Chapter 5

COAL

5.1 General

Coal is a sedimentary, organic, combustible rock. Carbon, hydrogen and oxygen are the primary constituents. It is formed as a result of diagenetic processes acting on vegetation, originally accumulated as plant material in swamps and peat bogs, which consolidated between other rock strata. In this way, coal seams are formed. Significant accumulations occurred during the Carboniferous, Permian and Cretaceous periods. Peat, the precursor of coal was initially converted into lignite (brown coal). This rank of coal has low organic maturity i.e. relatively high original organic content. Continued high temperatures and pressure transform lignite into sub-bituminous coals. With further chemical and physical changes and a progressive increase in organic maturity, these coals are transformed into anthracite (Figure 7).

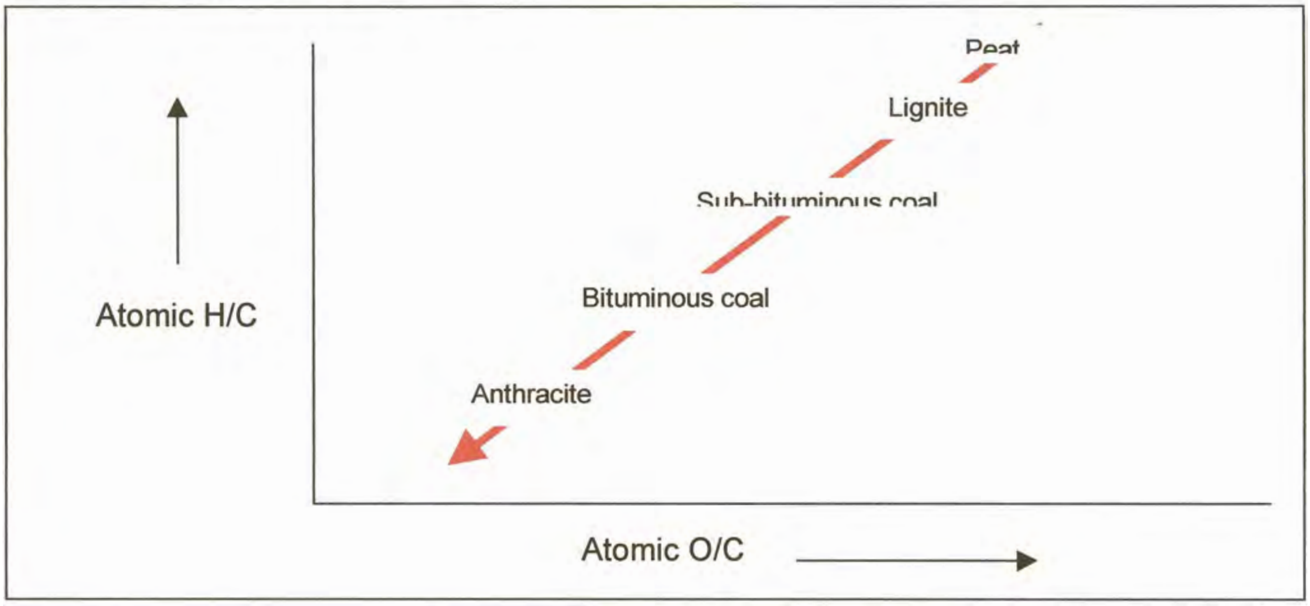

Figure 7: Metamorphism of organic matter as it increases in rank from peat to anthracite

Coal is the most abundant fossil fuel in the world. It is mined in more than 50 countries. Such abundant reserves ensure consumers a guaranteed supply at competitive prices. Coal is also stable and therefore the safest fossil fuel to transport, store and use, despite its potential to spontaneously combust. When used in accordance with current technologies, coal is a clean-burning fuel .

5.1.1 Mining methods

Coal is either mined on the surface or underground. The choice depends on the geology of the coal deposit. Figure 8 presents the choice of mining method as a function of seam thickness and mining depth. Most of the world's hard coal is extracted by means of deep mining. There are two principal methods of underground mining. These are room-and-pillar ("board-and-pillar") and longwall mining. The board-and-pillar method involves cutting a network of 'rooms' or panels into the coal seam and leaving behind 'pillars' of coal to support the roof of the mine. It is possible to recover the coal left in the pillars at a later stage. Longwall mining makes use of mechanical shearers to cut and remove the coal at the face. Self-advancing, hydraulically powered supports temporarily hold up the roof while the coal is removed. The roof over the area from which the coal has already been mined is allowed to collapse. Over 75% of a coal deposit can be extracted using the longwall method. Surface mining is only economically viable when the deposit is very close to the surface. A far higher proportion of the coal is recovered by this method. The overburden is removed by draglines. Large trucks transport the overburden and coal. The equipment used has increased dramatically in size, in order to promote the most efficient removal of coal and overburden alike. In developing countries, the high cost of importing this equipment can favour the selection of underground mining (UN/DTCD, 1991).

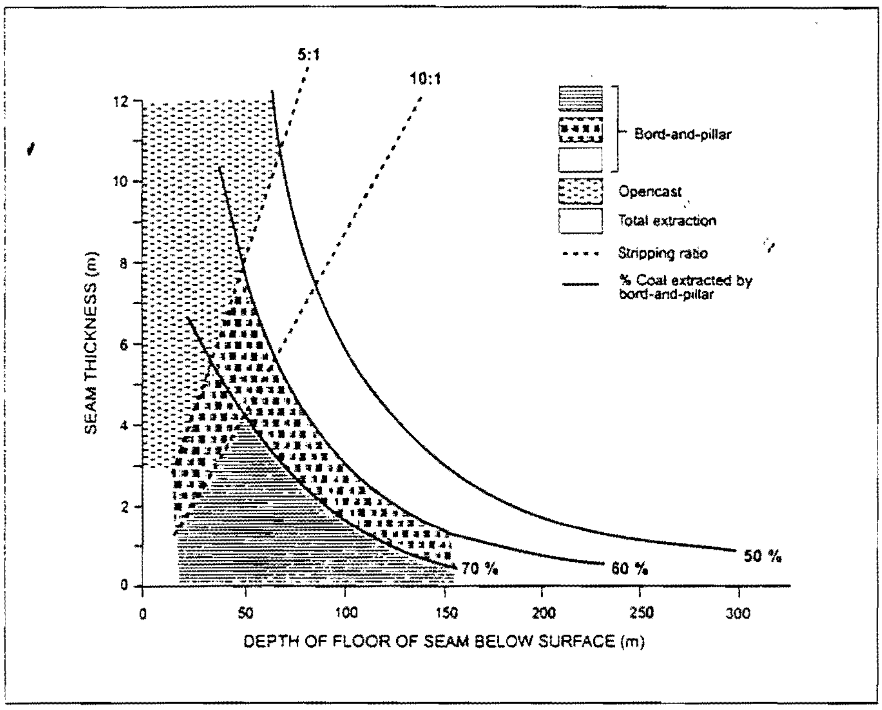

Figure 8: Mining method as a function of seam thickness and mining depth

5.1.2 *Coal preparation*

Coal consumers require coal of a consistent quality and size grading and each consumer may have different specifications. Run-of-mine coal contains a mixture of different size fractions and unwanted impurities. Coal preparation, or beneficiation, is the processing of run-of-mine coal into a range of graded and uniform coal, agreeing with the requirements of the commercial market. (In some cases the run-of-mine coal meets the user specification without the need for beneficiation. In this case, the coal would simply be crushed and screened) (Atwood, Redden and Bennett, 1994). Likely stages of environmental pollution in the production of coal are shown in Figure 9.

5.1.3 *Transport and storage*

Coal is generally transported by conveyor or truck over short distances. Trains, barges, ships or pipelines are used for longer distances. It is required by law that a number of preventative measures are taken during both transport and storage to reduce potential environmental impacts, such as water contamination should the load be released near an open surface water body (Atwood, Redden and Bennett, 1994).

5.1.4 Uses of coal

Coal is the predominant fuel for electric power generation. More than half of global coal production is used for making electricity. Other important uses are in steel and cement manufacture, industrial heating and gasification for the production of liquid fuel, organic chemicals and hydrogen, as well as for ammonia, fertiliser and explosives manufacture.

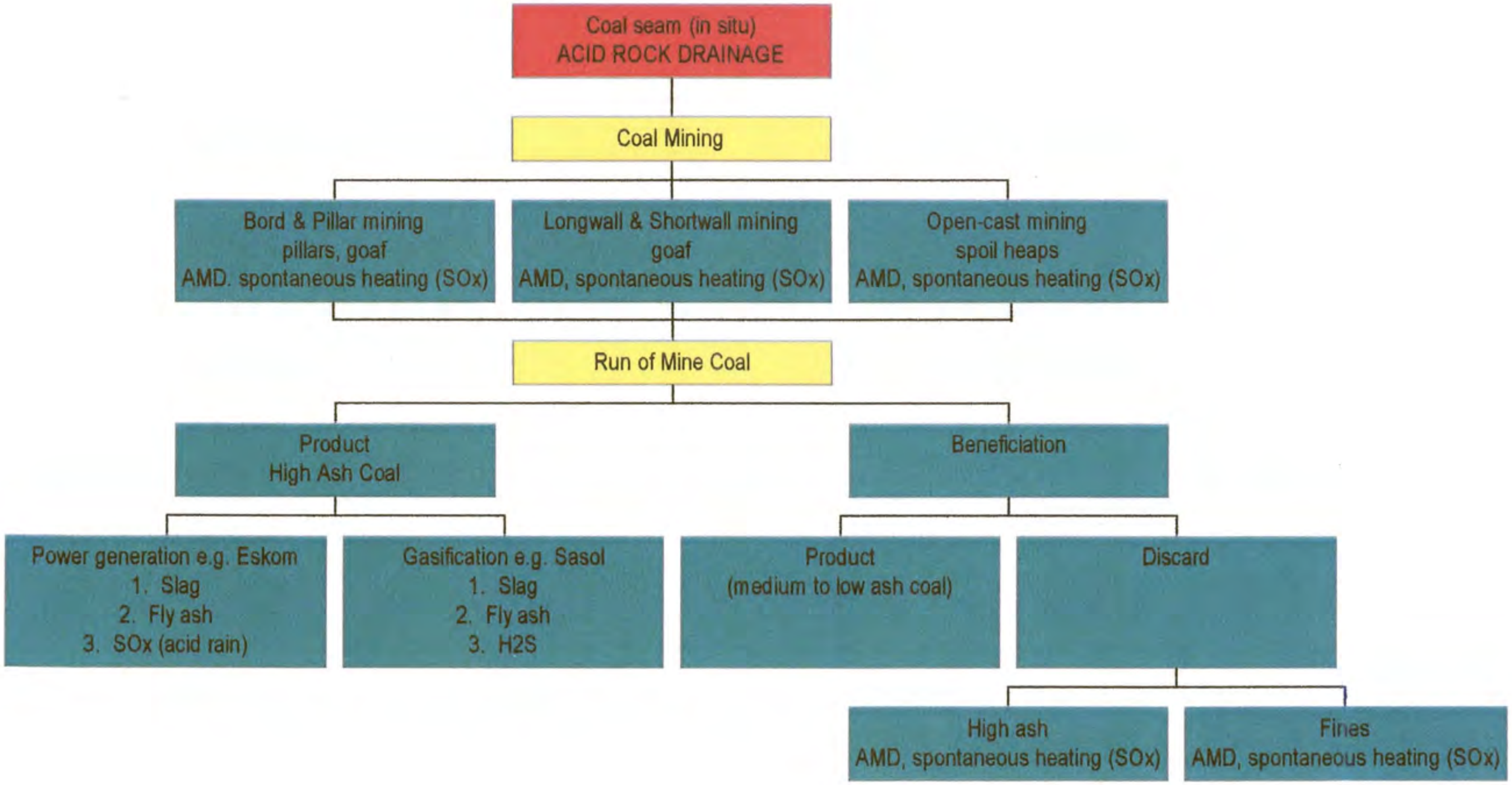

Figure 9: Scheme showing the likely stages of environmental pollution in the production of coal

To meet forecast electricity demand over the next 25 years, it is estimated that 1000MW of capacity, equivalent to a major power station, will have to be built every week throughout the world – 36% or more based on coal.

About 630 kg of coal are used to produce 1000 kg of steel. For the foreseeable future, coal will remain indispensable to the steel industry (Atwood, Redden and Bennett, 1994).

5.1.5 Coal in the environment

Although the coal industry of today is much more efficient and environmentally aware, it still has much work to do to rectify the false image which lingers from its past. Technologies have been developed to improve the environmental effect of coal-use techniques. An example of this is the use of electrostatic precipitators and/or bag filters, which means that power stations no longer emit large amounts of dust and fly-ash (Blight, 1987).

A more recent concern is that high amounts of greenhouse gases are being emitted as a result of the combustion of fossil fuels. However, greenhouse gases from coal contribute less than 20% to any enhanced greenhouse effect. The world community has largely accepted that every practicable step should be taken to improve the efficiency of all processes that involve fossil fuel combustion.

5.1.6 Clean coal technologies

Modern Clean Coal Technologies (CCTs) reduce CO_2 emissions per unit of electricity by up to 30%. CCTs are 'technologies designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use'. CCT programmes are being enthusiastically initiated in many countries. CCTs for the extraction of coal are readily available. Improved exploration techniques, such as geophysical techniques, also minimise potential environmental impacts. Clean Coal Technologies for the preparation of coal can reduce its ash content and clean the coal in terms of impurities. Pulverised Fuel combustion is the most widely used method for burning coal for the purpose of generating power. Post-combustion CCTs can reduce emissions from PF combustion. Flue Gas Desulphurisation methods can remove 90-97% of the oxides of sulphur from flue gases by converting it into gypsum, which can be used in the building industry. Application of advanced PF combustion results in relative reductions in CO_2 emissions, because less fuel is used per unit of electricity generated. Use of fluidised bed combustion has been stimulated by its better environmental performance (Bursky, 1992).

An alternative to coal combustion is coal gasification. In new developments of this method, over 99% of the sulphur present in the coal can be recovered by a process of electrostatic precipitation, for sale as chemically pure sulphur. Hybrid combined cycles are also under development. These combine the best features of gasification and combustion technologies (Bursky, 1992).

In addition to these CCTs, a development, which can apply to all generating systems, is the co-firing of coal with biomass or wastes. Benefits include reductions in CO_2, SO_x and NO_x emissions and the recovery of useful biomass and wastes at high efficiencies, depending on the composition of the waste. Hence, the coal-fired power industry can support the renewable energy and waste industries (Kruger, 1987).

5.1.7 Rehabilitation

It is now possible to restore mined land to a state whereby it may be used for its original purpose or another productive use. Today, the international coal mining industry is committed to the protection of the environment and land reclamation is an integral part of most mining operations (whether legally required, in the form of an Environmental Management Programme, or not).

5.1.8 Safety

Health and safety issues have been of primary concern to the coal industry for a long time. The technological advances in mining techniques have simultaneously led to improvements in productivity and safety. In most countries, miners receive regular job-skill and safety training. Coal companies recognise that improved productivity and safety are closely linked.

Coal does not present the same leakage and spillage hazards as oil and gas. The sinking of coal-carrying ships is fortunately rare and in no well-documented case has the coal cargo presented a pollution hazard. Distribution of coal on land, by conveyor, road or rail is relatively safer than in the case of other fossil fuels, despite the possibility of spontaneous combustion (Pulles *et al*, 1996).

5.1.9 The future

As the result of Clean Coal Technologies, coal will continue to be used more efficiently. These technologies also ensure that coal-fired power stations will meet the stringent environmental standards enforced globally. The coal industry will continue to adapt to community expectations (Bursky, 1992).

5.1.10 Economic implications

Mining activities incur two types of costs. Firstly, there are those that the producing firm must pay i.e. labour, capital and material inputs. Secondly, there are those that the producing firm does not pay, as is often the case for water pollution and other forms of environmental damage. The latter costs are commonly referred to as externalities. Society as a whole may never avoid these costs (Camm, 1995).

There is an optimal level for use for any given environmental resource. In economic terms, this occurs when the marginal social benefits equal the marginal social costs. The social benefit of an additional unit of pollution is the net value to society of the goods and services that the additional unit of pollution makes possible i.e. Marginal Social Benefits = Marginal Social Costs

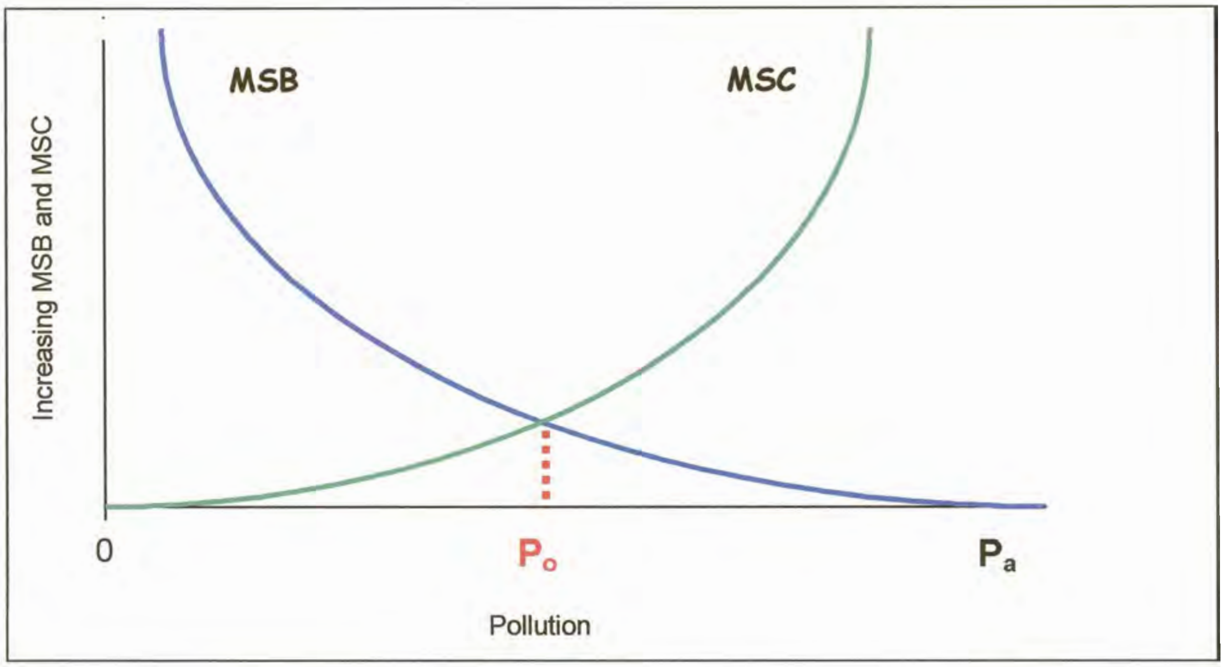

Figure 10: The marginal social costs (MSC) and marginal social benefits (MSB) of pollution.

Po represents the optimum level. The negative slope of the MSB curve represents the assumption that goods and services with lower social benefits per unit of pollution will be produced as the permitted level of pollution increases. The positive slope of the MSC curve implies that as the level of pollution increases the social costs incurred for each additional unit of pollution rise (Tilton, 1994).

Another way of representing this relationship is presented in Figure 11. Figure 11 counteracts the impression that may be given by Figure 10 i.e. that there can only be an inverse relationship between pollution/development and social benefits. In Figure 11, Po represents a critical value rather than the optimum.

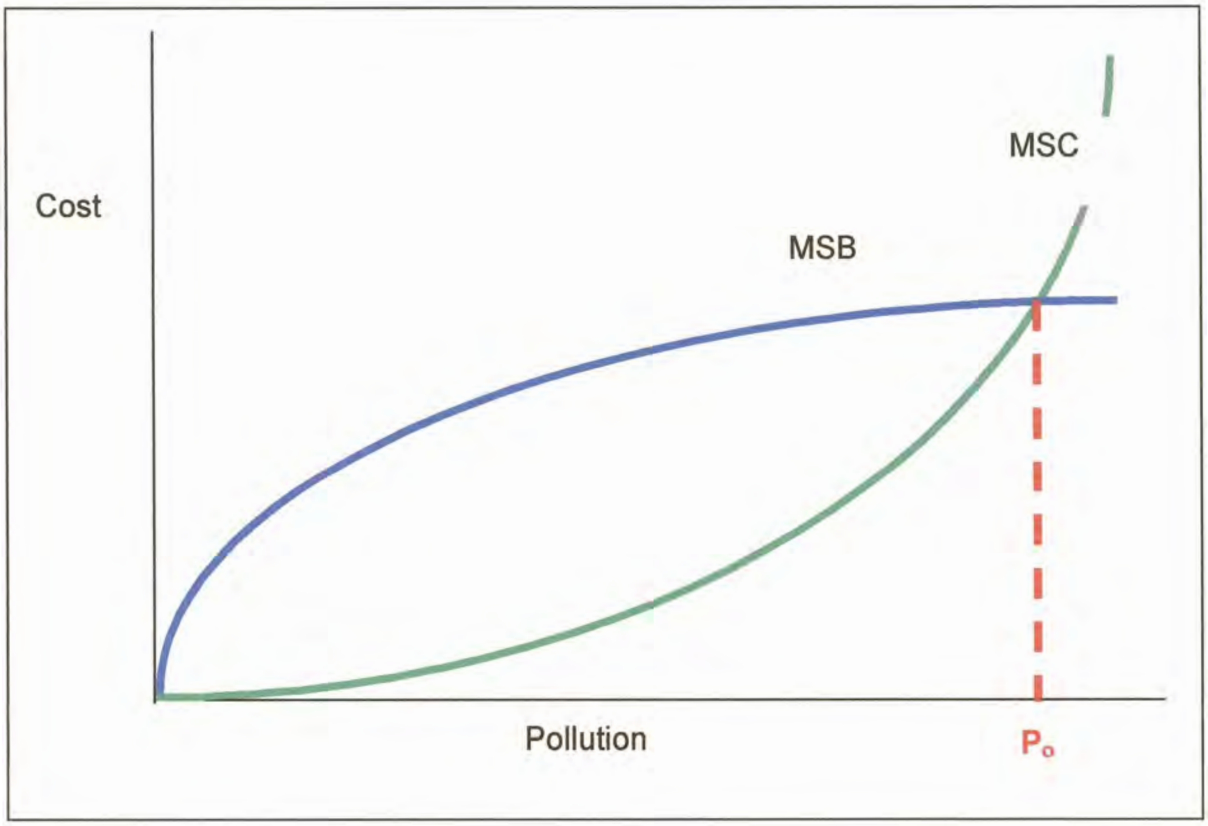

Figure 11: An alternative representation of the marginal social costs (MSC) and marginal social benefits (MSB) of pollution.

5.2 Coal characterisation

As was mentioned in the introduction, the rank of coal refers to its degree of development from peat to anthracite.

5.2.1 Proximate analysis

Proximate analysis comprises the moisture, volatile matter, ash and fixed carbon contents of air-dried coal and is determined under stringently specified conditions to ensure reproducible results. Fixed carbon is obtained by the difference between the total mass and moisture, volatile matter and ash percentage:

%fixed carbon = 100 - %moisture - %volatile matter - %ash

The moisture content is determined by heating the coal to constant mass to a temperature of 105°C – 110°C. The moisture content is calculated from the loss in mass.

The volatile matter is determined as the loss in mass, less that due to moisture, when coal is heated to 900°C in the absence of air under standard conditions.

The ash remaining after coal has been incinerated in air is derived from inorganic material present in the coal, mainly discrete mineral matter. The amount of sulphur retained in the ash is dependent on the lime content of the coal and the conditions of ashing.

The percentage of ash is calculated from the mass of the residue remaining after the sample is heated in air at a specified rate up to a temperature of 815°C.

5.2.2 Ash analysis

Ash analysis is essentially the same as any silicate analysis and can be done by atomic absorption spectrometry, X-ray fluorescence spectrometry, etc. In atomic absorption/emission analyses, the ash is fused with lithium tetraborate, followed by a final dissolution of the melt in dilute hydrochloric acid. The lithium tetraborate pellet can also be analysed by X-ray fluorescence spectrometry.

It should be noted that the chemical composition of coal ash is not identical to the composition of mineral matter in the coal or the composition of fly ash and slag resulting from combustion of pulverised coal. In the latter case chemical segregation takes place so that some components are preferentially enriched in the fly ash and others in the bottom slag.

The chemical composition of the ash gives an indication of the fouling and slagging potential of the coal during pulverised fuel combustion and pulverised fuel gasification, and also of the potential uses of the coal ash.

5.3 Coal in the study area

Table 6 provides a summary of the characteristics of the coal found in the study area.

Table 6: Characteristics of coal in the study area

MINE	Mining Methods	Washed/ Unwashed	Product	CV MJ/kg	Gross CV	H_2O %	Ash %	VM %	FC %	Tot S %
Greenside	underground; longwall	Washed :	Greenside	28.03	27.99	2.8	13.8	25.4	58.0	0.46
			Power station small	27.61	27.52	2.4	15.1	24.3	58.2	0.99
			Low ash	31.24	31.19	2.4	7.8	31.9	57.9	0.54
Kleinkopje		Washed :	Large nut	27.33	27.29	2.5	15.8	24.2	57.5	0.39
			Small nut	28.16	28.13	2.7	13.1	24.0	60.2	0.28
			Pea	27.43	27.39	2.8	15.5	21.9	59.8	0.41
			Small	27.74	27.70	2.8	14.5	21.3	61.4	0.42
			Duff	27.97	27.93	2.6	14.6	21.9	60.9	0.43
			Anglo	27.44	27.39	2.3	15.4	24.4	57.9	0.51
			Low ash	30.82	30.77	2.5	7.5	31.2	58.8	0.49
Matla	underground; #2=long and short-wall; #1 and #3 = underground	Unwashed:	Crushed coal	20.53	20.43	4.2	28.9	23.3	43.6	1.09
Kriel		Unwashed	Crushed coal	19.45	19.40	4.8	30.0	22.4	42.8	0.55
		Unwashed	Crushed coal	22.22	22.14	4.9	22.9	23.2	49.0	0.83
Syferfontein		Unwashed:	Crushed coal	20.13	20.08	5.9	28.3	22.8	43.0	0.57
Eikeboom	opencast	Washed :	High phosphorus:							
			Large nut	28.57	28.54	3.4	11.4	26.3	58.9	0.35
			Small nut	28.61	28.58	3.2	11.7	25.2	59.9	0.27
			Pea	28.46	28.41	3.0	11.8	29.2	56.0	0.50
			Grain	29.06	29.01	3.7	8.9	32.4	55.0	0.50
			Duff	26.90	26.86	3.7	14.3	26.2	55.8	0.44
		Washed :	Low phosphorus:							
			Large nut	28.51	28.47	3.7	11.3	31.3	53.7	0.47
			Small nut	28.55	28.50	3.0	12.3	31.0	53.7	0.57
			Pea	28.42	28.37	3.7	10.4	31.9	54.0	0.52
			Grain	28.29	28.25	3.8	11.5	28.6	56.1	0.47
			Duff	28.58	28.53	3.8	10.6	29.8	55.8	0.54

Table 6 (continued): Characteristics of coal in the study area

MINE	Mining Methods	Washed/ Unwashed	Product	CV MJ/kg	Gross CV	H_2O %	Ash %	VM %	FC %	Tot S %
Woestalleen	opencast	Washed	High phosphorus:							
			Large nut	26.10	26.04	4.1	15.5	24.1	56.3	0.59
			Small nut	27.44	27.37	3.7	13.8	26.4	56.1	0.77
			Pea	27.46	27.39	3.9	13.1	28.7	54.3	0.71
			Duff	27.25	27.19	4.1	13.1	28.4	54.4	0.67
			Low phosphorus:							
			Large nut	28.88	28.83	3.3	11.1	31.9	53.7	0.54
			Small nut	27.84	27.77	3.8	12.2	29.1	54.9	0.72
			Pea	28.77	28.70	3.4	10.8	33.4	52.4	0.73
Arnot	underground; board and pillar; shortwalling	Unwashed:	Duff	27.46	27.38	3.8	13.6	30.9	51.7	0.84
Koornfontein	underground; board and pillar	Washed :	Export	28.06	28.01	3.1	13.1	26.1	57.7	0.49
Middelburg	opencast	Washed :	Small	27.97	27.93	2.7	14.2	23.5	59.6	0.38
Goedehoop	Washed :	Goedehoop	28.33	28.27	2.6	13.6	26.6	57.2	0.62	
		Low ash	31.00	30.94	2.5	7.5	32.4	57.6	0.65	

(CSIR, 1999).

It may be stated that most calcium and magnesium will occur as carbonates and most iron will occur as pyrite in these coals (Gaigher, 1980).