate the classifying cyclones to establish why they are not operating optimally and how their performance can be improved
- Conduct plant trials to determine whether the crusher top size can be increased
- Perform Life-cycle Assessments to compare the environmental impacts of a proposed option with the current scenario

Other methods of promoting the awareness of Cleaner Technologies that have been identified as being successful in the Cleaner Production in the Metals Finishing Industry (CPMFI) Project, as well as in the Hammarsdale Waste Minimisation Club, are awareness raising, in-house training and providing evidence of the cost savings associated with Cleaner Production interventions (van der Spuy, 2006; Barclay, 2001).

Another technological barrier is the lack of infrastructure in place to accommodate some of the suggested options. Two slurry options were eliminated in the feasibility assessment in Chapter 4 because the South African power stations are not equipped with suitable technologies. The two options are:

- Produce a coal-water fuel from the slurry
- Combust the slurry in a fluidised bed combustor

In order to overcome this barrier it is necessary that the coal utilisation companies, in partnership with the coal mines, become actively involved in the research of Clean Coal Technologies. Eskom, South Africa's largest electricity provider, has realised this need and is becoming increasingly involved in this research (Eskom, 2005).

7.3.3 Managerial barriers

A barrier that was noted at the case study collieries is that no-one is allocated the task of investigating Cleaner Production. Unless responsibilities are clearly allocated to a multi-disciplinary team of employees at each site, the collieries cannot even begin to address or adopt Cleaner Production.

As described in Chapter 3, a difficulty in obtaining performance data from the case study collieries was observed. This is due to a number of factors. Firstly, the monitoring of resources and wastes at the collieries is minimal, resulting in a shortage of information. Secondly, the information that is available is not necessarily documented or compiled into a single document. Thirdly, the available information is not made easily accessible to the various employees, such that the knowledge is not distributed around the colliery. These difficulties in obtaining useful information are a barrier towards the adoption of Cleaner Production. However, it can be avoided by implementing thorough monitoring systems, by recording and compiling the key performance indicators into a single, regularly updated document, and by ensuring that the information is properly distributed to those who may benefit from it.

7.3.4 Legislative barriers

The continuous changing of South African mining-related legislation and regulation means that environmental managerial time is often mainly spent keeping up with the legislation rather than staying ahead of it. This was noted at the three case study collieries. As discussed in Section 1.1.3.2, another legislative barrier is the lack of incorporation of Cleaner Production into the mining legislation. Since environmental awareness in small mining companies has been found to be largely driven by legislation (Dama et al., 2005), incorporating Cleaner Production directly into the legislation will serve to encourage its adoption in the smaller mining companies. The government, however, is beginning to recognise the benefits of a preventative environmental approach. The Department of Minerals and Energy, for instance, is developing an energy efficiency strategy that aims to reduce the mining and industry sector's energy consumption by 15 % by 2015 (DME, 2005b). However, the holistic concept of Cleaner Production has not yet been incorporated into the legislation.

7.4. Summary of the Key Conclusions

Based on the findings of Chapters 3-6, and since the case study collieries are relatively representative of the industry, it can be concluded that there are opportunities to implement cost-effective Cleaner Production interventions in the South African coal mining industry. More specifically, it can be concluded that there are opportunities to implement Cleaner Production interventions to reduce the industry's impacts on the quality of water. Although the slurry, discards and energy were focused on in this thesis, there appear to be a number of opportunities to reduce several other wastes generated on the coal mines. By providing evidence of cost-effective and environmentally beneficial Cleaner Production interventions in this thesis, a step towards the adoption of Cleaner Production in the South African coal mining industry has been achieved. However, the industry will only be able to fully embrace the Cleaner Production approach once several economic, technological, managerial and legislative barriers have been overcome. Co-operation, a change of mind-set and innovation are required by the coal mining industry, coal utilisation industries, government and tertiary institutions educating for the minerals industry in order to overcome these barriers.

7.5. Summary of key recommendations

Although already discussed in this chapter, this section highlights the few key recommendations that have stemmed from the findings of this dissertation.

7.5.1 Recommendations to industry and associated bodies

In addition to the recommendations made earlier in this chapter and in Chapters 3-6, the following key recommendations are made to the coal mining industry and associated bodies to overcome some of the initial hurdles of implementing Cleaner Production:

- At each colliery appoint a team that is responsible for leading and carrying out Cleaner Production assessments.
- Measure and record mine mass and energy flows (i.e. install monitoring systems, conduct mass and energy balances).
- Modify company policies to encourage the adoption of Cleaner Production by facilitating the approval of Cleaner Production ventures, by implementing training programmes and by providing incentives for the employees to practise Cleaner Production.
- Involve vacation work students in on-site Cleaner Production studies to enhance the environmental education of future mining and minerals process engineers.

7.5.2 Recommendations for further research

The following key recommendations are made for further research:

- Conduct Life-Cycle Assessments of the more complex options suggested in this thesis to ensure that only environmentally preferable options are proposed to the industry.
- Carry out Cleaner Production assessments of the coal utilisation industries, such as the electricity generation industry, to ensure a complete life-cycle Cleaner Production assessment of coal.
- Conduct further research into Clean Coal Technologies that can be applied during the mining, processing and utilisation stages of the coal life-cycle. It is important that the economic viability, environmental preference and technological feasibility of a technology are all established.
- Undertake further research into coarse and intermediate coal dewatering techniques.

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APPENDICES

Appendix 1: Colliery Electricity Breakdown

In the absence of an electricity breakdown for the South African coal mining industry, a rough estimate was a arrived at as follows:

The following figure shows a breakdown of electricity use in the mining sector, but excludes the influence of gold and platinum mining (Gildenhuys, 2006*):

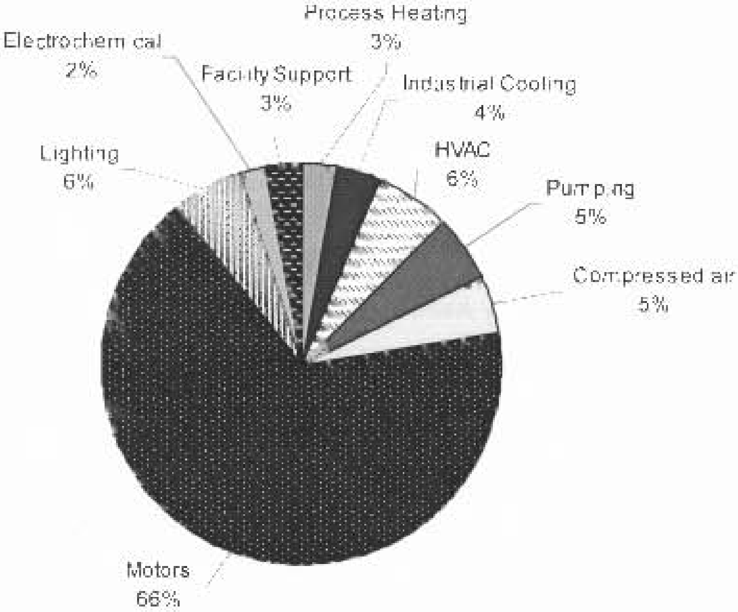

Figure 25: Breakdown of electricity consumed on a SA colliery; *Source: Gildenhuys, 2006*

Facility support refers to any non-process electricity end-use excluding heating, ventilation, air conditioning (*HVAC*) and lighting. The hot water heaters used in the laundries and change houses represent the bulk of this category. *Motors* includes all motor-driven activities, including materials handling and coal processing, but excludes any motor-driven activities that are listed as other end-users, such as compressors and pumps.

If electricity consumed in the gold and platinum mining industries is excluded, coal mining consumes roughly 50 % of the remaining electricity consumed in the mining sector (Howells, 2006[†]). Therefore, coal mining has the most significant impact on the breakdown in the above figure. For this reason, the estimated breakdown on electricity use in the coal mining industry was based on this information. The electricity users that are not applicable to coal mining, (i.e. process heating and cooling and electrochemical processing) were removed from the breakdown and the remaining end-users were re-totalled to form the breakdown shown in Figure 10.

*Gildenhuys, A. (2006): Senior Engineer, Integrated Strategic Electricity Planning (ISEP) Office, Eskom, Personal Communication, 2006

[†] Howells, M.I. (2006): *The targeting of industrial energy audits for DSM planning*; Journal of Energy in Southern Africa; Vol 17, No. 1 pp. 58-65.

Appendix 2: Colliery Information

This appendix presents the details of the relevant data pertaining to each colliery.

Colliery A

This section presents a full description of the current situation at colliery A. Colliery A is an underground mine situated in the Witbank coalfield that mines 2-seam and 4-seam coal in equal parts. The mine and coal washing plants are expected to operate for at least 20 more years. The following diagram simplistically illustrates the processing of the coal that occurs on-site.

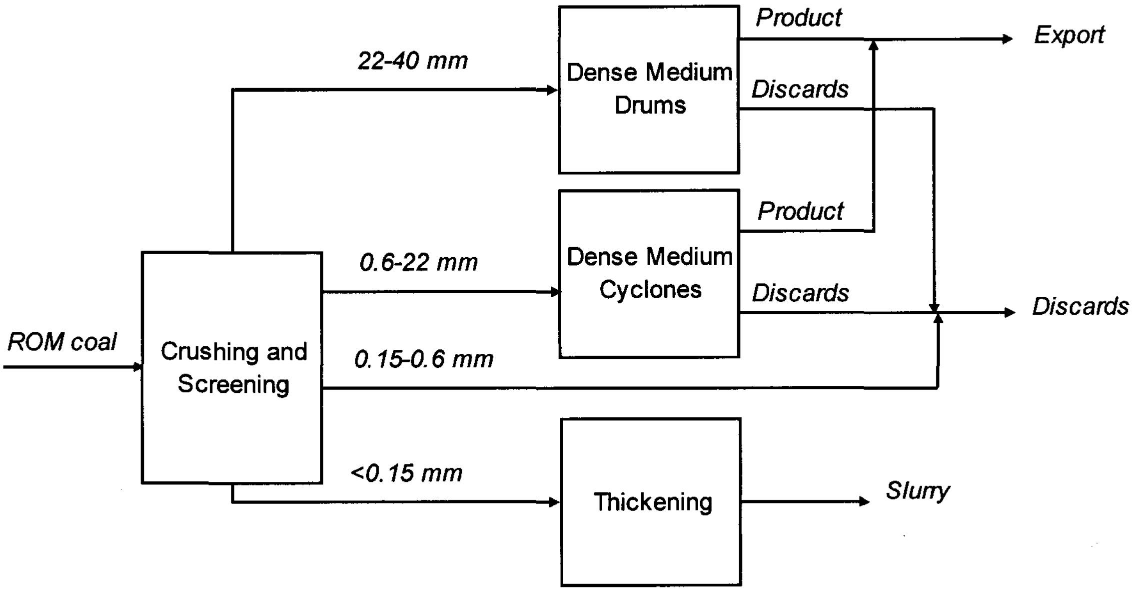

Figure 26: Block flow diagram of the coal processing at colliery A

The fine coal is discarded with the coarse discards on a surface dump. The ultra-fine coal is discarded underground in old mining shafts, in the form of a slurry. All of the saleable coal, which is a combination of the drum and cyclone products, is exported.

Coal washing plant inputs and outputs

Figure 27 displays the inputs and outputs of the coal washing plant at colliery A. The quantities that are indicated in the figure are expressed per ton of ROM coal. Table 31 shows the composition and actual tonnages of the streams where available.

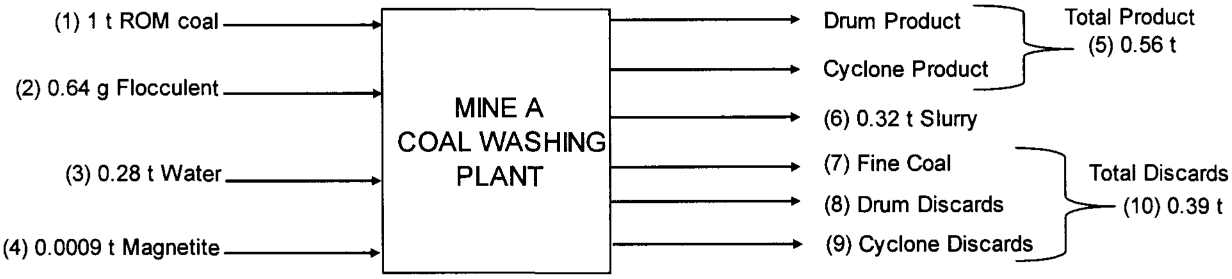

Figure 27: Inputs and outputs of the coal washing plant at colliery A per ton of ROM coal

Table 31: Composition and tonnages of the flows

Stream No.		1	2	3	4	5	6	7	8	9	10
Fixed Carbon*	%	47				55					
Ash*	%	25				14		21	55	52	50
Volatile Matter*	%	24				26					
Sulphur*	%	1.3				0.6					
Surface Moist.	%	4		100		4.8	85				
Magnetite	t/day				10						
CV*	MJ/kg	22				27.5		25	11	12	13
Total Mass	t/day	10800	0.007	3000	10	6000	3500				4200

*Air dry values

The total mass values of the ROM, clean coal and discards are air dry quantities, and therefore exclude surface moisture content. There are several significant contradictions in the reported values of the coal flows at mine A. The values reported in the Site Economic/ Labour Data report contradicted those in the year-end report, which contradicted those in the daily reports. For this reason it was decided that the daily reports, which are most likely to present the most accurate information, where consulted to predict the ROM coal, discards, slurry and magnetite consumption. The daily reports for the months of April-July 2005 were consulted to obtain the quantities. The compositions of the raw coal, clean coal and discards were all estimated from the average of the monthly averages for December 2004 and July 2005. A sample was taken on 6/9/2005 to determine the ash and calorific value of the fine coal that is discarded (stream 7). The amount of water consumed in the plant was estimated from water meter readings taken in June and July 2005. The flocculent usage was taken as the average consumption over the period October 2004 - February 2005.

Distribution of the ROM coal

In the absence of any data pertaining to the breakdown of coal fed to the various sections of the plant, with the exception that 5 % of the feed coal ends up in the slurry (see the mass balance), the following breakdown was assumed:

Table 32: Distribution of ROM coal at colliery A

Destination of the ROM coal	*%*
Drum and Cyclone	90
Fines (discarded)	5
Slurry	5

It is typical that 90 % of the feed is sent to the cyclones and drums, particularly since fine and ultra-fine coal that come into contact with moisture tend to clump together such that they are not removed in the appropriate screens and are sent to the cyclones.

Section 4.1.2 in Chapter 4 indicates that 24 % of the slurry solids are fine coal, rather than ultra-fines. If the process is modified, such that only ultra-fine coal is sent to the slurry, then the destination of the ROM coal becomes:

Table 33: Destination of ROM coal at colliery A assuming only ultra-fines in slurry

Destination of the ROM coal	*%*
Drum and Cyclone	90
Fines (discarded)	6
Slurry	4

Colliery inputs and outputs

Figure 28 shows the quantities of the major inputs and outputs of colliery A.

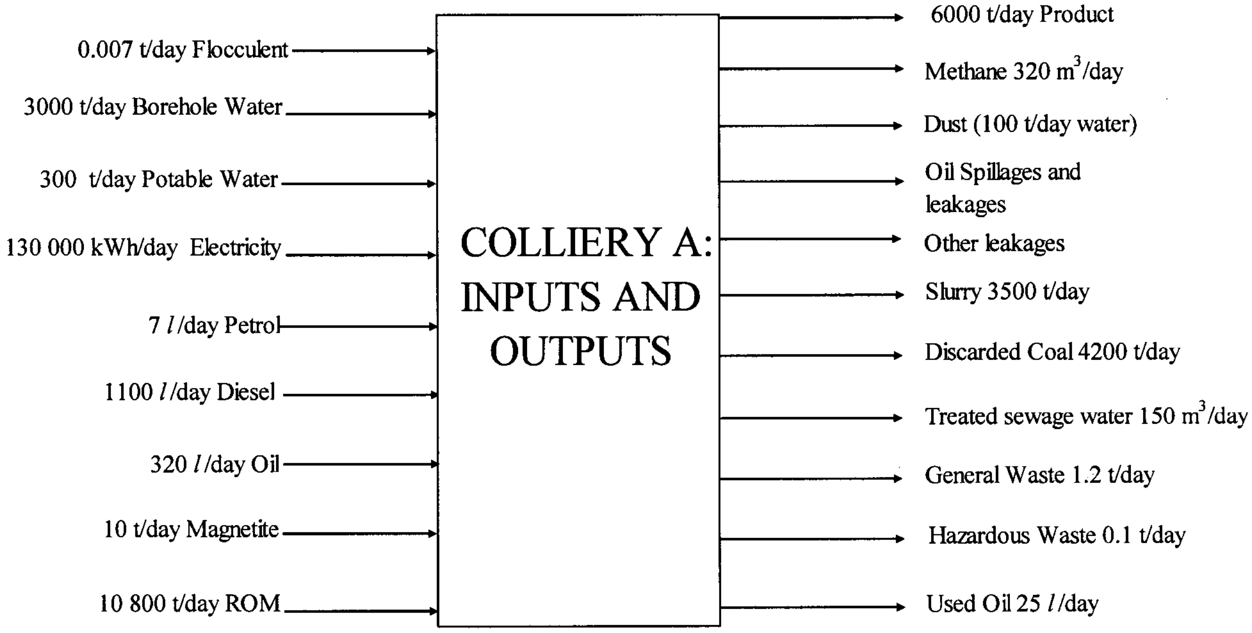

Figure 28: Major inputs and outputs of colliery A

The electricity, petrol, oil and diesel consumptions were estimated from the total respective consumptions for 2005. The quantity of used oil that is recovered was also estimated from the total annual amount recovered in 2005. The methane release rate was taken from the Methane Rating Report 3/2005 conducted by the outside consultants IT ASCA Africa. The general and hazardous wastes were estimated from the waste disposal contractor company's monthly reports for January-May 2005. The amount of potable water consumed, and the amount of water used to suppress dust, were both estimated from water meter readings taken in June and July 2005. It was estimated that the amount of sewage, or 'dirty water' that is treated is roughly equivalent to the amount of potable water consumed. Since half of the treated dirty water is released into a nearby river, while the other half is recycled back into the plant, only the released water is shown in Figure 28.

Colliery B

This section presents a full description of the current situation at colliery B. Colliery B is an underground mine situated in the Witbank coalfield that only mines 4-seam coal. The mine and coal washing plants are expected to operate for at least 15 more years. The following diagram simplistically illustrates the processing of the coal that occurs on-site.

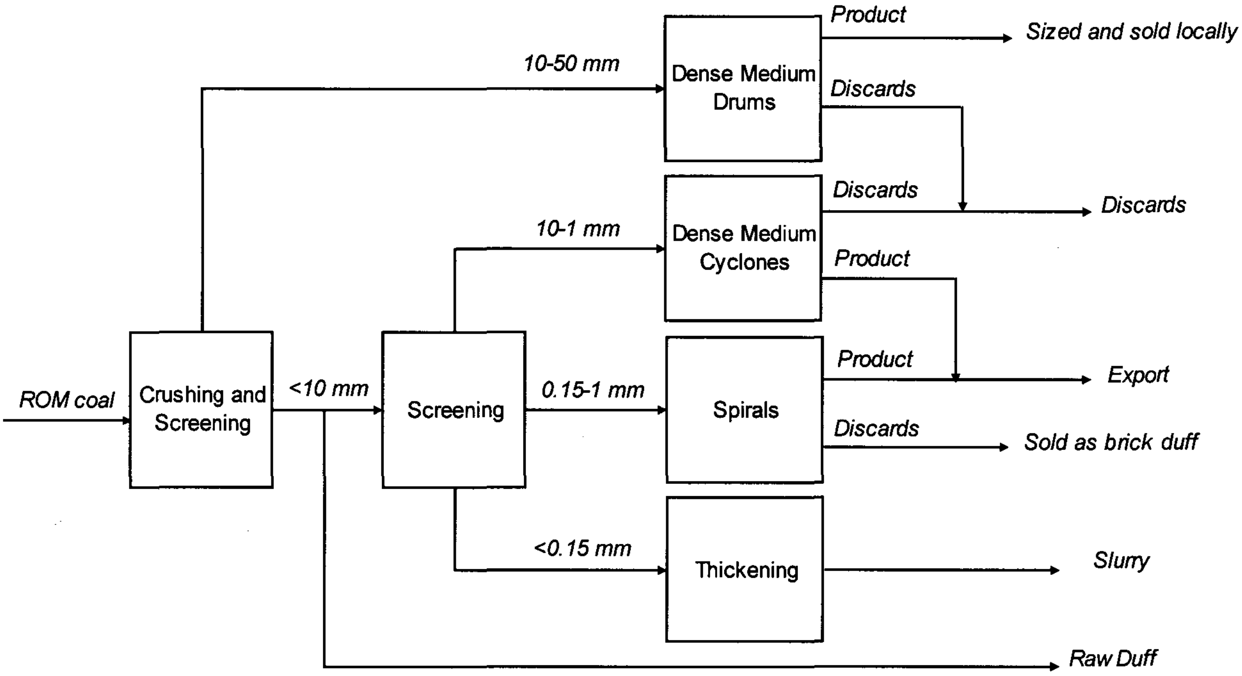

Figure 29: Block flow diagram of the coal processing at colliery B

The slurry and discards are disposed of together on a surface dam. The discards are used to make the dam walls, and the slurry is pumped into the void. The cyclone and spiral products are both centrifuged and exported, while the other products are sold locally. The unwashed raw duff is sold because the quantity of coal mined exceeds the capacity of the coal washing plant. The spiral discards, referred to as brick duff, are sold to a local brick manufacturing company.

Coal washing plant inputs and outputs

Figure 30 displays the inputs and outputs of the coal washing plant at colliery B. The quantities that are indicated in the figure are expressed per ton of ROM coal. Table 34 shows the composition and actual tonnages of the streams were available.

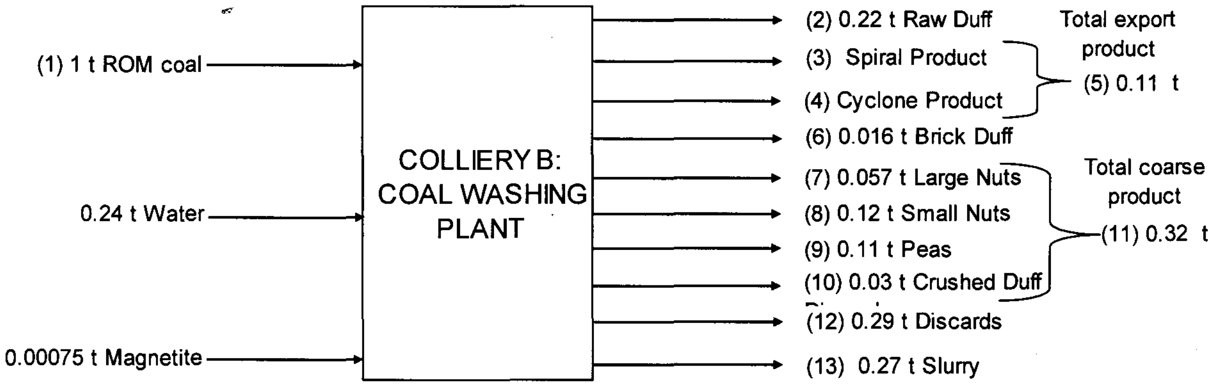

Figure 30: Inputs and outputs of the coal washing plant at colliery B per ton of ROM coal

Table 34: Composition and tonnages of the flows

Stream No.		1	2	3	4	5	6	7	8	9	10	11	12	13
Fix Carbon*	%													
Ash*	%	31	22.4	17.1	12.2	13.1		17.3	16.8	16.4	17.2	16.7	52	
Vol. Matter*	%													
Sulphur*	%													
Surf. Moisture	%			14	4									85
Cal. Value*	MJ/kg	20.8	24.1	26.2	28.1	27.7		26	26.2	26.4	26.1	26.2	13	
Total Mass	t/day	14800	3300	300	1300	1600	240	850	1800	1600	500	4800	4300	4000

*Air-dry values

Table 34 indicates that very little is known about the composition of the coal streams other than calorific value and ash. The total mass values of the ROM, clean coal and discards are air-dry quantities, and therefore exclude surface moisture content. The daily ROM, clean coal, discards, slurry and magnetite quantities, as well as their compositions, were all estimated by averaging the daily values for August 2005. Owing to a lack of a water balance, the amount of water consumed in the plant was estimated from monthly water meter readings taken from May to August 2005.

Distribution of the ROM coal

The following destinations of ROM coal were used in the assessments. These figures reflect the average daily distributions for August 2005.

Table 35: Destination of ROM coal at colliery B

Destination of the ROM coal	%
Drum	50
Raw Duff	22
Cyclone	21
Spirals	3
Slurry	4

Section 4.1.2 in Chapter 4 indicates that 18 % of the slurry solids are fine coal, rather than ultra-fines. If the process is modified, such that only ultra-fine coal is sent to the slurry, then the destination of the ROM coal becomes:

Table 36: Destination of ROM coal at colliery B assuming only ultra-fines in slurry

Destination of the ROM coal	%
Drum	50
Raw Duff	22
Cyclone	21
Spirals	4
Slurry	3

Colliery inputs and outputs

Figure 31 shows the quantities of the major inputs and outputs of colliery B.

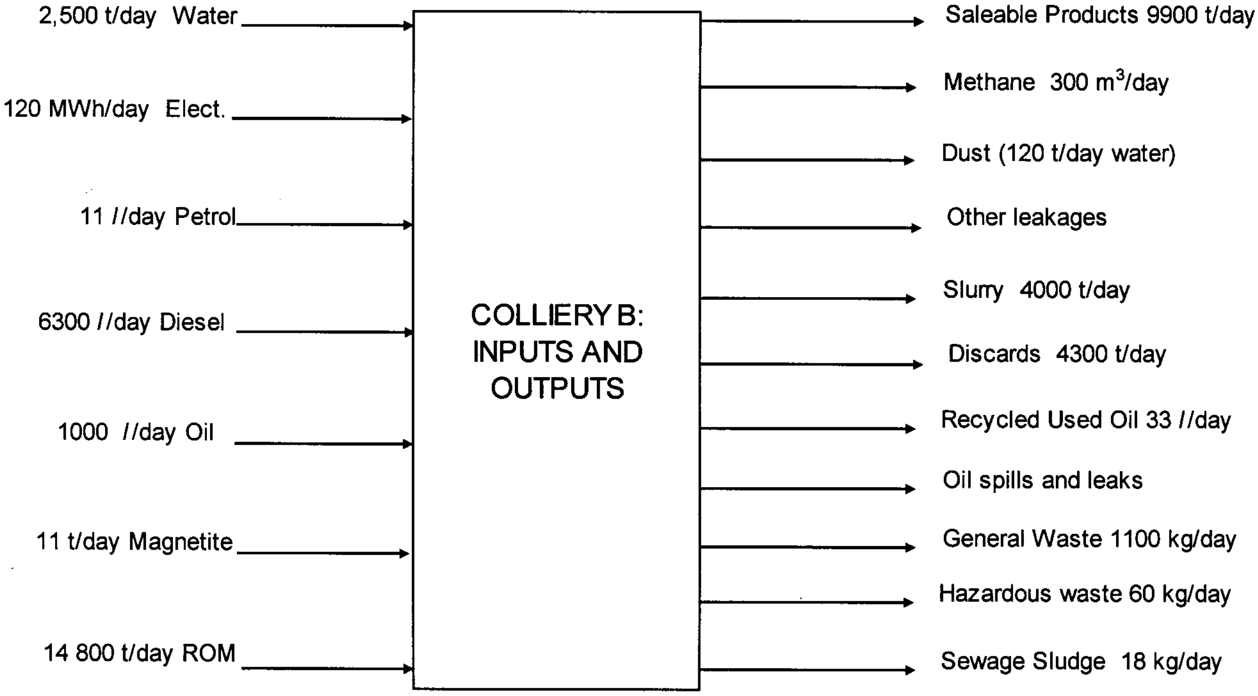

Figure 31: Major inputs and outputs of colliery B

The petrol, diesel and oil usages were estimated from the average monthly consumptions for 2004. Electricity was estimated from the average usage for the months January-May 2004. The methane release rate was taken from the Methane Rating Annual Review Report 9/2004 conducted by the outside consultants IT ASCA Africa. The quantities of general, hazardous wastes and sewage sludge were estimated from the waste disposal contractor company's monthly reports for January-May 2005.The recycled used oil quantities were taken as the average of the July and August 2005 amounts. Owing to a lack of a water balance, the amount of water consumed in the colliery, as well as the quantity used to suppress dust, was estimated from monthly water meter readings taken from May to August 2005.

Colliery C

This section presents a full description of the current situation at colliery C. Colliery C is an underground mine situated in the Highveld coalfield that only mines 2-seam coal. The mine and coal washing plants are expected to operate for at least 20 more years. The following diagram simplistically illustrates the processing of the coal that occurs on-site.

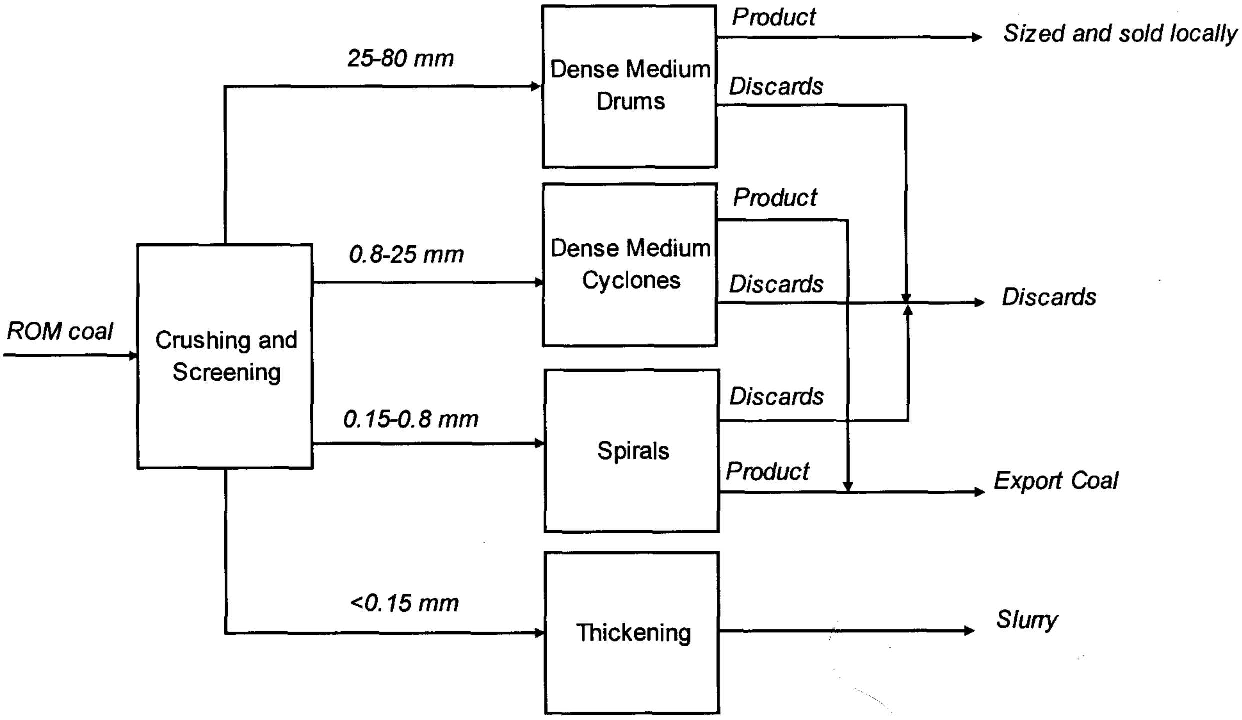

Figure 32: Block flow diagram of the coal processing at colliery C

The slurry and discards are disposed of together on a surface dam. The discards are used to make the dam walls, and the slurry is pumped into the void. The cyclone and spiral products are exported, while the other products are sold locally. The spiral product is dewatered in a centrifuge together with the 1-6 mm fraction of the cyclone product.

Coal washing plant inputs and outputs

Figure 33 displays the inputs and outputs of the coal washing plant at colliery C. The quantities that are indicated in the figure are expressed per ton of ROM coal. Table 37 shows the composition and actual tonnages of the streams were available.

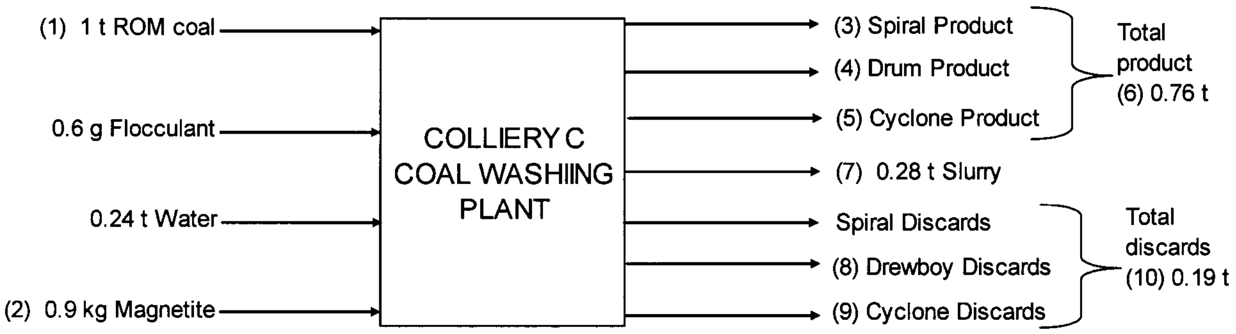

Figure 33: Inputs and outputs of the coal washing plant at colliery C per ton of ROM coal

Table 37: Composition and monthly tonnages of the flows

Stream No.		1	2	3	4	5	6	7	8	9	10
Fixed Carbon*	%				58	57			19	16	
Ash*	%	26			12	12			60	62	
Vol. Matter*	%				27	26			18	18	
Sulphur*	%				0.6	0.4			1.2	2	
Surf. Moist.	%			15	2	5.5		85	2	1.8	
Magnetite	t/month		73								
Calorific Value*	MJ/kg	23			28	28			10	10	
Total Mass	t/month	80000	73	3500	13000	44500	61000	22000			15400

* Air-dry values

The total mass values of the ROM, clean coal and discards are air dry quantities, and therefore exclude moisture content. The ROM, clean coal, discards, slurry, flocculent and magnetite quantities were estimated by averaging the monthly quantities for April-May 2005 and April 2006. The compositions of the drum and cyclone products, as well as the drum and cyclone discards were obtained from the daily averages for July 2005. The feed composition was estimated from the daily average for August 2005. The quantity of water consumed in the plant was estimated from the colliery water balance for 2004.

Distribution of the ROM coal

There is no available information describing the exact distribution of the coal to the various unit operations in the plant. Thus, combining the knowledge that 4 % of the ROM coal is sent to the slurry (see Table 37), that the coal is crushed to a relatively large size (-80 mm), that fine coal often gets sent to the cyclone because it has clumped together, and the knowledge that 23 % of the coal is coarse coal (FTP sample taken on 24 April 2006), the following distribution was assumed:

Table 38: Destination of the ROM coal at colliery C

Destination of the ROM coal	*%*
Drum	23
Cyclone	67
Spirals	6
Slurry	4

Colliery inputs and outputs

Figure 34 shows the quantities of the major inputs and outputs of colliery C.

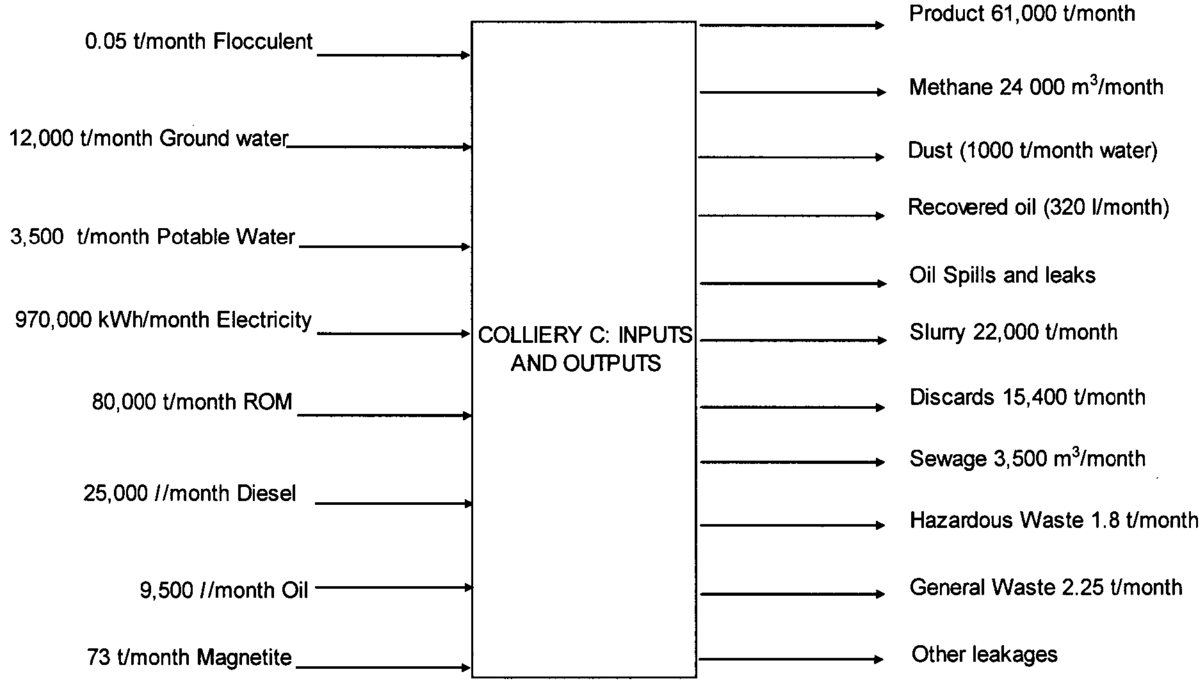

Figure 34: Major inputs and outputs of colliery C

Electricity, diesel, oil (recovered and consumed) and potable water consumptions were estimated from the average of the annual consumptions for the year 2005, quoted in the Environmental Report 2005. No petrol is consumed at this colliery. Hazardous and general wastes produced were also obtained from the annual production for 2005, quoted in the Environmental Report 2005. The colliery water balance for 2004 was used to determine the ground water consumed, and the amount of water used to suppress dust at the colliery. The amount of sewage produced was estimated from the amount of potable water consumed at the colliery. The methane release rate was taken from the Atmospheric Emissions Report 6/2004 for colliery C conducted by the outside consultants IT ASCA Africa.

A score of 5 represents a very high cost, while a score of 1 represents a low cost waste.

Environmental Impact

Based on the information provided in Section 2.2, the major environmental impacts of each waste are listed below. The allocated score is also show in the table, where five represents a high environmental impact and 1 a low impact.

Table 40: Allocation of points for the 'environmental impact' category

Waste	*Environmental Impact*	*Rating*
Methane	Greenhouse gas emissions	3
Dust	Water contamination	3
Other Leakages	Water contamination	2
Slurry	Acid mine drainage	5
Discards	Acid mine drainage	5
Sewage	Minimal	1
Hazardous Waste	Ground contamination at dump	3
General Waste	Ground contamination at dump	2
Energy Consumption	Acidification	4
Used Oil	Minimal	1
Oil Spillages / Leakages	Ground and water contamination	5

Potential for Cleaner Production interventions

The following table describes the potential for Cleaner Production interventions for each waste and lists the scores. The points were allocated as follows (BECO, 2000):

No idea:	*1*
Low potential:	*2*
High potential:	*3*

The points are allocated based on the findings of the pre-assessment and on a broad knowledge the processes at the collieries.

Table 41: Allocation of points for the 'potential for CP interventions' category

Waste	***Potential for Cleaner Production Interventions***	***Rating***
Methane	Energy utilisation, but very low methane content	2
Dust	Chemical dust suppressants, cover stockpiles or replace them with bins, tar the mine roads	A, C: 3 B: 2
Other Leakages	Concrete all of the water trenches, fix leaking hoses and taps, ensure all taps are turned off	3
Slurry	Optimise the thickeners, reduce the crusher top size, sell the ROM coal, utilise the slurry	3
Discards	Sell the ROM coal, sell the spiral discards, optimise the efficiency of the drums and cyclones	A, C: 3 B: 2
Sewage	A, B: No ideas; C: Install heaters in the change houses so that the workers do not run hot shower water to generate heat	A, B: 1 C: 2
Hazardous Waste	Ensure that only hazardous waste is placed in the bins allocated to hazardous wastes.	2
General Waste	No ideas	1
Energy Consumption	Install electricity meters, conduct fuel balances, implement energy saving interventions for compressors, motors etc.	3
Recovered Oil	No ideas	1
Oil Spillages / Leakages	Maintain equipment, educate workers, introduce incentives	3

Other

Other concerns the mine's compliance with present or known future regulations or charges and any safety or health hazards it poses to the mine employees and surrounding areas. At all three mines, methane, dust and hazardous wastes were allocated a score of 1 for the *other* category due to the direct health risks that these wastes pose. Recycled oil was allocated a score of -1 in the *other* category because it is recycled off-site.

Appendix 4: Ultra-fine Coal Dewatering Assessment

This appendix presents the methodology, assumptions and detailed findings of the option to beneficiate the ultra-fines using flotation, followed by product dewatering. The dewatered product is then combined with the export coal. Various dewatering techniques are compared in this section. Since only export coal is considered in this assessment, the coarse coal that is sold locally by mines B and C and the raw duff that is sold locally by mine B has not been included in the assessment.

Appendix 2 was used to predict the product moistures, yields and calorific values (CV) for the current scenario. Appendix 2 was also used to predict the ultra-fine coal feed rate to the flotation cells. It was assumed that the classifying cyclones had already been optimised (as suggested in Section 4.1.2) such that only ultra-fine coal is sent to the slurry. All of the collieries are required to meet the export coal net-as-received (NAR) CV specification of 6000 kcal/kg, which was made a constraint in the assessment. The product NAR CV was calculated from the gross-as-received (GAR) CV as follows:

$$GAR_{CV}\,(\text{kcal/kg}) = CV_{AD}.(1/(1\text{-}TM)).(1\text{-}IM).(238.85) \qquad [1]$$

$$NAR_{CV}\,(\text{kcal/kg}) = GAR_{CV} - (50.6).H - (5.85).O - (0.191).TM \qquad [2]$$

CV_{AD}, TM and IM refer to the product air-dry CV in MJ/kg, total moisture fraction and inherent moisture fraction respectively. O and H represent the percent oxygen and hydrogen in the coal, and were obtained from Pretorius et al. (2002).

The air-dry calorific value and the corresponding yield for the drum and cyclone products were varied until the overall product met the NAR CV specifications of 6000 kcal/kg. The assumed washability characteristics of the coal mined at the three collieries, shown in Figure 20, were used to obtain the yields corresponding to the appropriate air-dry CV for the cyclone and drum products. It was therefore assumed that the cyclones and drums wash the coal to the maximum yields dictated by the appropriate washability characteristics. In this manner, the coarse coal calorific value and yield was predicted for each option. It was assumed that the dewatering equipment will be able to achieve the performance as stated. The operating costs for 2005 were estimated from the 2000 operating costs as follows:

$$Cost_{2005} = Cost_{2000}.(PPI_{2005}/PPI_{2000}) \qquad [3]$$

The PPI_{year} represents the average Production Price Index for all commodities consumed within South Africa for a certain year. The capital costs for 2005 were assumed to be incurred in year 0 and were calculated as follows:

$$Cost_{2005} = Cost_{2000}.(X_{2005}/X_{2000}).(Capacity_2/Capacity_1)^{0.6}.(CEPCI_{2005}/CEPCI_{2000}) \qquad [4]$$

X_{year} represents the average R/$ exchange rate for a given year. $CEPCI_{year}$ represents the Chemical Engineering Plant Cost Index for a given year. Capacity represents the capacity that the unit is designed to handle. $Capacity_1$ represents the capacity of the quoted unit in 2000, and $Capacity_2$ represents the capacity that is required in the various scenarios. All capital investments were assumed to be imported.

Table 42: Assumptions and variables used in the ultra-fine coal beneficiation and dewatering assessment

2005 CEPCI	524.7	
2000 CEPCI	394.1	
2005 PPI SA	133.9	
2000 PPI SA	100	
Ave R/$ exchange 2000	6.94	(www.oanda.com)
Ave R/$ exchange 2005	6.38	(www.oanda.com)
Discount Rate (%)	15	
Hours on coal per year	6336	(assuming 22 operational days per month)
Flotation clean coal yield* (%)	75	
Combined inherent moist.* (%)	2.5	
Spiral product CV (MJ/kg)*	27	
Flotation product CV (MJ/kg)*	28	

Operating costs R/t:*	*2000*	*2005*
Spirals	R 0.69	R 0.92
Screen-bowl centrifuge	R 0.90	R 1.21
Horizontal Belt filter	R 0.95	R 1.27
Thermal Drying	R 4.00	R 5.36
Froth Flotation	R 12.00	R 16.07
Discard Disposal Coarse	R 1.50	R 2.01
Slurry disposal	R 1.00	R 1.34

*Capital Costs**	*2000*	*2005*
Belt Filter per ton fed	R 130,000	R 159,073
Flotation per ton fed	R 120,000	R 146,837
Centrifuge for 360000 tpa	R 8,000,000	R 9,789,109
Thermal Drier for 360000 tpa	R 9,500,000	R 11,624,567

Colliery	A	B	C	
FTP tpa (air-dry) (excl. ROM coal destined for the local market)	2,851,200	1,082,400	739,200	(From Appendix 2)
FOB Price (R/t)	278	279	297	(Average 2005)
Rail and Port Fees (R/t)	58	59	64	(Average 2005)
Truck fees (R/t)	0	0	17	(Average 2005)
Hydrogen % in coal[†]	4.13	3.73	4.05	
Oxygen % in coal[†]	7.40	7.91	7.32	

*2000 values were obtained from:

de Korte, G.J. (2000); *Dewatering of fine coal*, Progress Report No. 2, Report for Coaltech 2020

[†] Pretorius, C.C., Boshoff, H.P. and Pinheiro, H.J. (2002), *The Bulletin 114: Analyses of Coal Product Samples of South African Collieries 2001-2002*, Coal and Mineral Technologies (Pty) Ltd, Coal Exploration and Technology, South Africa, May 2002.

Table 43: Ultra-fine coal economic assessment for colliery A (Page 1 out of 3)

		i	V	vi	vii	
Dewatering Option	Current Scenario: Discard Fines, Discard Ultra-fines	Discard Fines; Flotation ultra-fines and Belt filter	Discard fines; flotation ultra-fines + thermal dry (8.4 % TM)	Discard fines; flotation ultra-fines + thermal dry (5.5 % TM)	Discard fines; flotation ultra-fines + thermal dry (3.5 % TM)	Spiral fines; flotation ultra-fines + thermal dry (3.5 % TM)
Per 100 tons of FTP :						
Tons ex Cyclone and Drum	58.95	54.62	59.09	59.67	60.00	60.44
Tons ex Spirals	0.00	0.00	0.00	0.00	0.00	4.14
Tons ex Flotation	0.00	3.06	3.06	3.06	3.06	3.06
Total	58.95	57.68	62.15	62.73	63.06	67.64
CV ex Cyclone + Drum (AD)	27.54	27.90	27.53	27.48	27.45	27.41
CV ex Spirals (AD)						27.00
CV ex Flotation (AD)		28.00	28.00	28.00	28.00	28.00
Combined CV MJ/kg (AD)	27.54	27.91	27.55	27.51	27.48	27.41
Moist ex Cyc + Drum (%)	7.30	7.30	7.30	7.30	7.30	7.30
Moist ex Spirals (%)						3.48
Moist ex Flotation (%)		30.00	8.35	5.43	3.48	3.48
Inherent Moist (%)	2.50	2.50	2.50	2.50	2.50	2.50
Combined Moist (%)	7.30	8.50	7.35	7.21	7.11	6.89
CV kcals/kg NAR	6000	6000	6000	6000	6000	6000
FOB Price (R/t NAR)	R 278	R 278	R 278	R 278	R 278	R 278
Tons railed p.a. (incl. moist)	1,767,813	1,752,495	1,864,816	1,879,320	1,887,291	2,019,553
Railage + Port fees per annum	R 101,896,753	R 101,013,791	R 107,487,989	R 108,323,997	R 108,783,478	R 116,407,052
Revenue per annum	R 491,452,071	R 487,193,511	R 518,418,821	R 522,450,921	R 524,667,016	R 561,435,819
Contribution per annum	R 389,555,318	R 386,179,720	R 410,930,833	R 414,126,924	R 415,883,538	R 445,028,766

Ultra-fine coal economic assessment for colliery A continued (page 2 out of 3)…

		i	v	vi	vii	
Dewatering Option	Current Scenario: Discard Fines, Discard Ultra-fines	Discard Fines; Flotation ultra-fines and Belt filter	Discard fines; flotation ultra-fines + thermal dry (8.5 % TM)	Discard fines; flotation ultra-fines + thermal dry (5.5 % TM)	Discard fines; flotation ultra-fines + thermal dry (3.5 % TM)	Spiral fines; flotation ultra-fines + thermal dry (3.5 % TM)
Tons per annum :						
Spiral Product	0	0	0	0	0	118,040
Feed to Froth Flotation	0	116,329	116,329	116,329	116,329	116,329
Froth Product	0	87,247	87,247	87,247	87,247	87,247
Discards (Ultra-fine)	116,329	29,082	29,082	29,082	29,082	29,082
Discards (Coarse)	1,054,089	1,177,546	1,050,097	1,033,560	1,024,151	893,566
Tons per hour :						
Spiral Product	0.0	0.0	0.0	0.0	0.0	18.6
Feed to Froth Flotation	0.0	18.4	18.4	18.4	18.4	18.4
Froth Product	0.0	13.8	13.8	13.8	13.8	13.8
Operating cost :						
Spirals	R 0	R 0	R 0	R 0	R 0	R 158,055
Screen-bowl centrifuge	R 0	R 0	R 0	R 0	R 0	R 0
Horizontal Belt filter	R 0	R 110,982	R 110,982	R 110,982	R 110,982	R 110,982
Thermal Drying	R 0	R 0	R 467,293	R 467,293	R 467,293	R 1,099,514
Froth Flotation	R 0	R 1,869,174	R 1,869,174	R 1,869,174	R 1,869,174	R 1,869,174
Discard Disposal	R2,272,902	R2,404,041	R2,148,061	R2,114,846	R2,095,948	R1,833,669
Total OPEX	R2,272,902	R4,384,197	R4,595,510	R4,562,296	R4,543,398	R5,071,394
Capital cost :						
Horizontal belt filter	R 0	R 2,190,436	R 2,190,436	R 2,190,436	R 2,190,436	R 2,190,436
Thermal dryer	R 0	R 0	R 4,662,193	R 4,662,193	R 4,662,193	R 7,790,349
Froth Flotation plant	R 0	R 2,695,921	R 2,695,921	R 2,695,921	R 2,695,921	R 2,695,921
Total CAPEX	R 0	R 4,886,356	R 9,548,549	R 9,548,549	R 9,548,549	R 12,676,705

Ultra-fine coal economic assessment for colliery A continued (page 3 out of 3)...

Dewatering Option	Current Scenario: Discard Fines, Discard Ultra-fines	i Discard Fines; Flotation ultra-fines and Belt filter	v Discard fines; flotation ultra-fines + thermal dry (8.5 % TM)	vi Discard fines; flotation ultra-fines + thermal dry (5.5 % TM)	vii Discard fines; flotation ultra-fines + thermal dry (3.5 % TM)	Spiral fines; flotation ultra-fines + thermal dry (3.5 % TM)
Net Contribution p.a.	R 387,282,416	R 381,795,522	R 406,335,322	R 409,564,628	R 411,340,140	R 439,957,373
Relative to Current Scenario	R0	(R5,486,894)	R19,052,906	R22,282,212	R24,057,724	R52,674,957
NPV Analysis						
Year						
0	R0	(R4,886,356)	(R9,548,549)	(R9,548,549)	(R9,548,549)	(R12,676,705)
1	R0	(R4,771,212)	R16,567,745	R19,375,837	R20,919,760	R45,804,310
2	R0	(R4,148,880)	R14,406,734	R16,848,554	R18,191,096	R39,829,835
3	R0	(R3,607,722)	R12,527,595	R14,650,916	R15,818,344	R34,634,639
4	R0	(R3,137,149)	R10,893,561	R12,739,927	R13,755,082	R30,117,077
5	R0	(R2,727,956)	R9,472,662	R11,078,198	R11,960,941	R26,188,763
6	R0	(R2,372,136)	R8,237,097	R9,633,215	R10,400,818	R22,772,837
7	R0	(R2,062,727)	R7,162,693	R8,376,709	R9,044,190	R19,802,467
8	R0	(R1,793,675)	R6,228,429	R7,284,095	R7,864,513	R17,219,537
9	R0	(R1,559,718)	R5,416,025	R6,333,995	R6,838,707	R14,973,510
10	R0	(R1,356,276)	R4,709,587	R5,507,822	R5,946,701	R13,020,444
NPV (10 yrs)	**R0**	**(R32,423,807)**	**R86,073,579**	**R102,280,719**	**R111,191,602**	**R251,686,715**
Payback Period (years)	0.00	-0.89	0.50	0.43	0.40	0.24
Return on Investment %		-112.29	199.54	233.36	251.95	415.53

Table 44: Ultra-fine coal economic assessment for colliery B (Page 1 out of 3)

		i	ii	iii	iv	v	vi	vii
Dewatering Option	Current Scenario: Spiral and Centrifuge Fines, Discard Ultra-fines	Spiral Fines; Flotation ultra-fines and Belt filter	Spiral fines; Flotation ultra-fines + screenbowl (20% TM)	Spiral fines; Flotation ultra-fines + screenbowl (16% TM)	Spiral fines; Flotation ultra-fines + screenbowl (12% TM)	Spiral fines; flotation ultra-fines + thermal dry (8.4 % TM)	Spiral fines; flotation ultra-fines + thermal dry (5.5 % TM)	Spiral fines; flotation ultra-fines + thermal dry (3.5 % TM)
Per 100 tons of FTP :								
Tons ex Cyclone	26.97				28.20	36.80	39.44	41.20
Tons ex Spirals	8.15				8.15	8.15	8.15	8.15
Tons ex Flotation	0.00				9.00	9.00	9.00	9.00
Total	35.12				45.35	53.95	56.59	58.35
CV ex Cyclone (AD)	28.14				28.10	27.35	26.96	26.74
CV ex Spirals (AD)	27.00				27.00	27.00	27.00	27.00
CV ex Flotation (AD)		Cannot meet export specification of 6000 kcal/kg for options i-iii			28.00	28.00	28.00	28.00
Combined CV MJ/kg (AD)	27.88				27.88	27.41	27.13	26.97
Moist ex Cyclone (%)	6.50				6.50	6.50	6.50	6.50
Moist ex Spirals (%)	16.00				12.25	8.35	5.43	3.48
Moist ex Flotation (%)					12.25	8.35	5.43	3.48
Comb. Moist (%)	8.70				8.67	7.09	6.18	5.61
Comb. Inherent moist (%)	2.50				2.50	2.50	2.50	2.50
CV kcals/kg NAR	6000				6000	6000	6000	6000
FOB Price (R/t NAR)	R 279				R 279	R 279	R 279	R 279
Tons railed p.a. (incl. moist)	405,974				524,056	612,791	636,527	652,406
Railage + Port fees p.a.	R 24,143,258				R 31,165,598	R 36,442,688	R 37,854,266	R 38,798,607
Revenue p.a.	R 113,266,672				R 146,211,564	R 170,968,723	R 177,591,059	R 182,021,378
Contribution p.a.	R 89,123,414				R 115,045,966	R 134,526,035	R 139,736,793	R 143,222,771

Ultra-fine coal economic assessment for colliery B continued (page 2 out of 3)...

Dewatering Option	Current Scenario: Spiral and Centrifuge Fines, Discard Ultra-fines	i Spiral Fines; Flotation ultra-fines and Belt filter	ii Spiral fines; Flotation ultra-fines + screenbowl (20% TM)	iii Spiral fines; Flotation ultra-fines + screenbowl (16% TM)	iv Spiral fines; Flotation ultra-fines + screenbowl (12% TM)	v Spiral fines; flotation ultra-fines + thermal dry (8.4 % TM)	vi Spiral fines; flotation ultra-fines + thermal dry (5.5 % TM)	vii Spiral fines; flotation ultra-fines + thermal dry (3.5 % TM)
Tons per annum :								
Spiral Product	88,216				88,216	88,216	88,216	88,216
Feed to Froth Flotation	0				129,888	129,888	129,888	129,888
Froth Product	0				97,416	97,416	97,416	97,416
Discards (Ultra-fine)	129,888				32,472	32,472	32,472	32,472
Discards (Coarse)	572,373				559,060	465,973	437,398	418,348
Tons per hour :		Cannot meet export specification of 6000 kcal/kg for options i-iii						
Spiral Product	13.9				13.9	13.9	13.9	13.9
Feed to Froth Flotation	0.0				20.5	20.5	20.5	20.5
Froth Product	0.0				15.4	15.4	15.4	15.4
Operating cost :								
Screen-bowl centrifuge	R 106,309				R 223,705	R 0	R 0	R 0
Horizontal Belt filter	R 0				R 0	R 123,918	R 123,918	R 123,918
Thermal Drying	R 0				R 0	R 994,243	R 994,243	R 994,243
Froth Flotation	R 0				R 2,087,040	R 2,087,040	R 2,087,040	R 2,087,040
Discard Disposal	R1,323,531				R1,166,351	R979,387	R921,994	R883,731
Total OPEX	R1,429,840				R3,477,096	R4,184,588	R4,127,195	R4,088,932
Capital cost :								
Screen-bowl centrifuge	R 0				R 6,578,893	R 0	R 0	R 0
Horizontal belt filter	R 0				R 0	R 2,445,748	R 2,445,748	R 2,445,748
Thermal dryer	R 0				R 0	R 7,812,435	R 7,812,435	R 7,812,435
Froth Flotation plant	R 0				R 3,010,151	R 3,010,151	R 3,010,151	R 3,010,151
Total CAPEX	R 0				R 9,589,044	R 13,268,334	R 13,268,334	R 13,268,334

Ultra-fine coal economic assessment for colliery B continued (page 3 out of 3)…

		i	ii	iii	iv	v	vi	vii
Dewatering Option	Current Scenario: Spiral Fines, Discard Ultra-fines	Spiral Fines; Flotation ultra-fines and Belt filter	Spiral fines; Flotation ultra-fines + screenbowl (20% TM)	Spiral fines; Flotation ultra-fines + screenbowl (16% TM)	Spiral fines; Flotation ultra-fines + screenbowl (12% TM)	Spiral fines; flotation ultra-fines + thermal dry (8.4 % TM)	Spiral fines; flotation ultra-fines + thermal dry (5.5 % TM)	Spiral fines; flotation ultra-fines + thermal dry (3.5 % TM)
Net Contribution	R 87,693,574				R 111,568,870	R 130,341,446	R 135,609,598	R 139,133,839
Variance from current scen.	R0				R23,875,296	R42,647,873	R47,916,024	R51,440,265
NPV Analysis								
Year								
0 (Capital Investment)	R0				(R9,589,044)	(R13,268,334)	(R13,268,334)	(R13,268,334)
1	R0	Cannot meet export specification of 6000 kcal/kg for options i-iii			R20,761,127	R37,085,107	R41,666,108	R44,730,665
2	R0				R18,053,154	R32,247,919	R36,231,398	R38,896,231
3	R0				R15,698,395	R28,041,669	R31,505,564	R33,822,809
4	R0				R13,650,778	R24,384,060	R27,396,142	R29,411,138
5	R0				R11,870,242	R21,203,530	R23,822,733	R25,574,903
6	R0				R10,321,950	R18,437,852	R20,715,420	R22,239,046
7	R0				R8,975,608	R16,032,915	R18,013,408	R19,338,301
8	R0				R7,804,877	R13,941,665	R15,663,833	R16,815,914
9	R0				R6,786,849	R12,123,187	R13,620,725	R14,622,534
10	R0				R5,901,608	R10,541,902	R11,844,108	R12,715,247
NPV (10 years)	**R0**				**R110,235,545**	**R200,771,471**	**R227,211,106**	**R244,898,454**
Payback Period (years)	0.00				0.40	0.31	0.28	0.26
Return on Investment %					248.99	321.43	361.13	387.69

Notes: (AD) = Air-dry

Table 45: Ultra-fine coal economic assessment for colliery C (Page 1 out of 3)

		i	ii	iii	iv	v	vi	vii
Dewatering Option	Current Scenario: Spiral and Centrifuge Fines, Discard Ultra-fines	Spiral Fines; Flotation ultra-fines and Belt filter	Spiral fines; Flotation ultra-fines + screenbowl (20% TM)	Spiral fines; Flotation ultra-fines + screenbowl (16% TM)	Spiral fines; Flotation ultra-fines + screenbowl (12% TM)	Spiral fines; flotation ultra-fines + thermal dry (8.4 % TM)	Spiral fines; flotation ultra-fines + thermal dry (5.5 % TM)	Spiral fines; flotation ultra-fines + thermal dry (3.5 % TM)
Per 100 tons of FTP :								
Tons ex Cyclone	69.45	62.94	65.10	67.82	70.11	71.83	72.97	73.77
Tons ex Spirals	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55
Tons ex Flotation	0.00	3.90	3.90	3.90	3.90	3.90	3.90	3.90
Total	75.00	72.39	74.55	77.27	79.56	81.28	82.42	83.22
CV ex Cyclone (AD)	28.00	28.44	28.31	28.12	27.94	27.78	27.67	27.59
CV ex Spirals (AD)	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00
CV ex Flotation (AD)		28.00	28.00	28.00	28.00	28.00	28.00	28.00
Combined MJ/kg AD	27.93	28.31	28.20	28.03	27.88	27.74	27.64	27.57
Moist ex Cyclone (%)	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Moist ex Spirals (%)	17.00	17.00	20.05	16.15	12.25	8.35	5.43	3.48
Moist ex Flotation (%)		30.00	20.05	16.15	12.25	8.35	5.43	3.48
Combined Moist (%)	8.67	9.88	9.53	9.00	8.50	8.04	7.71	7.49
Comb. Inherent moist (%)	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
CV kcals/kg NAR	6000	6000	6000	6000	6000	6000	6000	6000
FOB Price (R/t NAR)	R 297	R 297	R 297	R 297	R 297	R 297	R 297	R 297
Tons railed p.a. (incl. moist)	591,828	578,897	593,878	611,956	626,705	637,022	643,610	648,321
Railage + Port fees p.a.	R 37,900,652	R 37,072,549	R 38,031,967	R 39,189,689	R 40,134,180	R 40,794,903	R 41,216,765	R 41,518,494
Truck fees p.a.	R 9,966,380	R 9,748,621	R 10,000,911	R 10,305,346	R 10,553,710	R 10,727,454	R 10,838,387	R 10,917,730
Revenue p.a.	R 175,772,856	R 171,932,339	R 176,381,857	R 181,751,058	R 186,131,348	R 189,195,598	R 191,152,078	R 192,551,418
Contribution p.a.	R 127,905,823	R 125,111,168	R 128,348,980	R 132,256,023	R 135,443,458	R 137,673,241	R 139,096,926	R 140,115,193

Ultra-fine coal economic assessment for colliery C continued (page 2 out of 3)…

Dewatering Option		i	ii	iii	iv	v	vi	vii
	Current Scenario: Spiral and Centrifuge Fines, Discard Ultra-fines	Spiral Fines; Flotation ultra-fines and Belt filter	Spiral fines; Flotation ultra-fines + screenbowl (20% TM)	Spiral fines; Flotation ultra-fines + screenbowl (16% TM)	Spiral fines; Flotation ultra-fines + screenbowl (12% TM)	Spiral fines; flotation ultra-fines + thermal dry (8.4 % TM)	Spiral fines; flotation ultra-fines + thermal dry (5.5 % TM)	Spiral fines; flotation ultra-fines + thermal dry (3.5 % TM)
Tons per annum :								
Spiral Product	41,026	41,026	41,026	41,026	41,026	41,026	41,026	41,026
Feed to Froth Flotation	0	38,438	38,438	38,438	38,438	38,438	38,438	38,438
Froth Product	0	28,829	28,829	28,829	28,829	28,829	28,829	28,829
Discards (Ultra-fine)	38,438	9,610	9,610	9,610	9,610	9,610	9,610	9,610
Discards (Coarse)	146,362	194,484	178,517	158,411	141,483	128,769	120,342	114,428
Tons per hour :								
Spiral Product	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Feed to Froth Flotation	0.0	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Froth Product	0.0	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Operating cost :								
Screen-bowl centrifuge	R 49,440	R 0	R 84,182	R 84,182	R 84,182	R 0	R 0	R 0
Horizontal Belt filter	R 0	R 36,672	R 0	R 0	R 0	R 36,672	R 36,672	R 36,672
Thermal Drying	R 0	R 0	R 0	R 0	R 0	R 374,140	R 374,140	R 374,140
Froth Flotation	R 0	R 617,628	R 617,628	R 617,628	R 617,628	R 617,628	R 617,628	R 617,628
Discard Disposal	R345,436	R403,487	R371,418	R331,035	R297,036	R271,499	R254,574	R242,696
Total	R394,876	R1,057,787	R1,073,228	R1,032,845	R998,845	R1,299,939	R1,283,014	R1,271,136
Capital cost :								
Screen-bowl centrifuge	R 0	R 0	R 3,435,765	R 3,435,765	R 3,435,765	R 0	R 0	R 0
Horizontal belt filter	R 0	R 723,782	R 0	R 0	R 0	R 723,782	R 723,782	R 723,782
Thermal dryer	R 0	R 0	R 0	R 0	R 0	R 4,079,971	R 4,079,971	R 4,079,971
Froth Flotation plant	R 0	R 890,809	R 890,809	R 890,809	R 890,809	R 890,809	R 890,809	R 890,809
Total	R 0	R 1,614,591	R 4,326,574	R 4,326,574	R 4,326,574	R 5,694,562	R 5,694,562	R 5,694,562

Appendix 5: Assessment for the Option to Solar Dry and Sell the Ultra-fines

This appendix describes the methodology, assumptions and details of the economic assessment for the option to solar dry the ultra-fines, which are blended with re-washed discards to form a product that can be sold to local power stations. The following table lists the assumptions made in the assessment.

Table 46: Assumptions and parameters used in the economic assessment for the option to solar dry and sell the ultra-fines

Product produced per month	Mine B: 100 000 t*; Mine C: 60 000 t*
Revenue from coal sales (FOT)	R 60 / product ton*
Contractor costs	R 42.5 / product ton*
Cost of discard disposal	R 2 / discards ton†
Yield of the rewashed discards	50%*
Tax	29%
Discount Rate	15%
Period of Contract	Mine B: 5 years*; Mine C: 2 years*

*Based on a personal communication with Blenkinsop, M., Managing Director of WERM (2005). The values are rough estimates and are not based on detailed official quotes.

†Based on the 2000 value used in: de Korte, G.J. (2000); *Dewatering of fine coal*, Progress Report No. 2, Report for Coaltech 2020.

The revenue is expressed as a free-on-truck (FOT) value, which means that the buyer pays for the transport. Based on the communication with Blenkinsop (2005) it was assumed that roughly half of the discards that are washed originate from the discard dumps, while the remainder is the arising discards.

The contractor costs include all logistical costs, such as hauling, loading and diesel requirements. The installation, capital costs and operating costs of the discards washing plant and the slurry drying equipment, are also included in the cost. The cost of modifying the slurry dam to form four separated zones is not included.

Table 47: Economic assessment for colliery B for the option to solar-dry and sell the discarded ultra-fines

Year	*1*	*2*	*3*	*4*	*5*
Costs	**R 51,000,000**	**R 51,000,000**	**R 51,000,000**	**R 51,000,000**	**R 51,000,000**
Capital	*R 0*	*R 0*	*R 0*	*R 0*	*R 0*
Equipment	R 0	R 0	R 0	R 0	R 0
Installation	R 0	R 0	R 0	R 0	R 0
Operating	*R 51,000,000*	*R 51,000,000*	*R 51,000,000*	*R 51,000,000*	*R 51,000,000*
Contractor	R 51,000,000	R 51,000,000	R 51,000,000	R 51,000,000	R 51,000,000
Savings	**R 73,169,820**	**R 73,169,820**	**R 73,169,820**	**R 73,169,820**	**R 73,169,820**
Discards Handling	R 1,169,820	R 1,169,820	R 1,169,820	R 1,169,820	R 1,169,820
Additional Revenue	R 72,000,000	R 72,000,000	R 72,000,000	R 72,000,000	R 72,000,000
Profit Before Tax	R 22,169,820	R 22,169,820	R 22,169,820	R 22,169,820	R 22,169,820
Tax	R 6,429,248	R 6,429,248	R 6,429,248	R 6,429,248	R 6,429,248
Cash Flow	R 15,740,572	R 15,740,572	R 15,740,572	R 15,740,572	R 15,740,572
Discounted Cash Flow	R 13,687,454	R 11,902,134	R 10,349,682	R 8,999,723	R 7,825,846
NPV (cumulative)	R 13,687,454	R 25,589,588	R 35,939,270	R 44,938,993	R 52,764,839

Table 48: Economic assessment for colliery C for the option to solar-dry and sell the discarded ultra-fines

Year	*1*	*2*
Costs	**R 30,600,000**	**R 30,600,000**
Capital	*R 0*	*R 0*
Equipment	R 0	R 0
Installation	R 0	R 0
Operating	*R 30,600,000*	*R 30,600,000*
Contractor	R 30,600,000	R 30,600,000
Savings	**R 43,803,000**	**R 43,803,000**
Discard Handling	R 603,000	R 603,000
Revenue	R 43,200,000	R 43,200,000
Profit Before Tax	R 13,203,000	R 13,203,000
Tax	R 3,828,870	R 3,828,870
Cash Flow	R 9,374,130	R 9,374,130
Discounted Cash Flow	R 8,151,417	R 7,088,189
NPV	R 8,151,417	R 15,239,606

Appendix 6: Cyclone Product Thermal Drying Assessment

This appendix presents the details of the assessment of the option to thermally dry the cyclone products. The fine coal product yields and moisture contents were estimated from Appendix 2. All three collieries are required to meet the export coal net-as-received (NAR) CV specification of 6000 kcal/kg, which was made a constraint in the assessment. The product NAR CV was calculated in the same manner as in Appendices 4 and 7. The air-dry calorific value and the corresponding yield for the drum and cyclone products were varied until the overall product met the NAR CV specifications of 6000 kcal/kg. The assumed washability characteristics of the coal mined at the collieries, shown in Figure 20, were used to obtain the yields corresponding to the appropriate air-dry CV for the cyclone and drum products. It was therefore assumed that the cyclones and drums wash the coal to the maximum yields dictated by the appropriate washability characteristics. In this manner, the coarse coal calorific value and yield was predicted for each option. The operating and capital costs for 2005 were estimated in the same manner as in Appendices 4 and 7. The capital costs were assumed to be incurred in year 0. All other assumptions, which include the discount rate, cost indices, exchange rates, coal prices and operating and capital cost estimates, are the same as those made in Appendix 4.

Table 20 in Chapter 5 indicates the estimated reductions in discards that would be brought about if the option to wash the fine coal in spirals followed by thermal drying of the product is implemented. These reductions were arrived at as follows:

$$\text{Reductions in discards} = 100.(D_{cs} - D_o)/D_{total} \qquad [5]$$

D_{total} represents the total discards currently produced (includes discards generated from coal that is sold locally) (see Appendix 2).

D_{cs} represents the current scenario of discards generated *on account of export coal* (see Appendix 4).

D_o represents the discards (coarse) resulting *only on account of export coal* if the option to thermally dry the cyclone product is implemented (see Table 50 in this appendix).

Table 49 lists the variables that were used in order to predict the reduction in discards brought about by washing the fine coal in spirals and thermally drying the product.

Table 49: Predicted discards reductions for the option to thermally dry the cyclone product

Colliery	*A*	*B*	*C*
Total discards (tpa)	1,056,000	1,135,000	185,000
Current scenario discards (export only) (tpa)	1,056,000	572,000	146,000
Predicted discards for the proposed option (tpa)	764,000	440,000	56,000
Predicted discard reductions for the option	28 %	12 %	49 %

Table 50 provides the details of the assessment for the option to thermally dry the cyclone product for the three case study collieries. The assessment is relative to the current scenario. Tables 43, 44 and 45 in Appendix 4 provide the details of the current scenario for collieries A, B and C respectively.

Table 50: Economic assessment for the option to thermally dry the cyclone product (Page 1 out of 2)

Colliery	*A*	*B*	*C*
Per 100 tons of FTP :			
Tons ex (Drum) and Cyclone	69.21	39.24	81.72
Tons fines	0.00	8.15	5.55
Total	69.21	47.39	87.27
CV ex (Drum) and Cyclone	26.45	26.98	26.65
CV Fines		27.00	27.00
Combined CV MJ/kg AD	26.45	26.98	26.67
Moist ex (Drum) and Cycl.	3.50	3.50	3.50
Moist ex Fines		16.00	17.00
Combined moisture (%)	3.50	5.65	4.36
Comb. Inherent moist (%)	2.50	2.50	2.50
CV kcals/kg NAR	6000	6000	6000
FOB Price (R/t NAR)	R 278	R 279	R 297
Tons railed p.a.	1,993,764	530,073	657,636
Tons railed p.a. current scenario	*1,767,813*	*405,974*	*591,828*
Railage + Port fees p.a.	R 114,920,579	R 31,523,456	R 42,114,989
Truck fees p.a.	R 0	R 0	R 11,074,585
Revenue p.a.	R 554,266,499	R 147,890,438	R 195,317,795
Contribution p.a.	R 439,345,920	R 116,366,982	R 142,128,222
Tons per annum :			
Discards (coarse) generated from this option	763,836	439,563	55,662
Discards (coarse) current scenario	*1,054,089*	*572,373*	*146,361*
Total discards (coarse) currently produced: (i.e. includes discards generated from coal sold locally)	*1,054,089*	*1,135,200*	*184,800*
Reductions in total coarse discards by implementing this option (%)	*28*	*12*	*49*
Discards (ultra-fine)	114,048	129,888	38,438
Operating cost :			
Thermal Drying	R 5,284,539	R 2,274,874	R 3,235,422
Comb. Discard Disposal	R1,686,876	R1,056,782	R163,266
Total	R6,971,415	R3,331,656	R3,398,687
Capital cost :			
Thermal Drying	R 9,116,249	R 5,587,652	R 7,463,674
Total	R 9,116,249	R 5,587,652	R 7,463,674
Net contribution p.a.	R 432,374,505	R 113,035,326	R 138,729,535
Net contribution of the current scenario p.a.	*R 387,280,889*	*R 87,693,574*	*R 127,510,947*
Contribution relative to current scenario p.a.	R45,093,616	R25,341,753	R11,218,588

Economic assessment for the option to thermally dry the cyclone product, continued (Page 2 out of 2)...

Colliery	*A*	*B*	*C*
NPV Analysis			
Year			
0 (Capital invested)	(R9,116,249)	(R5,587,652)	(R7,463,674)
1	R39,211,840	R22,036,307	R9,755,294
2	R34,097,252	R19,162,006	R8,482,864
3	R29,649,785	R16,662,614	R7,376,403
4	R25,782,421	R14,489,230	R6,414,264
5	R22,419,497	R12,599,330	R5,577,621
6	R19,495,215	R10,955,939	R4,850,105
7	R16,952,361	R9,526,904	R4,217,483
8	R14,741,183	R8,284,264	R3,667,376
9	R12,818,420	R7,203,708	R3,189,023
10	R11,146,452	R6,264,094	R2,773,063
NPV (10 years)	**R217,198,177**	**R121,596,743**	**R48,839,821**
Payback Period (years)	0.20	0.22	0.67
Return on Investment %	4.95	4.54	1.50

Appendix 7: Fine Coal Management Investigation

This appendix presents the details of the assessment comparing the different fine coal management options. Since only export coal is considered in this assessment, the coarse coal that is sold locally by mines B and C and the raw duff that is sold locally by mine B has not been included in the assessment. Appendix 2 was used to predict the product moistures as well as the tonnages of the fine coal. With the exception of the thermal drying option, it was assumed that the fine coal is only dewatered using dewatering screens. All three collieries are required to meet the export coal net-as-received (NAR) CV specification of 6000 kcal/kg, which was made a constraint in the assessment. The product NAR CV was calculated from the gross-as-received (GAR) CV as follows:

$$GAR_{CV}\,(kcal/kg) = CV_{AD}.(1/(1-TM)).(1-IM).(238.85) \qquad [1]$$

$$NAR_{CV}\,(kcal/kg) = GAR_{CV} - (50.6).H - (5.85).O - (0.191).TM \qquad [2]$$

CV_{AD}, TM and IM refer to the product air-dry CV in MJ/kg, total moisture fraction and inherent moisture fraction respectively. O and H represent the percent oxygen and hydrogen in the coal, and were obtained from Pretorius et al. (2002).

The air-dry calorific value and the corresponding yield for the drum and cyclone products were varied until the overall product met the NAR CV specifications of 6000 kcal/kg. The assumed washability characteristics of the coal mined at the three collieries, shown in Figure 20, were used to obtain the yields corresponding to the appropriate air-dry CV for the cyclone and drum products. It was therefore assumed that the cyclones and drums wash the coal to the maximum yields dictated by the appropriate washability characteristics. In this manner, the coarse and intermediate coal product calorific values and yields were predicted for each option. It was also assumed that the dewatering equipment will be able to achieve the performance as stated. The operating costs for 2005 were estimated from the 2000 operating costs as follows:

$$Cost_{2005} = Cost_{2000}.(PPI_{2005}/PPI_{2000}) \qquad [3]$$

The PPI_{year} represents the average Production Price Index for all commodities consumed within South Africa for a certain year. The capital costs for 2005 were assumed to be incurred in year 0 and were calculated as follows:

$$Cost_{2005} = Cost_{2000}.(X_{2005}/X_{2000}).(Capacity_2/Capacity_1)^{0.6}.(CEPCI_{2005}/CEPCI_{2000}) \qquad [4]$$

X_{year} represents the average R/$ exchange rate for a given year. $CEPCI_{year}$ represents the Chemical Engineering Plant Cost Index for a given year. Capacity represents the capacity that the unit is designed to handle. $Capacity_1$ represents the capacity of the quoted unit in 2000, and $Capacity_2$ represents the capacity that is required in the various scenarios. All capital investments were assumed to be imported. As spirals are already installed at all three collieries, there is no capital cost associated with the spirals.

The fine coal management assessment is relative to the base case. Note that the base case differs from the current scenario in that the base case is simply the option to discard all the fines, whereas the current scenario reflects the current situation with regards to the export coal at each colliery.

Table 21 indicates the estimated reductions in discards that would be brought about if the option to wash the fine coal in spirals followed by thermal drying of the product is implemented. These reductions were arrived at as follows:

$$\text{Reductions in discards} = 100.(D_{cs} - D_o)/D_{total} \qquad [5]$$

D_{total} represents the total discards currently produced (includes discards generated from coal that is sold locally) (see Appendix 2).

D_{cs} represents the current scenario of discards generated *on account of export coal* (see Appendix 4)

D_o represents the discards resulting *only on account of export coal* if the option to wash the fine coal in spirals followed by thermal drying of the product is implemented (see Table 52 in this appendix).

Table 51 lists the variables that were used in order to predict the reduction in discards brought about by washing the fine coal in spirals and thermally drying the product.

Table 51: Predicted discards reductions for the option to thermally dry the spiral product

Colliery	*A*	*B*	*C*
Total discards (tpa)	1,056,000	1,135,000	185,000
Current scenario discards (export only) (tpa)	1,056,000	572,000	146,000
Predicted discards for the proposed option (tpa)	976,000	539,000	130,000
Predicted discard reductions for the option	8 %	3 %	9 %

The details of the fine coal management assessment are shown in the remainder of this appendix, together with a list of assumptions and parameters that were used in the assessment.

Table 52: Assumptions and variables used in the fine coal management economic assessment

100		2000 PPI
133.9		2005 PPI
394.1		CEPCI 2000
524.7		CEPCI 2005
15	%	Discount Rate
6.94	R/$	Exchange Rate 2000 (www.oanda.com, accessed 2/2/2006)
6.38	R/$	Exchange Rate 2005 (www.oanda.com, accessed 2/2/2006)
22	days	No. of operating days per month
28	MJ/kg	Fine coal product CV (Air-dry)*
25	MJ/kg	Unwashed fine coal CV (Air Dry)*
2.5	%	Inherent moisture content
25	%	Total moisture content of fines after dewatering screens

A	*B*	*C*	*Colliery*
Combo	4	2	Seam No.
35	20	50	Yield using double spiral* (%)
73	75	70	Yield in first stage of 2-stage spirals* (%)
52	33	70	Yield in DMC* (%)
2851200	1082400	739200	Feed to plant (tpa) (export only)
278	279	297	FOB Price (R/t) (Average 2005)
58	59	64	Rail and Port Fees (R/t) (Average 2005)
0	0	17	Truck fees (R/t) (Average 2005)
Capital Costs			
R 3,282,768	R 3,282,768	R 3,282,768	Spirals (2000) for 100 tph*
R 1,831,098	R 1,702,604	R 952,761	Spirals (2005) for actual feed
R 5,703,287	R 5,703,287	R 5,703,287	DMC (2000) for 100 tph*
R 3,181,241	R 2,958,004	R 1,655,270	DMC (2005) for actual feed
R 9,500,000	R 9,500,000	R 9,500,000	Thermal Drier (2000) for 360000 tpa**
R 3,962,265	R 2,633,436	R 2,553,624	Thermal Drier (2005) for actual feed
Operating Costs			
R 0.69	R 0.69	R 0.69	Spirals (2000) per t processed*
R 0.92	R 0.92	R 0.92	Spirals (2005) per t processed
R 2.37	R 2.37	R 2.37	DMC (2000) per t processed*
R 3.17	R 3.17	R 3.17	DMC (2005) per t processed
R 1.50	R 1.50	R 1.50	Discard Disposal (2000) per ton discarded*
R 2.01	R 2.01	R 2.01	Discard Disposal (2005) per ton discarded
R 4.00	R 4.00	R 4.00	Thermal Drying (2000) per ton dried**
R 5.36	R 5.36	R 5.36	Thermal Drying (2005) per ton dried
R 1.00	R 1.00	R 1.00	Ultra-fine coal disposal (2000) per ton discarded*
R 1.34	R 1.34	R 1.34	Ultra-fine coal disposal (2005) per ton discarded

*Values used by de Korte (2000b)
**Values used by de Korte, G.J. (2000a)

Table 53: Fine coal management economic assessment for colliery A (Page 1 out of 2)

Fine Coal Management Option	Base Case: Discard all fines	Add unwashed coal to the export coal	Wash fines in spirals	Wash fines in dense-medium cyclones	Wash fines in spirals and thermally dry the product
Per 100 tons of FTP :					
Tons ex Drum and Cyc.	58.95	43.99	56.88	55.76	59.67
Tons fines	0.00	6.00	2.10	3.12	2.10
Total	58.95	49.99	58.98	58.88	61.77
CV ex Drum and Cyclone	27.54	28.60	27.72	27.81	27.48
CV Fines		25.15	28.00	28.00	28.00
Combined CV MJ/kg AD	27.54	28.19	27.73	27.82	27.50
Moist ex Drum and Cyc	7.30	7.30	7.30	7.30	7.30
Moist ex Fines		25.00	25.00	25.00	3.50
Combined moisture (%)	7.30	9.42	7.93	8.24	7.17
Comb. Inherent moist (%)	2.50	2.50	2.50	2.50	2.50
CV kcals/kg NAR	6000	6000	6000	6000	6000
FOB Price (R/t NAR)	R 278	R 278	R 278	R 278	R 278
Tons railed p.a.	1,767,813	1,534,279	1,780,820	1,783,762	1,849,802
Railage + Port fees p.a.	R 101,896,753	R 88,435,840	R 102,646,443	R 102,816,014	R 106,622,612
Revenue p.a.	R 491,452,071	R 426,529,556	R 495,067,853	R 495,885,703	R 514,245,073
Contribution p.a.	R 389,555,318	R 338,093,716	R 392,421,411	R 393,069,689	R 407,622,461
Tons per annum :					
Fine Coal Product	0	171,072	59,875	88,957	59,875
Feed to Primary Spirals	0	0	171,072	0	171,072
Feed to Secondary Spirals	0	0	124,883	0	124,883
Feed to DMC plant	0	0	0	171,072	0
Discards (Coarse)	1,056,370	1,311,837	1,055,514	1,058,365	975,966
Discards (Ultra-fine)	114,048	114,048	114,048	114,048	114,048
Tons per hour :					
Fines Product	0.0	27.0	9.5	14.0	9.5
Feed to Primary Spirals	0.0	0.0	27.0	0.0	27.0
Feed to Secondary Spirals	0.0	0.0	19.7	0.0	19.7
Feed to DMC Plant	0.0	0.0	0.0	27.0	0.0

Fine coal management economic assessment for colliery A continued (Page 2 out of 2)...

Fine Coal Management Option	Base Case: Discard all fines	Add unwashed coal to the export coal	Wash fines in spirals	Wash fines in dense-medium cyclones	Wash fines in spirals and thermally dry the product
Operating cost :					
Spiral beneficiation	R 0	R 0	R 157,805	R 0	R 157,805
Fines DMC beneficiation	R 0	R 0	R 0	R 542,419	R 0
Thermal Drying	R 0	R 0	R 0	R 0	R 320,692
Comb. Discard Disposal	R2,274,429	R2,787,535	R2,272,711	R2,278,437	R2,112,938
Total	R2,274,429	R2,787,535	R2,430,516	R2,820,856	R2,591,434
Capital cost :					
Fines DMS plant	R 0	R 0	R 0	R 3,181,241	R 0
Thermal Drying	R 0	R 0	R 0	R 0	R 3,962,265
Total	R 0	R 0	R 0	R 3,181,241	R 3,962,265
Net Contribution	R 387,280,889	R 335,306,180	R 389,990,895	R 390,248,833	R 405,031,027
Relative to Base Case	R0	(R51,974,709)	R2,710,006	R2,967,944	R17,750,138
NPV Analysis					
Year					
0 (Capital invested)	R0	R0	R0	(R3,181,241)	(R3,962,265)
1	R0	(R45,195,399)	R2,356,527	R2,580,821	R15,434,903
2	R0	(R39,300,347)	R2,049,154	R2,244,192	R13,421,655
3	R0	(R34,174,215)	R1,781,873	R1,951,471	R11,671,004
4	R0	(R29,716,708)	R1,549,455	R1,696,932	R10,148,699
5	R0	(R25,840,616)	R1,347,352	R1,475,593	R8,824,956
6	R0	(R22,470,101)	R1,171,610	R1,283,124	R7,673,875
7	R0	(R19,539,218)	R1,018,792	R1,115,760	R6,672,935
8	R0	(R16,990,624)	R885,906	R970,226	R5,802,552
9	R0	(R14,774,456)	R770,353	R843,675	R5,045,697
10	R0	(R12,847,353)	R669,872	R733,630	R4,387,563
NPV (10 years)	**R0**	**(R260,849,037)**	**R13,600,893**	**R11,714,182**	**R85,121,573**
Payback Period (years)	0.00	0.00	0.00	1.07	0.22
Return on Investment %	-	-	-	0.93	4.48

Table 54: Fine coal management economic assessment for colliery B (Page 1 out of 2)

Fine Coal Management Option	Base Case: Discard all fines	Add unwashed coal to the export coal	Wash fines in spirals	Wash fines in dense-medium cyclones	Wash fines in spirals and thermally dry the product
Per 100 tons of FTP :					
Tons ex Cyclone	34.03		28.80	21.56	35.41
Tons fines	0.00		2.80	4.62	2.80
Total	34.03		31.60	26.18	38.21
CV ex Cyclone (AD)	27.52		27.99	28.58	27.39
CV Fines (AD)			28.00	28.00	28.00
Combined CV MJ/kg (AD)	27.52		27.99	28.48	27.43
Moist ex Cyclone (%)	7.50		7.50	7.50	7.50
Moist ex Fines (%)			25.00	25.00	3.50
Combined Moist (%)	7.50		9.05	10.59	7.21
Comb. Inherent moist (%)	2.50	Cannot meet export specification of 6000 kcal/kg	2.50	2.50	2.50
CV kcals/kg NAR	6000		6000	6000	6000
FOB Price (R/t NAR)	R 279		R 279	R 279	R 279
Tons railed p.a.	388,251		366,674	309,006	434,564
Railage + Port fees p.a.	R 23,089,289		R 21,806,087	R 18,376,606	R 25,843,517
Revenue p.a.	R 108,322,037		R 102,301,972	R 86,212,766	R 121,243,336
Contribution p.a.	R 85,232,748		R 80,495,885	R 67,836,159	R 95,399,819
Tons per annum :					
Fine Coal Product	0		30,307	50,007	30,307
Feed to Primary Spirals	0		151,536		151,536
Feed to Secondary Spirals	0		113,652	0	113,652
Feed to DMC plant	0		0	151,536	0
Discards (Coarse)	584,171		610,474	669,140	538,927
Discards (Ultra-fine)	129,888		129,888	129,888	129,888
Tons per hour :					
Fines Product	0.0		4.8	7.9	4.8
Feed to Primary Spirals	0.0		23.9	0.0	23.9
Feed to Secondary Spirals	0.0		17.9	0.0	17.9
Feed to DMC Plant	0.0		0.0	23.9	0.0

Table 55: Fine coal management economic assessment for colliery C (Page 1 out of 2)

Fine Coal Management Option	Base Case: Discard all fines	Add unwashed coal to the export coal	Wash fines in spirals	Wash fines in dense-medium cyclones	Wash fines in spirals and thermally dry the product
Per 100 tons of FTP :					
Tons ex Cyclone	72.33	55.37	69.59	67.67	73.27
Tons fines	0.00	7.79	3.90	5.45	3.90
Total	72.33	63.16	73.49	73.12	77.17
CV ex Cyclone (AD)	27.73	28.83	28.00	28.13	27.64
CV Fines (AD)		25.15	28.00	28.00	28.00
Combined CV MJ/kg (AD)	27.73	28.38	28.00	28.12	27.66
Moist ex Cyclone (%)	8.00	8.00	8.00	8.00	8.00
Moist ex Fines (%)		25.00	25.00	25.00	3.50
Combined Moist (%)	8.00	10.10	8.90	9.27	7.77
Comb. Inherent moist (%)	2.50	2.50	2.50	2.50	2.50
CV kcals/kg NAR	6000	6000	6000	6000	6000
FOB Price (R/t NAR)	R 297	R 297	R 297	R 297	R 297
Tons railed p.a.	566,627	506,330	581,369	580,843	603,015
Railage + Port fees p.a.	R 36,286,789	R 32,425,342	R 37,230,881	R 37,197,193	R 38,617,086
Truck Fees p.a.	R 9,541,998	R 8,526,589	R 9,790,257	R 9,781,398	R 10,154,774
Revenue p.a.	R 168,288,198	R 150,379,867	R 172,666,640	R 172,510,407	R 179,095,481
Contribution per annum	R 122,459,412	R 109,427,936	R 125,645,502	R 125,531,815	R 130,323,621
Tons per annum :					
Fine Coal Product	0	57,584	28,792	40,309	28,792
Feed to Primary Spirals	0	0	57,584		57,584
Feed to Secondary Spirals	0	0	40,309	0	40,309
Feed to DMC plant	0	0	0	57,584	0
Discards (Coarse)	166,098	233,883	157,560	160,236	130,358
Discards (Ultra-fine)	38,438	38,438	38,438	38,438	38,438
Tons per hour :					
Fines Product	0.0	9.1	4.5	6.4	4.5
Feed to Primary Spirals	0.0	0.0	9.1	0.0	9.1
Feed to Secondary Spirals	0.0	0.0	6.4	0.0	6.4
Feed to DMC Plant	0.0	0.0	0.0	9.1	0.0

Appendix 8: Supplement to the Energy Assessment

This appendix provides supplementary information for Chapter 6. The energy efficiency questionnaire that was conducted at the three case study collieries to assess the potential for electricity savings is shown in this appendix, together with the results of the audit, in Table 56.

Based on the findings of the audits, a list of energy saving strategies was drawn up for each mine. These lists are also included in this appendix as Tables 57-59.

Table 56: Energy efficiency questionnaire

No.		Mine A	Mine B	Mine C
	Compressors			
1	Is there a regular air leak monitoring and repair programme?	✗	✗	No Compressors at Mine C
2	Have all unnecessary compressed air users been eliminated?	✗	✗	
3	Are energy efficient air nozzles used instead of standard ones?	N/A	N/A	
4	Is there a control system in place to regulate the load?	✓	✓	
5	Is load-unload control used, rather than throttle, poppet or turn-valve control?	✓	✓	
6	Is the waste heat being utilised?	✗	✗	
7	Are the manual condensate drain traps left closed rather than jammed open?	✓	✓	
8	Is the air inlet temperature at a realistic minimum?	✓	✗	
9	Are the filters and coolers regularly cleaned?	✓	✓	
10	Are screw type compressors used instead of rotary vane types?	✓	✓	
11	Are the compressors regularly maintained?	✓	✓	
12	Is the compressor switched off when it is not required?	✓	✓	
	Motors			
13	Are energy efficient drive belts used on the motors?	✗	✗	✗
14	Are energy efficient motors used?	✗	✗	✗
15	Are the motors switched off when they are not required?	✓	✓	✓
16	Are the motors regularly maintained?	✓	✓	✓
17	Are the motors checked that they match the load requirements?	✗	✗	✓
	Pumping			
18	Are the pumps checked that they are correctly sized?	✗	✗	✓
19	Are VSD's used to control the pumps rather bypass control?	Manually controlled		
20	Are VSD's used to control the pumps rather throttle valve control?			
	Lighting			
21	Are lights only left on when they are needed?	✗	✗	✗
22	Are T8 fluorescent lights used rather than incandescent lights?	N/A	N/A	N/A
23	Are T8 fluorescent lights used rather than standard fluorescent lights?	✗	✓	✗
24	Are electronic, not magnetic, ballasts installed on the fluorescent lights?	✓	N/A	✓
	Heating, Ventilation and Air Conditioning			
25	Are fans operating at the most efficient operating point?	✓	✓	✓
26	Have the operational time and air volume of the fans been minimised?	✓	✓	✓
	Hot water			
27	Do the heaters operate continuously?	✓	✓	✓
28	Are the hot water pipes adequately insulated?	✗	✗	✗
29	Are thermostats installed on the heaters?	✓	✓	✓
30	Is a heat pump used to heat the water?	✗	✗	✗
	Continuous Miner			
31	Are the picks regularly checked that they are sharp?	✓	✓	✓

Table 57: Identified strategies to reduce end-user electricity consumption at colliery A

	"Stand alone" Energy Savings	*Corresponding Survey Question*
Compressed Air Systems		
Detect and fix air leaks	30%	1
Eliminate inappropriate users of air†	10%	2
*Total Known Compressed Air Electricity Savings**	**37%**	
Motor Systems		
Replace standard V-belts with efficient belts	5%	13
Replace standard motors with efficient motors as they are required	3%	14
Match the motor with the load	4%	17
*Total Known Motor Electricity Savings**	**12%**	
Pumping		
Ensure pumps are correctly sized	unknown	18
Total Pump Electricity Savings	**Unknown**	
Lighting		
Install occupancy or photoelectric sensors to reduce unnecessary lighting	unknown	21
Replace fluorescent lights with T8 fluorescent lights and electronic ballasts	40	23
*Total Known Lighting Electricity Savings**	**40%**	
Heating, Ventilation and Air Conditioning		
Utilise compressor waste heat for space heating	30%	6
*Total Known HVAC Electricity Savings**	**30%**	
Hot water Heating		
Ensure adequate insulation of hot water	unknown	28
Replace the electric resistance heater with an efficient heat pump	30%	30
*Total Known Water Heating Electricity Savings**	**30%**	

†Air-operated instrumentation and agitation are the inappropriate users of compressed air. Electronic, rather than air-operated instrumentation should be installed and blowers should be used to supply the air for agitation.

*The total savings per end-user are not additive, but rather iterative and were calculated by the following equation:

$$\text{Total savings per end-user} = 1-(1-x_1)(1-x_2)(1-x_3)\ldots$$

Where x_1, x_2, x_3... are the various stand alone savings for each end-user

Table 58: Identified strategies to reduce end-user electricity consumption at colliery B

	"Stand alone" Energy Savings	*Corresponding Survey Question*
Compressed Air Systems		
Detect and fix air leaks	30%	1
Eliminate inappropriate users of air[‡]	10%	2
Use cooler intake air[†]	1%	8
Total Known Compressed Air Electricity Savings[*]	**38%**	
Motor Systems		
Replace standard V-belts with efficient belts	5%	13
Replace standard motors with efficient motors as they are required	3%	14
Match the motor with the load	4%	17
Total Known Motor Systems Electricity Savings[*]	**12%**	
Pumping		
Ensure pumps are correctly sized	unknown	18
Total Pumping Electricity Savings	**unknown**	
Lighting		
Install occupancy or photoelectric sensors to reduce unnecessary lighting	unknown	21
Total Lighting Electricity Savings	**unknown**	
Heating, Ventilation and Air Conditioning		
Utilise compressor waste heat for space heating	30%	6
Total Known HVAC Electricity Savings[*]	**30%**	
Hot water Heating		
Ensure adequate insulation of hot water	unknown	28
Replace the electric resistance heater with an efficient heat pump	30%	30
Total Known Water Heating Electricity Savings[*]	**30%**	

[†] The inlet air is sourced from the warm compressor room. Sourcing air from outside in the shade can potentially reduce the inlet temperature from an estimated 3°C

[‡] Air-operated instrumentation, agitation, power tools and cleaning are the inappropriate users of compressed air. Electronic, rather than pneumatic instrumentation and power tools should be used, blowers should be used to supply air for agitation, and brushes and wipes should be used for cleaning.

[*] The total savings per end-user are not additive, but rather iterative and were calculated as follows:

$$\text{Total savings per end-user} = 1-(1-x_1)(1-x_2)(1-x_3)\ldots$$

Where $x_1, x_2, x_3\ldots$ are the various stand alone savings for each end-user