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METHANE EMISSIONS ASSESSMENT IN SOUTH AFRICAN COAL MINES AND THEIR POTENTIAL UTILIZATIONS

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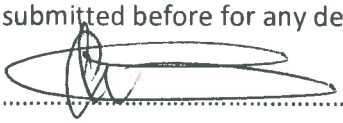
A Research Report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg 2011

DECLARATION

I declare that this is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.



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25 day of September 2011

ABSTRACT

Methane has been recognised as one among other greenhouse gases which contribute to global warming. Given that methane is a greenhouse gas as much as a danger to life in underground workings, it is important to know what factors impact on the emission rate of methane in South African coal seams. In addition, coal being both a generator and storage site for methane, sequestration of gases such as methane is a realistic option to consider in the search for reducing greenhouse gas emissions.

The research project aims to assess and conclude on the Coal Seam Methane (CSM) emissions data which has been collected over the past fifteen years from underground coal mines in South Africa. The assessment is expected to contribute to the bank of knowledge on methane potential in South African coal seams, which can be subsequently used in the assessment of the coal seams for methane emissions capture, and perhaps even carbon dioxide (CO_2) storage through Enhanced Coal Bed Methane (ECBM).

The assessment of the data of the selected samples in the Highveld and Witbank coal seams indicate the following results:

- Weak correlation between methane gas and fixed carbon ($0.304 \leq r \leq 0.368$); weak correlations between gas and moisture ($0.085 \leq r \leq 0.549$); weak correlations between gas and CV ($0.186 \leq r \leq 0.440$); weak, inverse correlations between gas and DAF volatiles ($0.061 \leq r \leq 0.254$) and weak, inverse correlations between gas and Ash ($0.185 \leq r \leq 0.416$); On the basis of these correlations, there is little or no relationship between methane content and proximate analysis calorific values.

- In most of the collieries the dominant gas emission ranges between 0 and $0.5 m^3/t$. The highest values encountered ($4.93 m^3/t$ in average) were found in Maloma Colliery, an anthracite mine. These results indicate that South African coals are generally low in methane content.

- Gas content increases with depth($r = 0.72$) although this is a weak to moderate relationship) in SA coal seams with the exception of the anthracite (Maloma colliery) where gas was shown be higher at shallow depths. The reason for this anomaly in the anthracite is due to the pressure of igneous sills and dykes which would have devolatilised the original coals and increased the rank to anthracite.

- No significant relationships were established between gas content and petrographic analyses (maceral and rank) due to the fact that sampling was limited to small samples hand selected during mining in the case of methane emission testing whereas the petrographic analyses were conducted on averages of full seam or colliery samples as reported in Bulletin 113.

- Emission ranges within each colliery are scattered with a diverse histogram for each and there is no clear pattern or trend in most collieries. However, the extended ranges of value in most of the collieries indicate the presence of limited areas where sills and dykes may have increased the gas content in normally low gas-bearing bituminous coal. These extended ranges could be of value to mining operations to indicate areas of high risk.

- Methane content and emission prediction in South Africa remains a difficult apart from depth or proximity to igneous intrusions. The fact that Loyd and Cook amended the formula in 2010 in order to obtain more realistic values in methane prediction, has not removed the complexity of this task.

The limited data (quality of coal and of gas composition) precluded the reaching of any further significant conclusions in this Project Report but what could be noted is that the source of methane emissions in South Africa is highly variable due to the highly variable nature and composition of the coals and to the variable proximity to igneous intrusions.

The potential for the utilisation of methane from coal mines is considerable, subject to the quantities and qualities obtained and the ability of process technologies to utilise this form of fossil fuel. Such user processes include power generation in boilers, and/or gas turbines, gas-to-liquid production and metallurgical reductions technologies.

A further use in terms of storage capacity for the CO_2 greenhouse gas is also under consideration. In this process Enhanced Coalbed Methane (ECBM) is envisaged wherein CO_2 is pumped into the coal seam thereby replacing CBM and forcing it to the surface for capture and use. This process has yet to be proven in South Africa.

The conclusion is that further in depth investigation in methane emissions in South Africa is necessary for safety, potential capture and commercialisation purposes. In order to do this, it is recommended that more detailed studies in situ in mines and advancing boreholes should be undertaken along with more comprehensive associated geological data. Unless this is done, little true correlations or predictions of methane potential are possible.

ACKNOWLEDGEMENTS

The successful accomplishment of this report would never have been possible without the help provided by other people. First of all I would like to thank Professor R Falcon for making it possible for me to have a project and offer advice whenever I requested although I indicated late that I wanted a research project.

I would also like to thank Alan Cook for being very welcoming and allowing me to have access to the database of his company. I would not have a project report if he did not allow me also to visit his company, and also travelling with me to the mines with the aim of familiarising me with his work.

Lastly, I would like to thank my family for their understanding and support, particularly my wife Paulina who has always wanted me to achieve my goals. I am also grateful to my two children Njabulo and Sithokozile although sometimes I felt that I did not have enough time for them.

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List of Acronyms

BP	British Petroleum
CBM	Coalbed Methane
CBMC	Coal Bed Methane Company
CH_4	Methane
CIA	Central Intelligence Agency
CIAB	Coal Industry Advisory Board, UK
CMM	Coal Mine Methane
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DME	Department of Minerals and Energy
DTI	UK Department of Trade and Industry
ECBM	Enhanced Coalbed Methane
EIA	Energy Information Administration, United States
IPCC	Intergovernmental Panel on Climate Control
KGS	Kentucky Geological Survey
M2M	Methane to Market
SA	South Africa
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USBM	US Bureau of Mines
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
VAM	Ventilation Air Methane
VCBM	Virgin Coalbed Methane
VM	Volatile Matter

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1 INTRODUCTION

Coalbed Methane (CBM) is a natural gas, which is generated from coal during the maturing stages of coalification. It is trapped within coal seams in situ and, at times, in the surrounding rock strata. It is one of several combustible gases emitted from coal but it is by far the most predominant one (Rice, Lae and Clayton 1993). Methane is also notable as a greenhouse gas which contributes to global warming.

During mining, the geologic pressure is reduced and methane is both into mine workings and ultimately into the atmosphere. In small concentrations, it is an explosive gas, and therefore underground coal operations require adequate and competent ventilation systems to ensure the safety and health of miners during operation. For these reasons, mining regulations require methane to be diluted in the ventilation air and then expelled to the atmosphere. In the US mines also remove methane before and during mining using degasification systems (USEPA, 1999).

In underground mining operations, *Coal Seam Methane* (CSM) is released to the workings when the coal is extracted by mechanical or conventional methods (such as bord and pillar/drill and blast). With regards to safety of personnel underground, ventilation is the only way to mitigate against the perils of CSM.

In surface mining, CSM is released directly to the atmosphere once the overlying strata have been removed. As there is no threat to human life in this latter instance, no methane emission mitigation options are considered.

Not all methane is removed during underground mining to the atmosphere. Some methane, referred to as *Coal Mine Methane* (CMM), remains in the coal when mining has ceased, In this case, some gas may be slowly released into old underground working areas overtime thereby rendering such workings as potentially hazardous.

While in the past the focus on methane was on safety in underground mines, more recently other reasons have been added to increase the interest in this gas. Bibler (1997) lists the following three factors as important with regard to the recovery of coal mine methane:

- to increase mine safety underground
- to improve mine economics
- to recover coalbed methane to benefit local and global environment to reduce the impact of global climate change

In South Africa drilling into coal seams is typically carried out for exploration reasons. With the singular exception of the CBM exploration site by Anglo Coal in the Waterberg, methane encountered in such drilling programmes is generally vented to the atmosphere without attempts to recover it for environmental and economics reason.

Now however, increasing interest in methane for the reasons above, there is a relatively urgent need to understand the status quo of methane in the coal mining industry in this country, and for this reason, the following steps need to be taken: namely,

1. To establish an inventory of methane emissions from coal mines in South Africa in order to assess the possibility of CSM and CMM recovery in the country,
2. To understand what factors impact on the emission on the emission of methane in South African coal seams, and
3. To quantify methane as a potent greenhouse gas in global climate change,
4. To consider methane-storing coal as a potential site for the sequestration of undesirable greenhouse gases such as carbon dioxide (CO_2)

In order to contribute to the knowledge required, this Research Project aims to assess and evaluate the CSM emissions data that have been collected from underground coal mines in South Africa over the past fifteen years and to establish, if possible, the factors that impact upon methane emission. In particular, the following questions were investigated:

1. From the data on emissions, do South African coals show any relationship between methane content and chemical, petrographic, and seam depth parameter?

2. If there is a relationship between methane content and the above mentioned factors, what is the noticeable trend?

3. Could any significant trends be used to predict methane content and emissions in SA coal seams in future?

The results of this work are expected to contribute to the bank of knowledge on origin, formation, distribution and emission rates of methane in South African coal seams.

This study will be structured in 6 chapters. The first chapter will focus on introducing the topic.

Chapter 2 will present the literature survey. In this it will cover the theory about the existence of methane in coal, methods of predicting methane in the mines with emphasis on the status of methane emissions and their potential use internationally and in South Africa.

Chapter 3 will address the gas capturing and the processing method used on the ROM samples to establish gas content in the coal.

Chapter 4 will deal with the analysis of the data and the results, and Chapter 5 will focus on conclusions. Chapter 6 will deal with recommendations. This project is limited to

underground coal mining methane emissions and does not address surface mining methane emissions.

2 LITERATURE REVIEW

Since the beginning of underground mining, many people have died due to methane explosions in mines. This has drawn the attention of many researchers around the world to probe the characteristics of methane and to find the best way to deal with it. This chapter reviews the background to methane in coal, how it is formed, where and how it is stored, levels of gas contents, analytical techniques used in determining methane content, estimating methane rate of emission in a mine, the potential uses for coal mine methane and local and worldwide coal resources. Specific focus is placed upon current developments in South Africa with regard to coal mine methane

2.1 Methane in coal

Coalbed gas has been considered a major mine hazard since the early to mid 19th century when the first documented coal mine gas explosions occurred in the United States in 1810 and in France in 1845. Since the late 20th century, coalbed methane has received increased emphasis as a potential energy resource.

In the past coalbed methane was not a problem when coal was mined from surface outcrops by stripping and shallow shafting in the United Kingdom and other European countries. However, as shallow coal resources were slowly depleted at the end of the 18th century and technology was improved to permit construction of large deep mines, mining went underground and coalbed methane was encountered. In the early 19th century, coal mine explosions were recorded in Britain, France, and United States. In the late 19th and early 20th century minor to major disastrous explosions were reported in deep underground coal mines in Australia, Canada, Belgium, Germany, Japan, Poland, Russia, and United States (Flores, 1998).

The first attempts to remove gas from coal were undertaken in Europe in the late 19th century to reduce mining hazards. First large scale use of cross measure holes took place in Germany in 1940, at the Mansfield Colliery, where the first recorded successful use of vertical boreholes to drain gas from virgin coal also occurred in 1943 (Rice, 1993). Since the late 20th century, coalbed methane has received increased emphasis as a potential energy resource. Coal beds contain a mixtures of gases in which methane represents between 80-99% volume, and has a calorific value ranging from 8455 to 9354 cal/m3 (CIAB, 1994 and Flores, 1998). The other components of coalbed gas are carbon dioxide, nitrogen and other hydrocarbons, with negligible quantities of hydrogen sulphide and sulphur dioxide even in high sulphur coals.

There are four main benefits of recovering and using coal mine methane.

1. The first benefit is *economic.* For example, methane recovery through degasification systems can reduce ventilation costs and improve mine productivity. Also, the mine can realize cost savings by using the methane for on-site energy needs. Alternatively, the methane can be sold to customers off site. If the cost of recovering and using (or selling) the gas is less than the value of the energy derived, the mine earns a profit.

2. The second benefit is the potential of *supplying energy* to the neighbouring community where a coal mine is situated. The gas can be used as a residential, commercial, or industrial fuel. This increased source of domestic energy can be especially important in nations where demand is growing rapidly and domestic supplies are constrained. The increased reliance on domestic energy resources can also help reduce energy imports, thereby improving energy security and the balance of payments.

3. The third benefit in recovering coalbed methane is in the reduction of this greenhouse gas which, in turn, would aid in both the global and local *atmospheric environments.* As a greenhouse gas, methane is an important for

the global warming effect, second only to carbon dioxide. Methane emissions from coal mines range from 18Mt to 25Mt (Rice, 1993; CIAB, 1994; M2M, 2006a and USEPA, 2006a) and represent between 4% and 8% of all anthropogenic methane emissions (CIAB, 1994; Sloss, 2005 and M2M, 2006a). Methane is also responsible, in part, for depleting the ozone layer.

4. The fourth benefit relates to *safety in mining*. At gaseous concentrations of 5 to 15 percent, methane is explosive. Thus the buildup of methane in underground mines poses a serious safety hazard. Increased use of degasification systems may improve safety by reducing methane levels in the mine. Techniques for recovering methane before mining through use of vertical wells drilled from the surface can significantly reduce the amount of methane in the coal when mining occurs (USEPA, 1993).

2.2 Storage and generation.

Coalbed Methane (CBM) is a natural gas, generated and/or stored in coal seams, in situ, and mainly composed of energy gases (combustible gases) of which methane is the most predominant (Rice et al 1993). CBM can also be detected in many sedimentary rocks but generally only in low concentrations. It occurs in much higher concentrations in coal rather than in any other rock type because of the 'adsorption' process which enables methane molecules to be densely packed into the coal substance, in almost the same manner as a liquid (Creedy and Tilley, 2003). Haney (1996) describes coal as an aquifer because the cleats are generally saturated with water. Coal is, in fact, a microporous solid with large internal surface areas (10-100m2/g of coal) and, as such, it has the ability to sorb large amounts of gas (Rice et al., 1993).

According to Diamond and Schatzel (1997) the storage of gas in the coalbed is different from that of the conventional reservoirs. It is because of this difference in the storage mechanism in reservoirs that alternative evaluation methods are used when dealing with oil and gas industries.

Natural gas is generated in coal by two different processes known as biogenic and thermogenic processes. Biogenic gas, primarily methane and carbon dioxide, is produced by the decomposition of organic matter through partial oxidation by micro-organisms and is commonly generated in peat swamps (Rice, 1993). The thermogenic process occurs during coalification in high-volatile lower ranking bituminous coal and increasingly in higher ranks. As the degree of coalification increases due to higher temperatures and pressure, coal becomes enriched in carbon whilst large amounts of volatile matter rich in hydrogen and oxygen are released. Methane, carbon dioxide and water are the most important by-products of this devolatisation process (Rice et al., 1993).

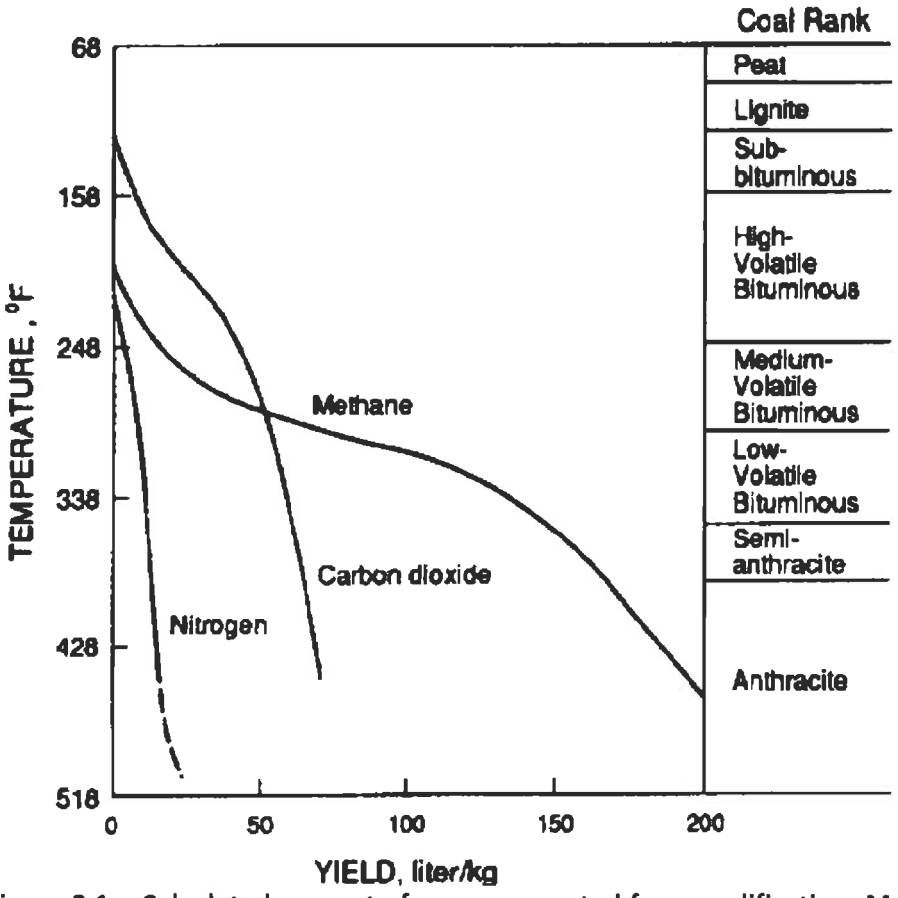

Figure 2.1 – Calculated amount of gases generated from coalification. Modified from Hunt (1979)

The ability of coal to produce gas decreases as the rank increases and this is illustrated in figure 2.1. In addition to rank, total methane storage is also affected by pressure and temperature. Increasing pressure results in greater methane storage capacity, whereas increased temperature results in less methane content. Thakur *et al.* (1996) suggests that the amount of gas retained in coal can be as much as 25 m^3/tonne, generally increasing with depth while Rice (1993) reported a higher value of 31 m^3/tonne for high rank coals and a maximum value of 2.5 m^3/tonne for low-rank coals.

Total quantities of gases generated during the entire coalification process can be as much as 1300 m^3/tonne of coal formed (CIAB, 1994). The highest volume of by-product gases is generated in anthracite coals. Rice *et al.* (1993) suggested a generation rate in the range of 150 to 200 m^3/tone of methane gas under natural conditions and later Flores (1998) suggested a value between 100 and 300 m^3/tonne during the latter stages of coalification.

Coalbed gas is stored in the coal on (adsorbed) or within (absorbed) the molecular structure of the coal, or within the micropores and cleats (Rice, 1993). Haney (1996) illustrated coal as an excellent reservoir, see figure 2.2.

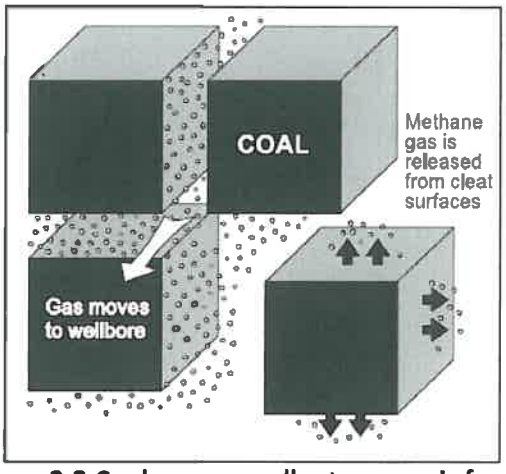

Figure 2.2 Coal as an excellent reservoir for gas

2.3 Gas measuring methods on mines

Coalbed gas content measurements are used for the purposes of mine safety, methane resource assessment and recovery applications. In addition to that, the data obtained from the coalbed gas content can be used in the calculation of gas resources as an input data for reservoir model production simulators to forecast gas production (Diamond and Schatzel, 1997).

In most coal gas content analysis, the total gas in coal is divided into three components: lost gas, desorbed and residual gas. Each method is measured using different techniques and added to determine the total gas content of the coal sample.

Lost Gas

The lost gas is described as that portion of the total gas that escape from the sample when is collected and retrieved prior being sealed into an airtight desorption canister. Lost gas volumes cannot be measured but can be estimated from subsequently measured gas volume data (Diamond and Schatzel, 1997). The volume of gas lost prior to sealing a coal sample depends on sample retrieval time, physical character of the sample, the type of the drilling fluid and water saturation/relative amount of free gas.

Desorbed Gas

Desorbed gas is that which accumulates inside the desorption canister once the sample is sealed. The desorbing gas can be measured directly by some variation of the water displacement method (Betard et al, 1970). This system was later refined by Kissel et al (1973). USBM later developed a more accurate method known as the Modified Direct Method (MDM) to measure the desorbed gas and this entailed the abandonment of the water displacement apparatus for measuring desorbed gas volumes. Instead, the MDM test procedure relies on the measurement of differential pressures (pressure build up between readings) and the ideal gas law to calculate the volume of gas released into the

desorption canister at STP conditions (Diamond and Schatzel, 1997). It is said the MDM measurement apparatus utilizes pressure transducers with digital readouts that offer superior resolution compared with other instrumentation incorporated in conventional direct method gas content testing apparatuses.

Residual gas

The volume of gas desorbing from a coal sample diminishes with time. Eventually measurements for the extended desorption techniques reaches a point where they have to be terminated due to low emission rate of gas in the coal sample. The termination point does not imply that there is no longer gas in the coal sample.

In the past, people thought of the residual gas as a gas that is 'trapped' within the coal structure due to slow diffusion rates. Others like Betard et al. (1970) and Levine (1992) held a view that residual gas may not depend on diffusion but in part represents gas remaining in equilibrium under approximately 1 atm of methane pressure in the desorption canister.

The residual gas volume can be determined by crushing the sample in an airtight container and measuring the volume of gas released by the same method used as that used for the desorbed gas (Diamond, LaScola and Hyman 1986).

Methods of Determining Gas Content

Basically the methods of determining gas content can be grouped into direct and indirect methods.

Direct methods: The gas content determination under direct methods can be achieved using different direct measurements techniques (Diamond, 1997). The techniques are divided into quick-crushing techniques and extended desorption methods.

The quick-crushing techniques use coal samples that are obtained from underground drill holes. In order to get results quickly, the coal sample is crushed to release the

remaining gas over a few days from the coal sample. Quick crushing techniques are generally used for assessment of gas conditions ahead of the production face. Sawyer, Zuber, Kuuskraa and Horner (1987) pointed out that crushing the sample early in the desorption process makes it impossible to determine the relative amounts of desorbed and residual gases and also the sorption time commonly used in coalbed gas reservoir models.

The extended desorption gas content measurement technique functions on the premise that a coal sample is allowed to desorb a gas until a low desorption rate cut-off point is reached (Diamond and Schatel, 1997). Figure 2.5 below illustrates the type of apparatus that is used in direct measurements of gas for a given coal sample.

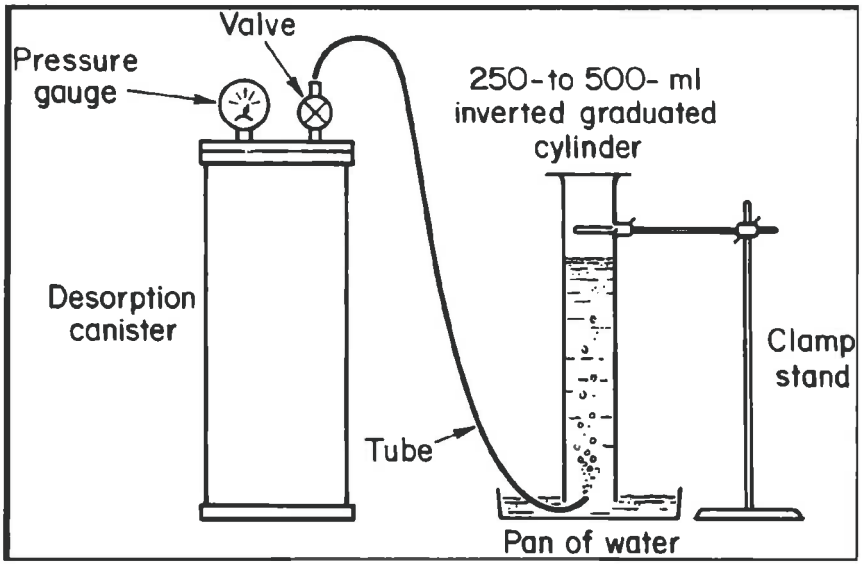

Figure 2.3 - USBM direct method gas volume measurement apparatus (Diamond et al., 1997)

Owen and Shearer suggested (1992) the possibility of determining gas content in a sample without considering the lost gas, the method that they mention is pressure coring. Pressure coring obtains a coal sample at reservoir pressure thus eliminating the need for determining lost gas.

Indirect Methods: Gas content in coal can be estimated indirectly using sorption isotherm data (Kim, 1977). Another approach to determine gas content indirectly can be based on empirical estimation curves of measured gas content results plotted against other measurable variable like coalbed depth and coal rank (Diamond *et al.* 1986).

Sorption isotherms, derived from laboratory results describe the quantitative relationship between adsorbed methane at different pressures and a constant temperature. This method provides a measure of maximum methane sorption or storage capacity of the coal sample. The gas estimation contents based on the isotherm data are less accurate since all coalbeds are not fully saturated with methane (Diamond and Schatel, 1997). In addition, isotherm based methods have the tendency of overestimating the actual gas contents.

Another method used to determine the gas contents in coalbeds is wire line geophysical logging (Mullen, 1989). This method is not a direct measurement method but an empirical estimation curve technique. Basically this method generates algorithms relating to gas contents and apparent coal rank. These factors are derived from actual gas content and coal proximate analysis data from cores obtained in a particular area of focus. The coal properties data derived from the log are then used to estimate gas content as a function of coal rank and depth.

Diamond and Schatzel (1997) argue that indirect methods can be useful in the preliminary assessment tool for mine planning or targeting potential areas for commercial coalbed methane exploration.

John Pope *et al.* (2006) have been working on a new method to determine critical desorption pressure and gas content. This method is facilitated by development of a Raman spectroscopy based sensor capable of detecting and quantifying trace amounts of solution gas. The main reasons cited for this new method were technical challenges in the current standard technique for deriving critical desorption pressure from gas content and adsorption isotherm data. Other challenges in the current standard

techniques are: inherent uncertainties, including high expense and risk for core retrieval, difficulties in controlling or measuring "lost gas", a high sensitivity of petrophysical properties to reservoir conditions (e.g. temperature and moisture content), and the weeks to months required to obtain accurate desorption data.

According to this new technique, by determining the concentration of methane in the water and using a solubility law to calculate a partial pressure it is then possible to use that partial pressure, along with an adsorption isotherm, to calculate the gas content of the coal seam itself as illustrated in figure2.4 below.

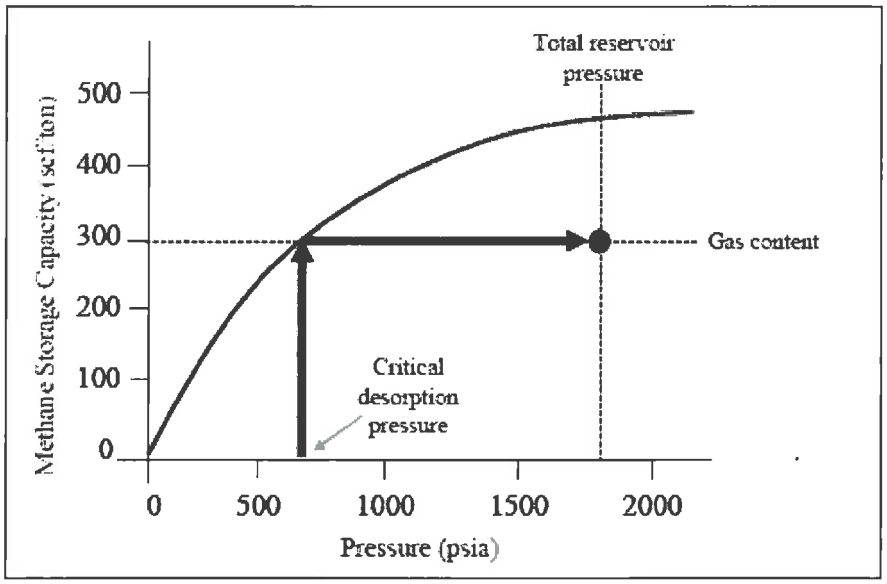

Figure 2.4 New method for correlating partial pressure, i.e. critical desorption pressure, to gas content using an adsorption isotherm.

It is possible, given modern bottom hole sampling techniques, to retrieve a sample of fluid from a coalbed reservoir and analyze methane concentration (or partial pressure directly) in a laboratory. Future publications will report in more detail the accuracy of this method, case studies illustrating its practical use, and the results of in-depth laboratory and field petrophysical and reservoir studies using this technology (Pope *et al*. 2006).

2.4 Estimating methane emissions in a mine

Methane emission in a particular mine can be predicted if the reservoir properties, such as gas content, reservoir pressure, permeability and porosity of coal seams, and the mining methods are known. It is of great importance to mention that if the estimation has to cover many mines in a country with various coal fields each with many coal seams, then the whole exercise becomes more complicated. Williams and Mitchel (1992) argue that methane emissions and the rates of release will differ at each mine due to following: mining method used, different working depths, types of ventilation, the different drainage or pre-drainage and capture systems that are used and other related factors.

Methane emissions are usually estimated utilizing emission factors. An emission factor is an average value used to calculate total emissions of a gas from a certain source type. Normally, coalbed methane emission factors are calculated in methane cubic meters per tonne of coal produced using regression equations. To obtain relatively accurate estimates, emission factors should be obtained based on coal rank along with certain geological factors such as depth (Thakur, 1996). However, this technique requires extensive accurate coal seam data and is not feasible for obtaining country or global estimates. For example, Thakur (1996) suggests emission factors ranging from 5 to 55 m^3/tonne for mines in the United States depending on coal geology, while USEPA (2006b) reported emission factor values between 1.61 m^3/tonne to 169 m^3/tonne for 56 gassy mines also in the United States, from 0.5 m^3/tonne to 169 m^3/tonne for China's 678 state-run mines and form 0.5 m^3/tonne to 90 m^3/tonne for 34 Russian Federation coal mines.

Methods of Calculating Methane Emissions

In calculating methane emissions from coal mining, very detailed mine by mine, seam by seam validated information is required (Williams and Mitchell, 1992). In smaller coal producing countries a simpler approach may be used. It is because of the complexity in this calculation that the three tier approach was devised, dividing the methods into three. These are known as the Global Average Method, Country or Basin Average Method and Mine specific Method.

Global Average Method: This method uses a pre-determined range of emission factors (derived from experience in different countries) to estimate emissions. In this method methane emission is achieved by multiplying the underground coal production by a factor or range of factors representing global average emissions from underground mining and this includes both ventilation and degasification system emissions. This method is best suited where total coal production from underground is known but its limitation is that more detailed data on emissions for example geological conditions, coal characteristics and related information is not available hence the estimation contains errors. The Global Average Method equation is shown below.

$$\text{Low } CH_4 \text{ Emissions (tonnes)} = \text{Low } CH_4 \text{ Emission Factor } [m^3 CH_4 \text{ (tonne of coal mined)}^{-1}]$$

$$\times \text{ (Underground Coal Production (tonnes)} \times \text{ Conversion Factor} \qquad (1a)$$

$$\text{High } CH_4 \text{ Emissions (tonnes)} = \text{High } CH_4 \text{ Emission Factor } [m^3 CH_4 \text{ (tonne of coal mined)}^{-1}]$$

$$\times \text{ (Underground Coal Production (tonnes)} \times \text{ Conversion Factor} \qquad (1b)$$

Where the Low Low CH_4 Emission Factor equals $10m^3$/ton and the High CH_4 Emission Factor is $25m^3$/ton. The conversion Factor converts the volume of CH_4 to a weight measure based on the density of methane, 1.49×10^9 m^3 Mt^{-1}.

Country or Basin Average Method: This method can be used to refine the range of emission factors used for underground mining by incorporating some additional country or basin information. In this method, a country with limited available data can be able to determine where within the range of global average emissions, their underground coal mines are likely to be located. Some countries, for example, may have enough data to determine that their mines are gassy while others may not. This assessment can be achieved best by examining measurement data from a limited number of underground coal mines to estimate where within the Global Average Emission Factor range a country's mines fall and whether a reasonable narrower range of emission factors might be calculated.

Although this method can provide some additional information about methane emissions in a particular country or coal basin, it is still subject to uncertainty because of the limited solid information about emissions data. The use of this approach is only necessary when there is a strong need to make an estimate that is more refined than the Global Average Method in the absence of enough data to prepare a Mine specific Method.

Mine Specific Method: Methane is a gas that is hazardous to underground mine safety, based on that reasoning in the past many countries collected data on methane emissions from mine ventilation systems while others collected data on mine degasification systems. In the instances where such data is available, the Mine Specific Method offers the most accurate estimate of methane emissions from underground mines. The fact that these data have been collected for safety and not for environmental reasons means that it is important to ensure that this data is manipulated to account for total emissions from coal mines. The OECD Expert Group (Kruger, 1993) has formulated recommendations with regard to using mine safety data to estimate methane emissions (see Table 2.2).

Table 2.1 - Key issues for consideration when using Mine Specific Method

Issue	Description	Recommendation
Where and how are ventilation system emissions monitored?	When used to develop overall methane emission estimates, the optimal location for ventilation air monitors is at the point where ventilation air exhausts to the atmosphere.	If ventilation emissions are not monitored at the point of exhaust, emission data should be corrected based on estimated additional methane emissions between the point of measurement and the point of exhaust to the atmosphere.
Are ventilation system emissions monitored and/or reported for all mines?	In some countries, emissions are only reported for 'gassy mines'.	Estimates should be developed for non-gassy mines as well. Estimates can be prepared using information about the definitions of gassy and non-gassy mines and data on the total number of mines.
Are methane emissions from degasification systems reported?	Some countries collect and report methane emissions from ventilation and degasification systems, while others only report ventilation system	If degasification system emissions are not included, those mines with degasification systems should be identified and estimates prepared on

	emissions. Both emission sources must be included in emissions estimates.	emissions from their degasification systems. Emissions estimates can be based on knowledge about the efficiency of the degasification system in use at the mine or the average efficiency of degasification in the country.

From coal mine data in the USA, the USEPA developed the following equation (Boyer, 1990):

Methane emissions (m^3/tonne) = 2.04 methane adsorbed (m^3/tonne) + 8.16 (2.1)

Williams and Mitchell (1992) came out with a table of emissions factors for a selected number of countries that can be used to estimate methane emissions (see table2.2) and note that South Africa is not mentioned.

Table 2.2 – Estimated underground emission factors for selected countries

Country	Emission Factor/m^3 $tonne^{-1}$
Former Soviet Union	17.8-22.2
United States	11.0-15.3
Germany (East and West)	22.4
United Kingdom	15.1
Poland	6.8-12.0

Czechoslovakia	23.9
Australia	15.6

The Intergovernmental Panel on Climate Change (IPCC) in 1996 produced guidelines for calculating the inventories for emission factors. These guidelines are based upon a model involving even and fair distribution of the methane throughout the seam, retention of the methane within the coal measures due to hydrostatic pressure and the release of the pressure and thus of the retained methane because of mining activity. According to this theory methane will be liberated in the following pattern:

- Firstly and rapidly from the broken surface of the newly mined coal
- Secondly, and more slowly, from deeper in the newly mined coal, and
- Finally, more slowly still, from pillars, roof and floor created by mining

During mining, there would be a general and reasonably constant release of methane which will be reduced when mining rate decreases. The methane emission will reduce further once mining ceased, and finally the only methane sources would be the floor, roof and pillars (Lloyd and Cook, 2004).

2.5 Global Methane Emissions

Global Coal Mine Methane emissions increased approximately 20% from 1990 to 2000, and are expected to increase by 2010 (Pilcher, Cote', Collings and Marshall 2003). However, not all countries experienced an increase in CMM emissions. For example CMM emissions from Russia and Ukraine dropped nearly 50% during the 1990's, while significant reductions occurred in the United States, Germany, South Africa, Kazakhstan and the United Kingdom as illustrated in figure 2.5 below.

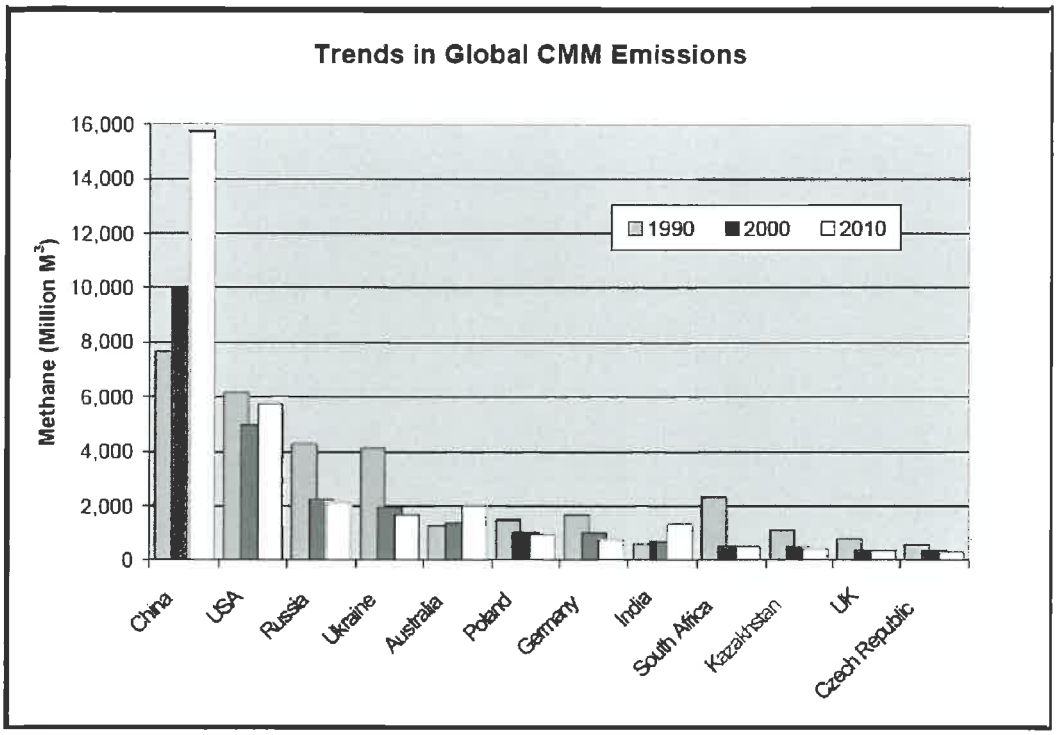

Figure 2.5 - Trends in global CMM emissions 1990-2010 (Pilcher et al., 2003)

Predicting methane emissions on the global scale seems to be a difficult task. Heilig (1992) stated three types of uncertainties in projecting future trends of global methane emission as follows:

First, there is a lack of scientific knowledge concerning the identification and quantification of current methane sources, sinks, and chemical mechanisms in the atmosphere.

Second, there are uncertainties associated with possible technological advances, such as improvements in paddy rice production, livestock management, domestic sewage treatment, or waste recycling and finally, it is extremely difficult (if not impossible) to predict changes in human behaviour, such as life style change, social restructuring, economic reform, and political revolution.

2.6 Utilisation of Coal Mine Methane and technologies

As mentioned before, the principal mine gas utilisation driver is global environment concern. Mine gas utilisation schemes are now being encouraged and assisted in developing countries by governments and international aid agencies including Japanese 'green' aid, World Bank Global Environment Fund and the USEPA (Creedy and Garner, 2001).

The lessons from coal producing countries, where the utilization of coal methane is well developed indicate that extraction of methane is possible and reasonable at three stages of coal mine development: before mining takes place and this is known as Coal Bed Methane (CBM extraction), in an abandoned or closed mine (AMM extraction), and in an operating mine (CMM extraction).

Pre-drainage CBM, AMM, and CMM can be extracted through drainage systems. Drainage systems remove the gas from coal-bearing strata before, during, and after mining, depending on the particular needs of the mine. These systems include vertical premine wells, gob wells and in-mine boreholes Su *et al.* (2006).

Vertical pre-mine wells

If a mine owner uses vertical pre-mine wells for CBM extraction before putting a mine into operation or before developing a coal seam of an operating mine, the methane concentration in the mine can be considerably lower than without pre-mining CBM extraction. Pre-mining CBM extraction increases safety, reduces mining delays, and decreases ventilation costs and methane emissions in the operating mine.

Without applying additional measures to enhance CBM extraction, it is impossible to produce CBM before the seam is de-stressed during coal mining. It is important to mention that CBM development can cause negative impacts on the environment, most significant of which are the destruction of land and wildlife (USEPA, 2009).

Gob wells

At abandoned or closed mines, gas with methane content fills the fracture zone caused by the collapsed strata after mining has been completed. In this case, methane is produced using existing drainage systems or gob wells drilled especially for this purpose.

In-mine boreholes

At operating mines, methane is extracted using the existing degasification systems, after mining de-stresses the coal carrying strata and the methane loses its close absorption connection with coal media. It is important to note that "CMM drainage is an essential part of mining of coal seams where the gas emissions from the seams, disturbed by mining, are higher than can practicably be diluted by ventilation air. Various methane drainage techniques have been developed to capture as much CMM as possible before it enters the airways of underground coal mines" (USEPA, 2009). In-mine boreholes include underground horizontal boreholes drilled along the mined coal seam and cross-measure boreholes drilled through the coal seam and surrounding rock.

Depending upon the method of extraction and quality, methane utilisation options may differ considerably. Table 2.4 shows typical characteristics for the different coal bed gas sources.

Table 2.3 - Typical methane concentration and flows of coal bed gas (Creedy, 2003)

CBM source	Methane concentration	Pure methane flow (1000 m3/d)
VCBM wells	>95	1-18
CMM schemes	35-75	6-195
VAM	0.05-0.8	4-140

AMM schemes	35-90	11-86

More than that, it is also important to understand the characteristics of CBM looking at the various methods of recovery. Table 2.4 below summarises the characteristics of CBM from unmined coal, working mines (drained gas and ventilation air) and abandoned mines.

Table 2.4-Characteristics of CBM from the various sources

Source	Advantage	Disadvantage
Virgin CBM surface wells (VCBM)	Consistently high gas purity obtainable. Operations independent of coal mining activities. Gas captured prior to mining could improve mine safety. High turndown capability with no environmental emission risk.	Initial drilling and completion costs high. Land access agreements needed for drilling and production sites. A large number of boreholes needed together with surface collection pipework.
Working coal mines (CMM)	Mine gas is delivered to the surface at a fixed location using existing infrastructure installed for safety reasons. The gas is produced as a	Gas purity can be variable (medium to low). Potential interruptions in supply as linked to the mining operation but can

	waste product, the primary reason for capture being mine safety. Utilisation reduces greenhouse gas emissions by converting methane to less harmful carbon dioxide. High flow rates may be achievable.	be buffered to a limited extent using gas holders. No turndown capability. An external fuel supply may be necessary to sustain a utilisation process.
Abandoned coal mines (AMM)	Access to gas reservoir using former mine entries or boreholes. Can, in some instances, install access borehole on customer's site. Reduction in greenhouse gas emissions from closed mines. High gas flow rates can be produced with generally stable purity (high to low). Can adjust supply to match demand within specified limits.	Remedial work may be needed to adequately seal surface entries. The accessible gas reservoir may be progressively reduced in size by rising mine water levels. May be necessary to continue mine water pumping.

The most common CMM usage is heat and power generation and there are prerequisites for successful CMM utilization. The prerequisites include:

- Adherence of mine owners to methane recovery and utilization;
- An existing, carefully managed methane drainage system providing well-controlled air intrusion;
- Sustainable gas capture; and
- Appropriate infrastructure.

On-site CMM combustion technologies include: decentralized or centralized combined heat and power units (CHP), internal combustion engines or gas turbines, and boilers that can burn CMM or co-fire CMM and coal.

CHP plants generate heat and power simultaneously through cogeneration. In decentralized CHP, each CHP unit supplies heat to cover individually connected heat loads and deliver power for local needs, while any surplus is sold into the public grid. Centralized CHPs supply electricity to the mine and the rest to the public grid, and provide heat to the mine and municipal heating system. Combined heat and power units are used for electric power and heat generation via combustion of CMM with a methane concentration of 25-30%.

Internal combustion engines and gas turbines produce electricity, which is used for onsite consumption or/and grid-connected power transmission. Electricity is generated via combustion of CMM with a methane concentration of about 45% for internal combustion engines and above 35% (with minimal variability) for gas turbines.

Boilers burning CMM, or CMM and coal provide space heating and hot water production via combustion of CMM with a methane concentration of 25-30%. Some applications of methane combustion technologies may need additional equipment for gas enrichment and/or purification to ensure continuity of power generation, especially if the generated power has to be sold to the public electric grid (USEPA, 2009).

In concluding the utilization, Williams and Mitchel (1992) mentioned that methane emissions can potentially be reduced by up to 50-70% at gassy mines using available techniques. Emissions can potentially be reduced by up to 90%, depending upon the demonstration of additional technologies. Also, there are factors to consider in reducing methane emissions and these include mine conditions (gassings), current mine gas systems, potential gas quality, use options, technical and economic resources. The quality of gas that is recovered will determine the possible utilisation option.

Markets for Coal Mine Methane

According to Pilcher et al. (2003) six of the twelve largest emitters of CMM needed to import gas in 2001 to meet demand. Countries with largest expected increase in annual gas consumption in 2010 will be USA (125Bcm), China (35Bcm), Kazakhstan (31Bcm) and India(29Bcm). Opportunities to sell CMM in natural gas markets in China, USA, Australia, Germany, Poland, India, Kazakhstan are substantial. A summary of production and consumption of natural gas by CMM countries is shown in figure 2.13.

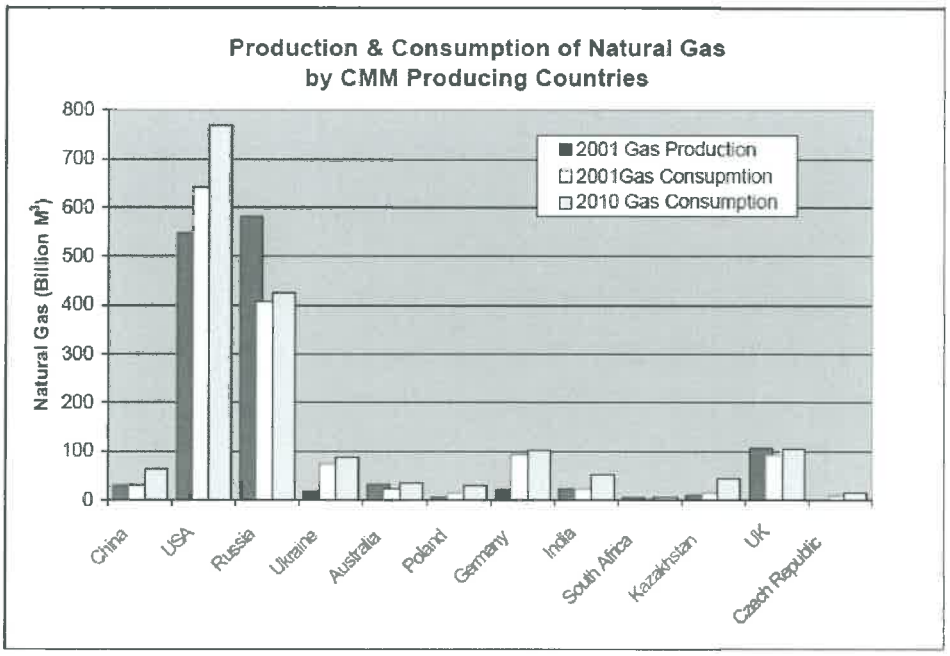

Figure 2.6 - Production and consumption of natural gas by CMM countries (Pilcher et al., 2001)

It is a known fact that currently the whole world is in need of more energy including South Africa and therefore any means of producing more energy will be highly accepted in the market.

2.7 Barriers to Coal Mine Methane emissions reduction

In order to decrease the emissions of methane to the atmosphere, increasing CMM use can be of assistance but there are barriers that can prevent this. Barriers are of two types: technical and institutional. The technical barriers include for example, the low permeability in the coal seams as this type of coal poses a special problem for developing successful methane drainage and recovery systems (Bibler, Marshall and Pilcher 1997). Other technical barriers include variable or low gas quality, variations in gas supply demand and lack of infrastructure.

The institutional obstacles to expanding CMM recovery and achieving increased utilization include the following: (1) coal mine safety and economic issues, (2) ownership issues, (3) tax incentives and industry financial condition (CIAB, 1994). Governments can play an important role in helping companies through tax incentives for example to promote coal mine methane projects. Figure 2.7 below illustrates all factors that need to be considered for the viability of CMM and the possible actions to be taken to overcome these barriers.

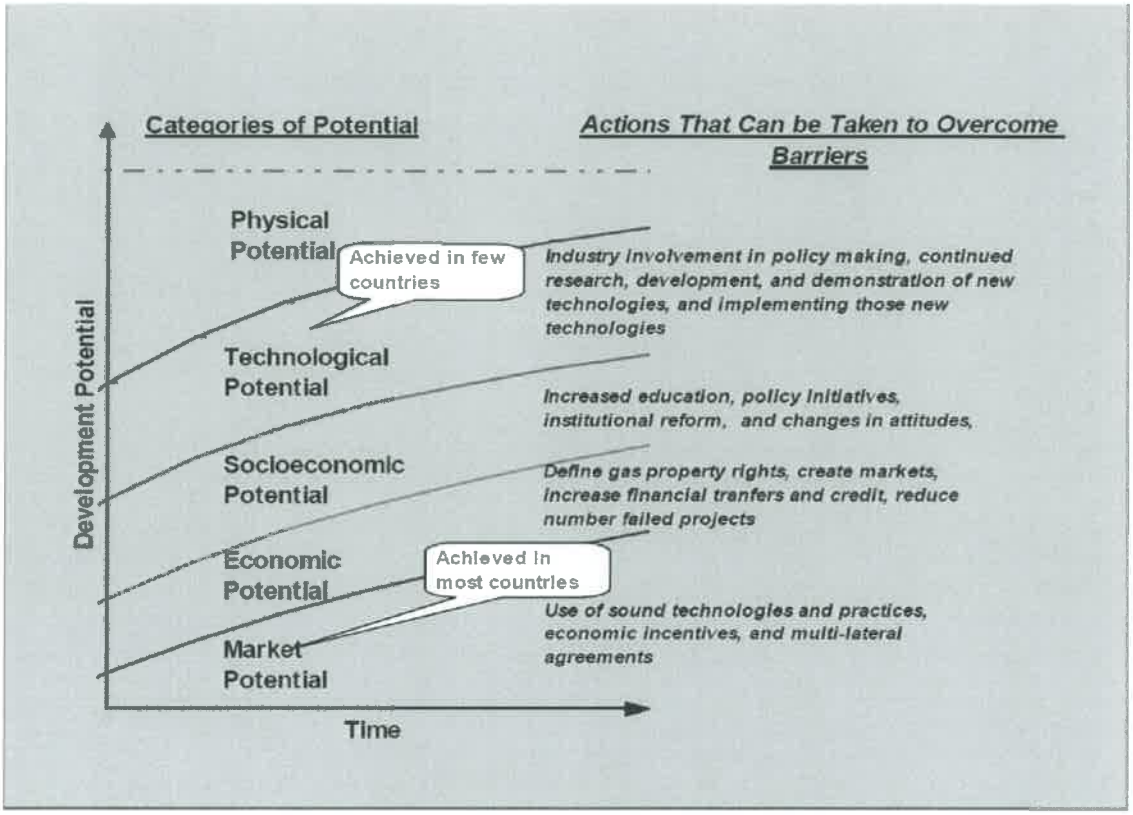

Figure 2.7 - Coal Mine Methane development potential (IPCC Working Group III report, 2001)

An exercise has been conducted as well to rank the countries according to their potential for CMM development (see table 2.5). It is of significance to note that in all the countries ranked, South Africa seems to have a low potential for CMM development. Countries that seem to be in a better position for CMM development include Germany, Russia and Australia.

Table 2.5 - Ranking countries with largest CMM development potential

	Market Potential			Economic Potential			Socio-Economic Potential			Technical Potential			Physical Potential		
	Use of sound technologies and practices	*Utilize existing economic incentives*	*Bi-lateral or multi-lateral agreements*	*Define gas property rights; Create and expand markets*	*Reduce risk and failure rates of projects*	*Unsubsidized, free gas market*	*Educational and institutional reform*	*Changes in attitudes*	*Industry involvement in policy making*	*Government initiates, CBM energy plan*	*Continued research development and demonstration of new technologies*	*Implemeting new technologies*	*Increased use of new technologies*	*Widespread use of new technologies*	*New technologies commonplace*
China	X	X		X			X	X					X		
USA	X	X	X	X	X	X	X			X			X		
Russia	X	X	X	X			X	X							
Ukraine	X	X													
Australia	X	X	X	X	X	X	X	X	X	X	X		X		
Poland	X	X	X										X		
Germany	X	X	X	X	X		X	X	X	X	X		X		
India	X	X	X												
South Africa	X	X													
Kazakhstan	X	X													
UK	X	X	X	X	X	X	X						X		
Czech Republic	X	X											X		

2.8 Worldwide coal resources

Total recoverable reserves of coal around the world are estimated to be 929 billion tons (IEA, 2010). Actual proved reserves are considered to be 826 billion tons (BP, 2009).

World coal consumption grew by 3.1% in 2008, the first below average increase since 2002(BP, 2010). Coal nonetheless remained the fastest growing primary energy source for the sixth conservative year. China alone accounted for more than 85% global growth. Most of these coal resources are concentrated in four countries: Canada, China, Russia, and the United States (see figure 2.8). However, the rest are widely distributed around the globe.

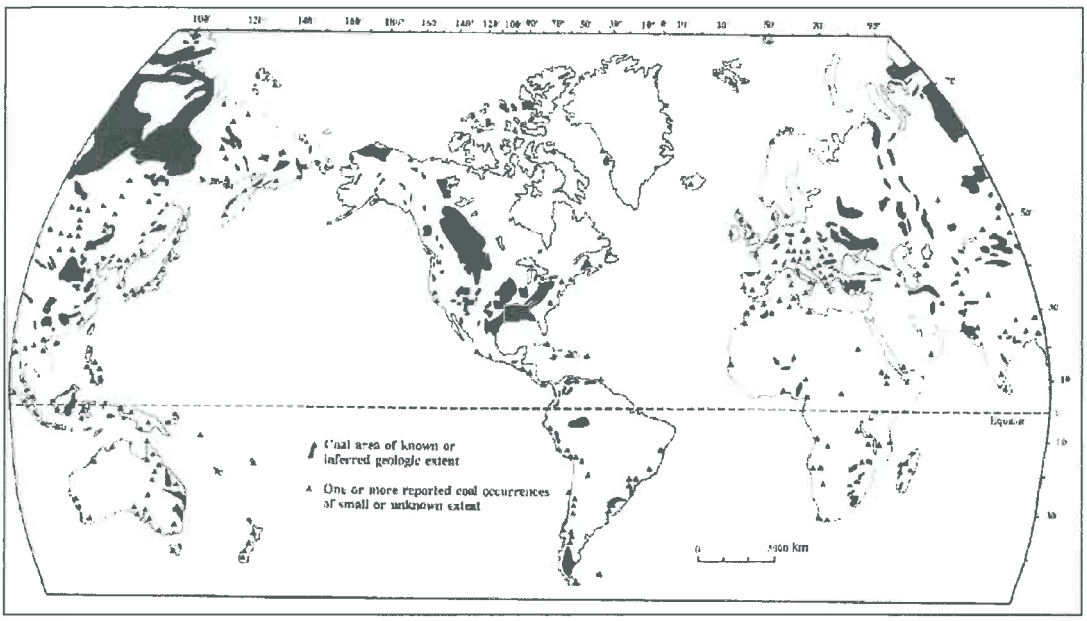

Figure 2.8 - Global distributions of coal deposits (Rice et al., 1993)

2.9 South Africa

2.9.1 *Background*

South Africa is the world's seventh largest producer of coal with a tonnage of 250 million tons in 2010 and is a leader in Africa (BP, 2010). It is also the third largest coal exporter in the world (GCIS, 2010). Most of the coal production (about 99%) in Africa takes place in South Africa (BP, 2010). A survey conducted in 1987 revealed that South Africa's coal resources are estimated at 115 billion tonnes (DME, 2010a). The estimate of South African coal reserves according to BP (2010) is about 30.4 billion tonnes composed mostly of anthracite and bituminous coal. Coal is the main fuel that is consumed in South Africa accounting for 72% of total primary energy consumption supply in 2007 (IEA, 2010). Three quarters of its production is consumed internally and one quarter is exported to the European Union and East Asia (EIA, 2010).The

consumption pattern is demonstrated very well in figure 2.9 below. The industrial sector, including mining, consumed 4.2 percent, the metallurgical industry used 3 percent, and merchants bought 6 percent of domestic coal.

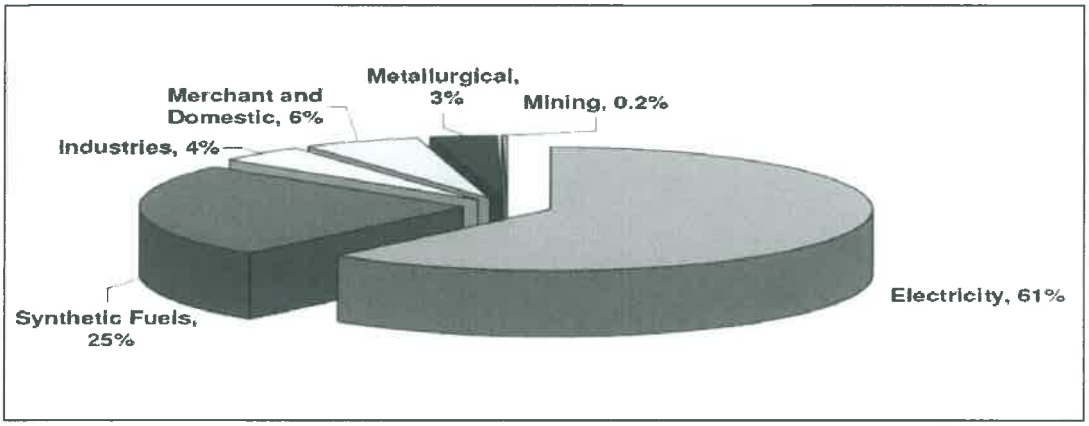

Figure 2.9 – South Africa's domestic coal consumption by sector (DME, 2008)

Seventy percent of the recoverable coal reserves in South Africa are situated in the Highveld, Waterberg and Witbank coalfields. The great bulk of the coal reserves are concentrated in 19 Karoo (Permian) coalfields in the Mpumalanga region of the country and underlay an area of about 115, 000 square miles (IEA,2005). Figure 2.15 captures all the coal basins in South Africa.

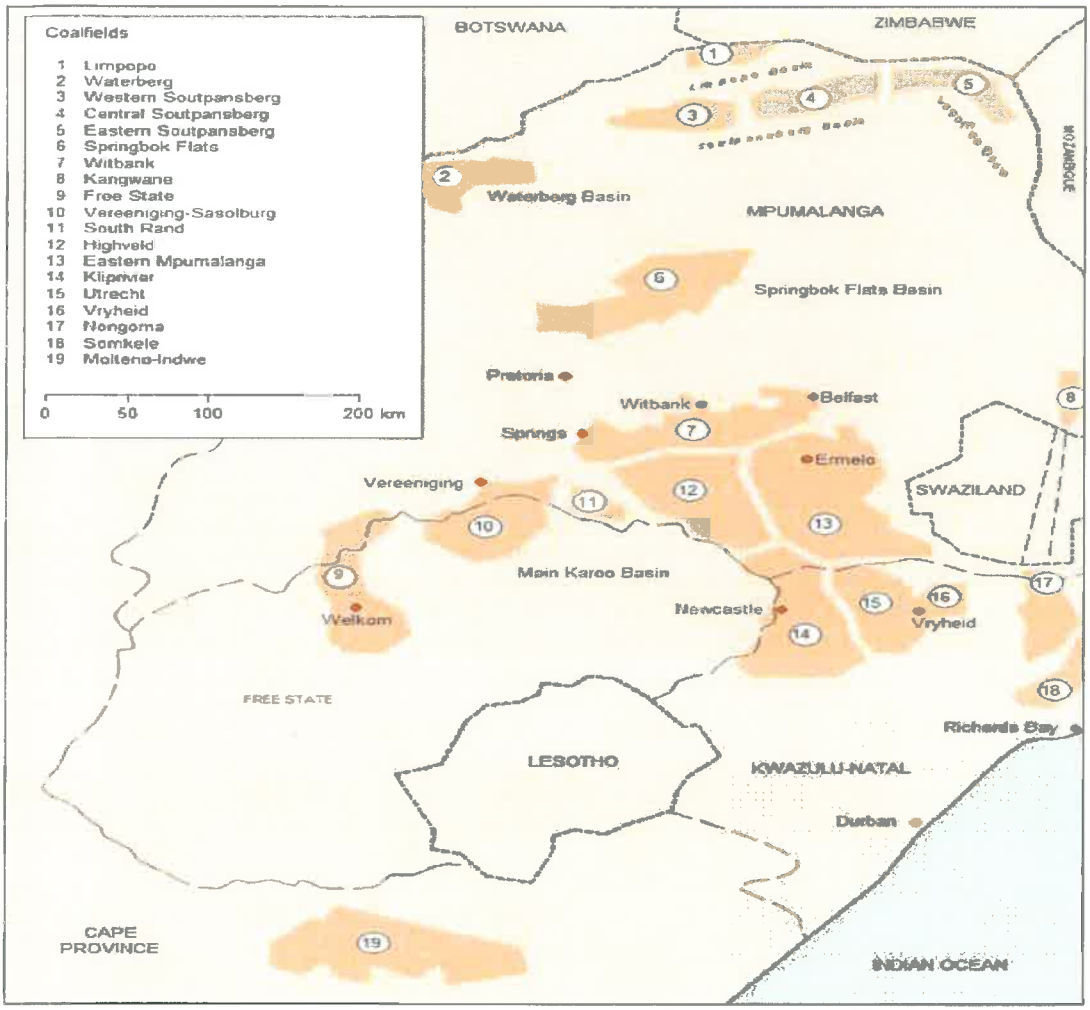

Figure 2.10 - South Africa's Coal Basins (Walker, 2000)

2.9.2 Operating coal mines

In 2005 there were about 69 coal mines that were operational. This includes underground, opencast as well as those operations that combine underground and opencast (M2M, 2009). The number of mines that were operational increased from 69 in 2005 to a total number of 93 in 2008 as per statistics for coal mining in South Africa (See table 2.6). Forty operations use only surface mines, eighteen (18) combined surface and underground mining operations, and 35 are solely underground mining operations (DME, 2009). About 47 percent of South Africa's coal production is from underground mines and about 53 percent is from surface mines (GCIS, 2009).

Table 2.6 - Total production of South African coal mines (DME, 2009)

Type of Mine	Production (million tons)	Number of mines
Underground (Active)	NA	35 (2008)
Opencast/Surface (active)	NA	40 (2008)
Combined Opencast and Underground	NA	18 (2008)
Total Production	239.3 (2003)	93 (2008)

The coal mining industry is operated by private companies. Increasingly these companies are consolidating and multinational coal mining companies are joining large domestic companies. Forty-two companies currently operate coal mines in South Africa (DME, 2009), although only six companies—Anglo Coal, BHP Billiton, Kumba Resources, SASOL Mining, Exxaro Coal and Xstrata Coal—are responsible for about 90 percent of the country's saleable coal production. The eight largest mines account for 61 percent of output (GCIS, 2009).

The was an agreement reached in July 2003 for Anglo Coal to establish a new opencast operation on the northern portion of the coalfield and Sasol was granted access to the southern portion of the Kriel South coalfield, through the expansion of its existing underground operations at Syferfontein Colliery. Together the operations are expected to secure coal supplies from the Kriel South reserve to Sasol for a period of 20 years (Anglo, 2005). In the future, mining operations will be concentrated mainly in two provinces - Limpopo and Mpumalanga. Coal of Africa (COA, 2009) is progressing with plans for two mines in the Limpopo province, which at full capacity will produce a total of 10 Mt per year (combined investment US$755 million). ESKOM estimates that 40 new

mines will be necessary over the next decade to produce enough coal to fuel future electricity demand (SAinfo, 2009).

2.9.3 Mine methane emissions and development potential in SA

In 1998, South Africa ranked within the top five Coal Mine Methane emitters in the world due to its high coal production (Bibler et al 1997). The leading countries in Coal Mine Methane emissions are China, Former Soviet Union, United States and Germany followed by South Africa. Later the there was an observation that these estimates were overstated. In 2008, its rank in worldwide CMM emissions dropped to ninth with estimated emissions of almost 10 million tonnes of carbon dioxide equivalent ($MmtCO_2e$) (USEPA, 2009).

It is stated that Global CMM emissions increased by 20% from 1990 to 2000 and another increase by 20% is expected by 2010. There were countries in which the CMM emissions dropped and these included Ukraine, Russia, United States, Germany, Kazakhstan, Australia, India and South Africa (Pilcher *et al* 2003). The reasons for a reduction in CMM were not stated.

Recently, the Global Methane Initiative (formerly Methane to Markets Partnership) International CMM Projects Database has identified one CMM recovery project in South Africa (M2M Projects, 2010). The recovery project is a flaring project at Anglo American Thermal Coal's New Denmark colliery near Standerton. The operation involves the incorporation of two enclosed Swiss-designed mobile flares into the mine's methane drainage system. A small diesel blower delivers the methane to four flaring nozzles whereby the gas is mixed with air to a concentration that enables it to burn safely. The flare's communication is system is solar powered.

2.9.4 Coal Mine Methane emissions in operating mines

The mining industry in South Africa conducted a study in the past to assess the CMM emissions in the country led by the *Coaltech 2020* project. This study was conducted by

Council for Scientific and Industrial Research (CSIR) measuring ventilation air methane concentrations from most major mines (USEPA, 2004a).

One major factor that this project had to address was the application of the emission factors in the context of South Africa as in the past the inventories were generally prepared according to the IPCC guidelines of 1996 and this has resulted in the over estimation of methane emissions in South Africa. According to Lloyd and Cook (2005) validating the IPCC model with measurements from South African coal mines could not work instead their measurements showed that methane was very variable, sporadically failing to zero and because of that alternative models had to be developed to cater for the South African coalbed characteristics.

The reasons that have been given to explain why South African coals differ from the coalbeds that gave data for the IPCC model include:

- The igneous activity that took place after coal formation, as shown by the the extensive network of dolerite dykes through, and sills over the coal seams and the 'burnt' coal associated with intrusive dykes. The heat associated with these events may well have driven off much of the methane generated during the process of coalification, leaving the seams relatively underpressured, as has been observed in South Africa.
- It has been pointed out that the high inertinite content of South African coals, relative to equivalent coals elsewhere, has long been thought to be the result of the coals having been heated to above the glass transition point of ~140°C for extended periods. Such heating would certainly be expected to displace the *in situ* methane.

Below is the summary of work that has been undertaken in the project under the auspices of Coaltech 2020 in the process of addressing the emission factors in South Africa (see figure 2.11).

During the course of this work most of the production shafts on underground mines have been sampled repeatedly. In total there were 243 measurements of methane in the return air from 27 different shafts. As we have seen, a wide scatter was observed, but taken as a whole the results give us some measure of the quantities involved. For each shaft the average methane concentration was multiplied by the known ventilation rate, which gave a contribution to the total methane emission of 40.8 Gg CH4/a (with an error of ±30.2 Gg).

Seam gas contents had been determined for about 72% of the coal production. Assuming 50% was lost underground, and contributed to the methane in the return air, and that the mines for which data were missing were represented by the mines for which there was data, then the total lost after leaving underground mines was about 28.6 Gg CH4/a (with an error of about 24 Gg).

Thus the best present estimate of the release of methane from South African coalmines is:

- 40.8 Gg CH4/a in ventilation air from underground mines;
- 28.6 Gg CH4/a from coal after it has left the mine; and
- <3 Gg CH4/a from surface mining operations, or approximately 72 Gg/a.

However, there are very large errors associated with these estimates. The source of these errors is largely the physical processes responsible for the release of much of the methane from South African coalmines, particularly the sporadic release of free methane. This causes huge fluctuations in the measurable concentrations of methane in the return air. To improve the estimates will require effectively continuous measurements over several weeks on each shaft. Further errors arise from the considerable variation in the seam gas content of the coal, and it will require repeated measurements of the residual gas in coal coming from underground in each mine before these errors can be reduced significantly.

Figure 2.11-Coal Tech 2020 Summary Results of CMM in SA (Lloyd and Cook, 2004)

Based on the work that has been mentioned above, models were proposed, from the measured data, to estimate the methane emissions from South African coal mining. The basic formula to calculate methane emissions from underground mines in cubic meters is (IPCC, 1996):

$CH_{4t} = (CH_{4e})$ X SGC X Total tons produced

Where CH_{4t} is the total methane emitted from underground mining,

CH_{4e} is the Methane Emission Factor (MEF) = m^3/t mined / m^3/t *in situ*

The Methane Emission Factor (MEF) is a measure of the gas emitted in the mine ventilation system, and exhausted to surface via the upcast fans. It is the ratio of the

methane emitted per ton of coal mined (specific emission rate, SER), to the volume of methane present per ton of coal *in situ* (seam gas content, SGC). This factor is then used to calculate the total gas emitted by mine ventilation based on the seam gas content of a mine, and the total tons of coal mined.

After the process of working out the relevant emission factors for the South African coal mines the following version below were finally adopted by the IPCC late in 2010.

These versions are stated below in their simplest forms:

Underground methane emitted (m^3) = (1.11 +/- 0.26) X Seam Gas Content X Tons (a)

Surface methane emitted (m^3) = (0.014 +/- 0.012) X Tons (b)

Post mining methane emitted (m^3) = (0.28 +/- 0.05) X Seam Gas Content X Tons (c)

In the energy sector, fugitive emissions contributed 323 Gg of methane in 1990 and 327 Gg in 1994, which represents about 16% of the total methane emissions. In 1990 methane emissions from coal mining contributed almost 100% of the fugitive emissions and 97% in 1994 when emissions from natural gas processing were included. Of the coal mining fugitive emissions, 88% were from underground mines in South Africa (UNFCCC, 2000). Table 2.6 below indicates the work that was carried out with CMM projections regarding South African mines contribution to greenhouse gases.

Table2.7 - South African CMM Emissions (million cubic meters) [UNFCCC (2000); *USEPA: 2006]

Emission Category	**1990**	**1994**	**1995**	**2000**	**2005 Projected**	**2010**	**2015**
Underground coal mines – drained emissions	418	423					
Emission Category	**1990**	**1994**	**1995**	**2000**	**2005 Projected**		

Surface mine emission (total)	57	58					
Total emitted (= Total liberated – recovered & used	471*	-	466*	495*	519*	520*	521*

The coal seams in the main Karroo coalfields are not considered gassy owing to the fact that they are shallow. There is little evidence of Coal Mine Methane recovery for re-use in South Africa. However there are a few mines that are gassy such as Majuba Colliery which has experienced a higher than expected levels of methane in the mine workings (8.5 cubic meters or 300 cubic feet per ton). It appears that there were attempts to implement CMM drainage but that was unsuccessful and the mine was eventually closed for other reasons (USEPA, 2004b). The attempt to conduct pre-mining methane through surface holes drainage in some of the collieries in South Africa for the recovery and use of methane has been investigated in the past but no further development have taken place or been reported (UNFCC, 2000).

CMM Emissions from Abandoned Mines

There are a number of abandoned coal mines in South Africa. The number of operating mines declined by about one half between 1986 and 2004 (Limpitlaw, Aken, and Lodewijks 2005). There is no data quantifying emissions from abandoned mines in South Africa to date and it would appear that there are no mines extracting methane from abandoned operations. It is believed that key barriers to this exercise revolve around legal and regulatory constraints and possible legal liabilities associated with mine closure.

Virgin Coalbed Methane operations

South Africa's coalbed methane (CBM) resource is estimated to be 0.14–0.28 trillion m^3. There is no commercial CBM production reported currently but it appears there are significant discussions about possible future projects, and several pilot wells have been installed and are undergoing testing. Moreover, adoption of CBM/CMM technologies could become increasingly likely as additional mines are expected to open in gassy coal fields (M2M, 2010).

The most promising areas for CBM are the deeper, thicker, and gassier coal resources. The Waterberg Basin in the northwest Mpumalanga region of the country and the southwest portion of the Highveld coalfield near Paardekop-Amersfoort are deeper (> 1,000 feet) and gassier (4–10 m^3/tonne at 1000-1200ft and appear to have the best potential for CBM development (Kelafant, Stevens and Boyer 1992).

Anglo Coal has been conducting a CBM exploration program in the Waterberg Basin for the past several years. As part of this program, a series of core wells were drilled and tested and a five-well pilot production project is currently underway. It is also a well known fact that Sasol has been doing extensive research on CBM in the past though there is no production information coming to the forth. Barriers to project progress include its remote location, delays in rights conversions, lack of prior experience among government authorities, and lack of incentives (DME, 2006; Merwe, 2007). Other CBM licenses are held by Badimo, NT Energy Africa, Molopo/Highland Energy, Msix, and numerous smaller companies, but little work has been done to date.

Apart from coal mines, there are two cases where methane is captured and utilised. The first case is the Harmony Gold Mine in the Free State where methane from the shaft where kitchens stoves and bathhouse were fuelled by captured mine methane (USEPA, 2004b). The second case is the Beatrix Gold Mine where pipeline is currently been installed to capture methane faults and fissures intersected during normal operations.

Plans are place to begin construction of a methane fuelled 5 megawatt (MW) power plant in 2011 (Creamer, 2010).

2.10 Regulations affecting the production of CBM

South Africa is a signatory to the UNFCCC and the Kyoto Protocol and this imply that South Africa is eligible to host Clean Development Mechanism projects to reduce the effect of greenhouse gases emission. See Table 2.7.

Table 2.8 Climate change mitigation commitment for South Africa (UNFCCC, 2004)

Agreement	Signature	Ratification
UNFCCC	June 15, 1993	August 8, 1997
Kyoto Protocol		July 31, 2002 (Accession)

The M2M regulations governing CBM exploration and exploitation in South Africa are unique and different to those that are applicable to coal in the same coal seam. This implies the rights to exploration and development need to be applied for separately to those applicable to coal in the same coal seam. Under the Minerals Act of 2004, all mineral rights are vested with the government. Technically, development licenses are required by law after successful exploration.

Electricity, petroleum pipelines and piped gas including natural gas and CBM are regulated by the National Energy Regulator of South Africa (NERSA). In addition, NERSA also issues licenses for construction and operation of gas transmission, storage, distribution, liquefaction and degasification facilities (Gas Act, 2001). Under these conditions coal and CBM development would lie in two separate government institutions/departments. This has contributed to the difficulties in CBM exploration and exploitation in South Africa.

3 METHODOLOGY AND INSTRUMENTS

3.1 Introduction

This chapter outlines the sampling data and the methods used to obtain the methane contents of the coal seams so far investigated in South Africa.

3.2 Method used to establish CMM on ROM coal

The procedures to calculate methane content are not complex but simple and practical, using intentionally low technology and straightforward calculations. Procedures are based on the fact that the desorbing gas can be measured directly by water displacement method, Betard et al. (1970). Since then, this method has been modified by others including Kissel et al. (1973), as mentioned earlier.

Cooke (2000) further modified this method to calculate an emission rate during mining as well as the gas content, hence making this method suitable for the variable and relatively low gas contents of South African seams. This method has become the standard for the South African coal mining industry. The current database is in excess of 1300 samples, compiled over approximately 10 years.

For the purposes of this project, the equipment used was the direct gas volume measurements techniques.

3.3 CMM measuring equipment

Equipment that is used underground includes a canister in which one or two direct volume displacement readings required to measure methane being emitted from newly mined coal samples, normally collected from shuttle cars within 2 minutes after the coal has been cut (Cook, 2000). The coal sample is then put into the desorption canister and sealed. This takes a few minutes at each location. However, due to the relatively

low methane contents and low initial gas volume released in South Africa, a practical innovative new measurement kit was developed, as shown in Figure 3.1.

The equipment consists of a desorption canister (100mm X 600mm) with a valve, a brush, tube, stop watch and a graduated cylinder with an inbuilt water pan to measure water displacement in millimetres when the valve is opened to release the gas emitted from the coal sample. Included is also a log sheet for registering water displacement measurement and time.



Figure 3.1 Underground sampling and measuring kit

The entire sampling kit is fully self-contained and fits into a protective carrying case. The hand held meter allows for rapid repeat measurement of desorbing methane volumes, without the need for the previously cumbersome equipment. This considerably reduced the time and effort required at each sampling area.

3.4 Laboratory Processing

The final sample processing is completed on surface using a laboratory rod mill to crush the coal sample and release the remaining gas. The milling process normally takes a few hours, depending on the volume of gas released from the sample (Cook, 2000). The

standard sample from underground is about 2 kg, and about 1 kg is milled for gas release.

Figure 3.2 shows a laboratory rod mill. It is electrically operated with a fixed AC motor and it is 160mm X 300mm in dimension. Inside the rod mill there are 8 rods that are used for crushing the coal to liberate the residual gas in it. The lid is tightened by screws to seal for any gas leakages. Before use the equipment is subjected to pressure test to check for air leakages. During the crushing process the rod mill is stopped every 10 minutes to record the gas reading and thereafter the process continues until there is no further reading on gas content. This is used in conjunction with a balance accurate to 1 g and standard direct measurement volume displacement equipment such as a basin and 500 ml measuring flask.

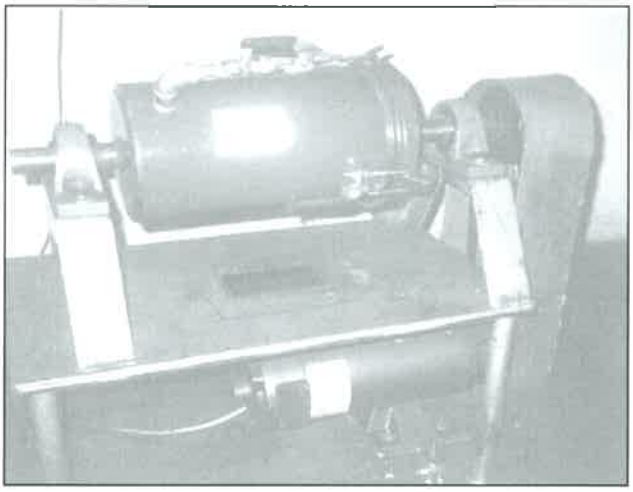

Figure 3.2 Laboratory rod mill

3.5 Gas Content

The gas content is the total volume of gas contained in the coal as it was mined. It is given in cubic metres per ton (m^3/t), and is calculated from the standard direct methods of calculation, considering all the gas given off during underground sampling, further desorbing and laboratory milling (Cook, 2000).

The total gas content (Q_t) is then measured using the following formula:

$Q_t = (Q_l + Q_d)/M_t + Q_r/M_c$

Where Q_l =lost gas volume; Q_d=desorbed portion of the gas content and Q_r= residual gas

Mt is the total air-dried mass (weight) of the sample and *Mc* the air-dried mass (Weight) of the sample crushed to a powder in the ball mill. The values obtained in cm^3/grams are then converted to m^3/ton. The method used to capture gas in this exercise will not be evaluated as that is beyond the scope of this investigation.

4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of methane emissions from the 31 collieries and attempts to correlate the results of various factors which may impact on the quantities of methane stored and emitted in the various seams. See appendix B for all the relevant data from mines which participated in this research.

4.2 Methane Content and Proximate Analysis

Table 4.1 below presents the results of selected mines considered for the purpose of establishing possible relationships between gas content, calorific values and the individual proximate analysis parameters for the respective operations.

Table 4.1 - Correlation values (r) for selected mines in the Highveld, Witbank and Swaziland

Mine	No of samples	Gas-Ash (ad)	Gas- Volatile matter (daf)	Gas-Calorific value (ad)	Gas-Moisture (ad)	Gas-Fixed Carbon (ad)
Bosjespruit (Highveld)	43	r = - 0.315	R = - 0.254	r = 0.201	r = 0.549	r = 0.304
Middelbult(Highveld)	47	r = - 0.416	R = - 0.061	r = 0.440	r = 0.308	r = 0.368
Matla (Witbank)	41	r = - 0.185	R=- 0.119	r = 0.186	r = 0.085	r= 0.341
Maloma (Swazi)	3	r = - 0.684	R = - 0.327	r= 0.712	r= - 0.655	r = 0.697

In all the respective collieries regardless of the coalfield location the following has been observed:

- Correlation between gas content and ash is low and inversely related
- Correlation between gas and dry-ash-free (daf) volatiles is low and inverse
- Correlation between gas content and moisture is low
- Correlation between gas content and fixed carbon (ad) is low

However the correlation values for Maloma are higher compared to those of the other mines listed in table 4.1 despite the low number of samples tested.

4.3 Methane content and Depth

There seems to be a weak to moderate relationship where a gas content increases with depth (r = 0.72). This is due to the fact that depth influences increase in rank and pressure which then results in more gas being emitted and trapped at these greater depths.

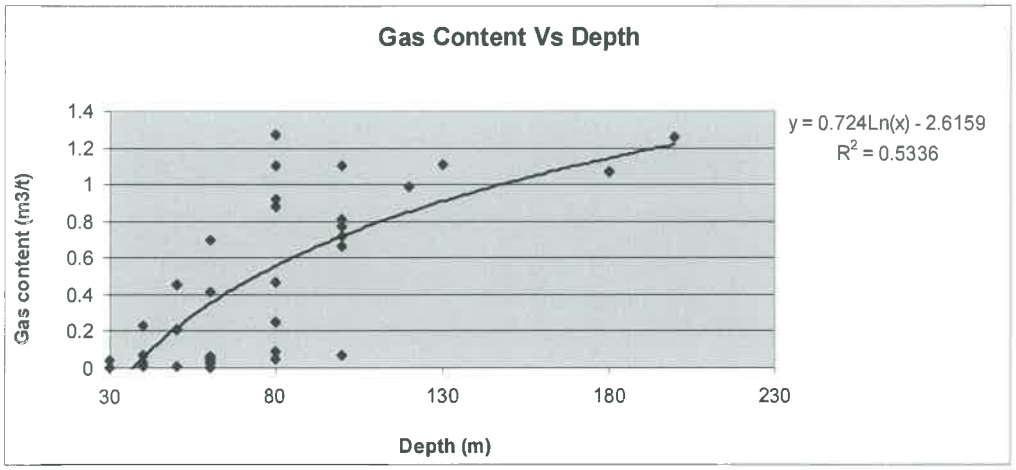

Figure 4.1 - Influence of depth to gas content in coal

However, when observing the curve (figure 4.1) there are exceptions where greater depth does not necessarily imply more gas content. Maloma colliery is an example with

a high average of methane content in its coal (4.9 m^3/t) compared to the other collieries at similar depths. Possible reasons for such deviations are listed in table 4.2 below.

Anomalies:

Table 4.2 - Comparison of gas content and depth for selected collieries

Colliery	Gas Content (m^3/t)	Depth (m)	Remarks
Maloma	4.93	70	Anthracite coal at high rank close to massive igneous intrusions with highly reactive organics emitting high methane (RoV%:3.9).
Springlake	2.28	80	Semi anthracitic to anthracite close to some igneous intrusions (RoV%:2.8).
Forzando	0.28	80	Bituminous coal with relatively high reactive organic components which would give off more methane (RoV%:0.68)
Khuthala	0.09	100	Bituminous coal-relatively inert with some reactive organic materials (RoV%:0.63).
Vlaklaagte	0.05	80	Bituminous coal with high ash and high inert organic material (RoV%:0.60)

For further clarity of the results mentioned above, it will be of interest to look at figure 4.3b below.

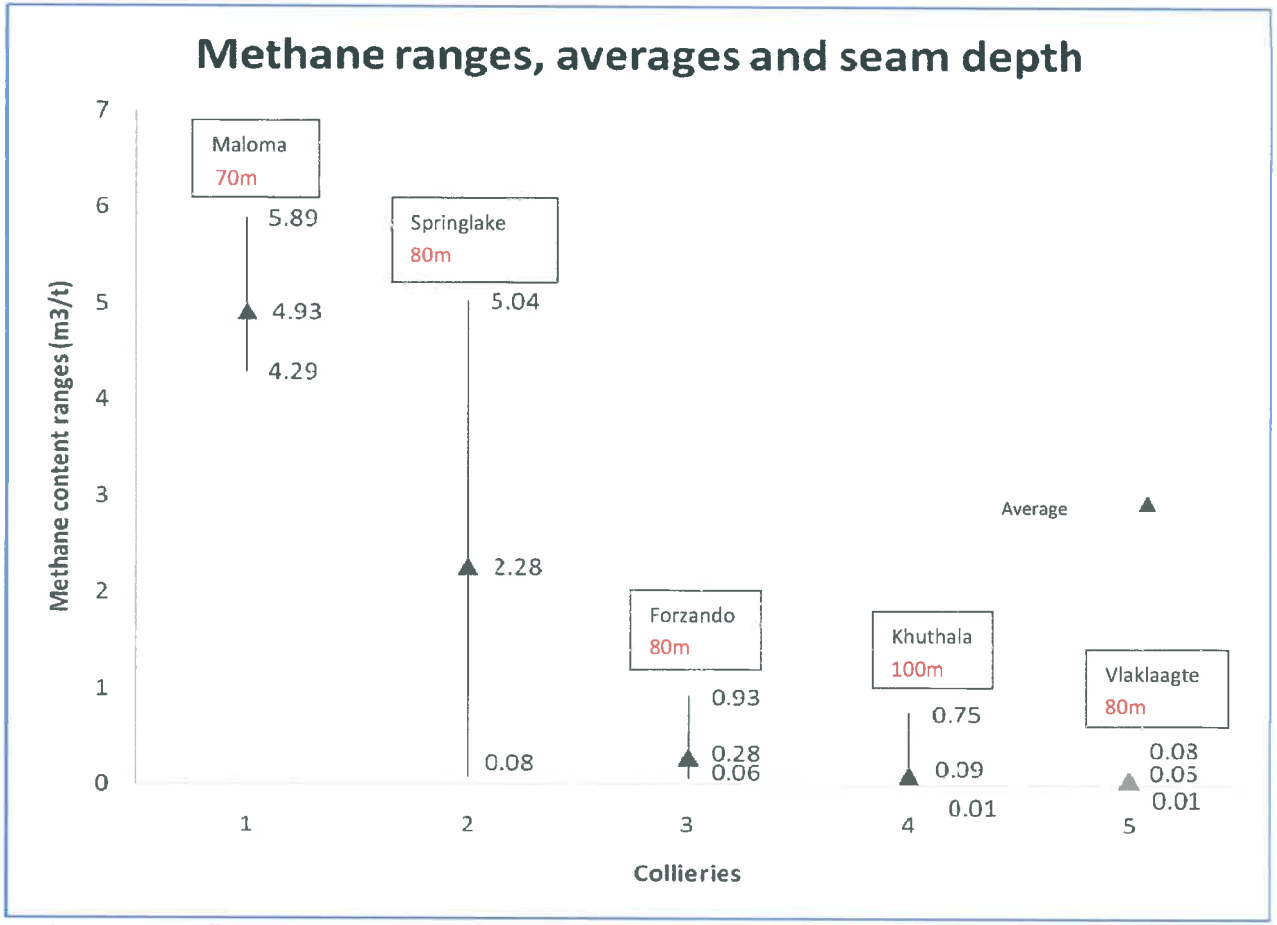

Figure 4.2 - Influences of rank on methane ranges and averages in coal seams at same depth.

4.4 Methane content and ranges in South African Coalfields

Based upon the ranges of methane content in collieries found in three major coalfields under investigation, it may be noted in Table 4.3 that the Witbank and Highveld coalfields emit relatively low range of methane (0.02-1.32m3/t) whereas the Natal coalfields indicate higher range of methane because they are higher in rank, posses high reactive organic materials and have been exposed to high temperature through considerable igneous intrusions (Falcon, pers. comm.).

Table 4.3 – Methane ranges for SA coalfields

Coal Field	Range of Methane Content (m^3/t)
Highveld	0.26 – 1.32
Witbank	0.02 – 1.11
Natal	2.28 – 4.93

4.5 Methane content and petrographic analyses

Petrographic analyses were not undertaken on the samples tested for methane content, however a correlation was drawn up using seam and colliery averaged petrographic data for some of the samples obtained from analyses undertaken by the CSIR (Bulletin 113). This approach was undertaken to establish a possible trend. The correlation between reflectance and gas content is non-existent (r= - 0.300) and therefore reflectance has no significant effect on the CH_4 content as indicated in figure 4.4 below.

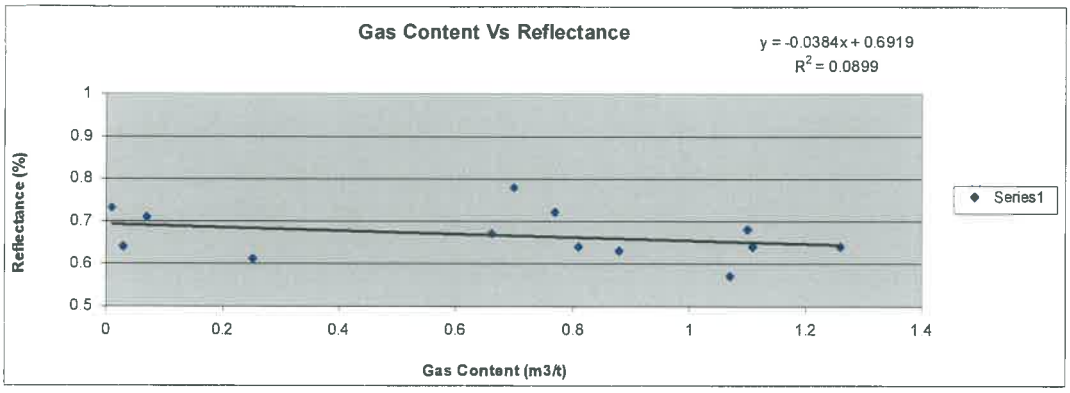

Figure 4.3 - Influence of reflectance to CH_4 content in coal

4.6 Collieries' frequency diagrams

Individual collieries have been considered for this exercise. The purpose of the frequency diagrams is to establish a relationship between numbers of samples in relation to Gas content. It is intended to give a reliable statistical overview of the data in question.

The mine that has the highest number of samples is Twistdraai Colliery with 133 samples and the collieries with the smallest number of samples are Mooifontein, Spitzkop and Tselentis (all have only 2 samples each).

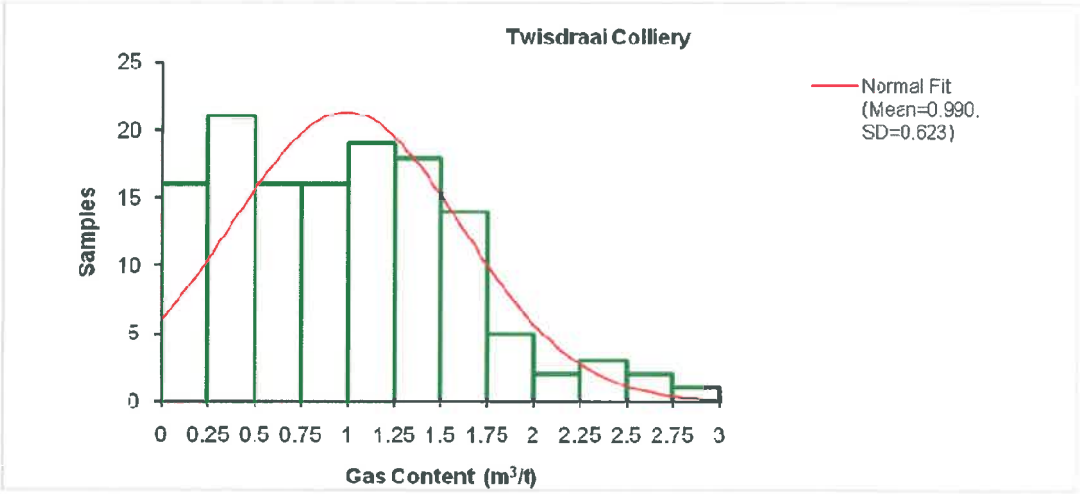

Figure 4.4 – Twistdraai Histogram

The dispersion of Twistdraai samples is portrayed by a truncated histogram. This pattern may result from any of the following:

- Samples collected from the same seam but at different locations (i.e. at different depths and coordinates);
- Immediate roof and floor changes over the entire seam which in turn affects the gas content in the coal seam;
- Presence or absence and proximity of dykes and sills;

The sample ranges are spread with no single range showing extreme dominance.

Tselentis is an example of a mine that has very few samples. It has two samples only and the two samples are 0.02 and 0.03m^3/t, falling within the range 0-0.5m^3/t. No pattern can be drawn in this case due to a very low number of samples.

Figure 4.6 summarises the emission range patterns of the various collieries involved in the exercise. It may be noted that in all the collieries, the dominant range in methane content is between 0 and 0.5m^3/t.

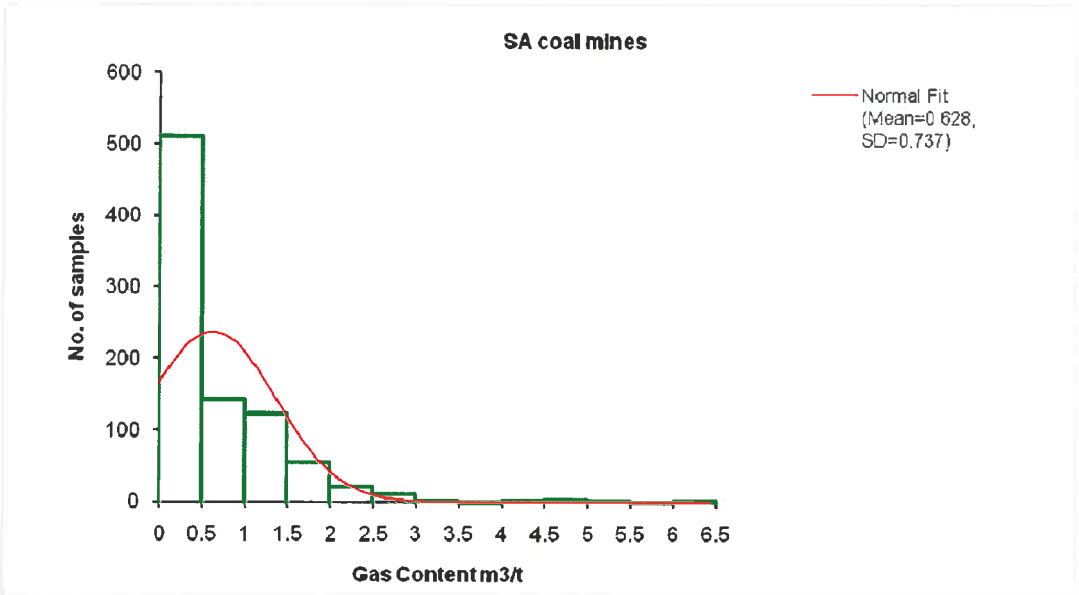

Figure 4.5 – Emission patterns of all SA collieries combined

Further information on Histograms for all the collieries that participated in this exercise is presented in Appendix A.

4.7 Overview of ranges of different Collieries

Ranges of values (gas content) for each colliery and their mean values are shown in table 4.4 below.

Table 4.4 - Emission ranges and RoV% for the various collieries

Colliery	No. Of samples	Min. Value (m3/t)	Max. Value(m3/t)	Ave. Value(m3/t)	RoV%
Arnot	3	0.01	0.03	0.02	0.65
Bank	6	0.01	1.76	1.02	0.73
Bosjesspruit	67	0.05	2.25	0.85	0.60
Brandspruit	85	0.03	2.79	0.64	0.61
Delmas	4	0.01	0.45	0.20	0.72
Doorsfontein	16	0.02	1.01	0.40	0.69
Douglas	47	0.01	0.73	0.10	0.65
Goedehoop	14	0.05	2.56	0.92	0.75
Forzando	9	0.06	0.93	0.28	0.68
Golfview	3	0.03	0.03	0.03	0.58
Greenside	9	0.01	1.31	0.40	0.69
Khuthala	81	0.01	0.75	0.09	0.63
Koornfontein	28	0.04	3.38	1.11	0.74
Kriel	19	0.18	1.91	0.77	0.65
Maloma	3	4.29	5.89	4.93	3.9
Matla	28	0.01	0.87	0.21	0.61
Middelbult	93	0.06	2.58	0.91	0.64
Mooifontein	2	0.03	0.04	0.04	-
New Clydesdale	4	0.05	0.47	0.21	0.75
New Denmark	7	0.46	1.89	1.27	0.62

Rietspruit	6	0.01	0.03	0.02	0.72
Sigma	13	0.05	2.16	0.67	0.62
Colliery	**No. Of samples**	**Min. Value (m3/t)**	**Max. Value(m3/t)**	**Ave. Value(m3/t)**	**RoV%**
Syferfontein	13	0.27	4.89	1.32	0.58
Spitzkop	2	0.05	2.12	1.09	0.64
Springlake	5	0.08	5.04	2.28	2.5
Strathrae	3	0.02	0.13	0.09	0.65
Tavistock	20	0.01	0.19	0.06	0.68
Tselentis	2	0.02	0.03	0.03	0.68
Tshikondeni	5	0.02	1.03	0.23	1.25
Tweefontein	24	0.01	0.33	0.06	0.59
Twistdraai	133	0.02	2.83	0.99	0.59
Vlaklaagte	4	0.01	0.08	0.05	0.58

In general the variation in methane content ranges could be due to the following:

- Collieries that have low values are those that are shallow in depth. This result in low pressure, hence little gas is trapped and any gas that was formed has been released to the atmosphere.

- Collieries that have high values are those that are deeper due to high pressure and/or high rank (e.g. anthracites) which affect the production of gas and good entrapment.

- Collieries that are shallow but with high gas content values are mines that have been heated by igneous intrusions in the vicinity of the whole mine.

- In cases where a wide range of gas values were found in the samples from the same mine, the reasons are likely to be due to (1) varying sample locations both

vertically in different bands or coal types within the seam and (2) laterally. In the latter case, geological factors such as variations in depth, in roof and floor rocks and in proximity to faults or igneous intrusions would have impacted on local gas emissions, storage and release.

5 SUMMARY CONCLUSIONS

The key aspects of this research are presented below.

The assessment of the data indicates the following important results:

- Weak correlation between methane gas and fixed carbon ($0.304 \leq r \leq 0.368$); weak correlations between gas and moisture ($0.085 \leq r \leq 0.549$); weak correlations between gas and CV ($0.186 \leq r \leq 0.440$); weak, inverse correlations between gas and volatiles DAF ($0.061 \leq r \leq 0.254$) and weak, inverse correlations between gas and Ash ($0.185 \leq r \leq 0.416$). On the basis of those correlations, there is little or no relationship between methane content, proximate analysis calorific values.

- In most of the collieries the dominant gas emission ranges between 0 and $0.5 m^3/t$. The highest values encountered ($4.93 m^3/t$ in average) were found in Maloma Colliery, an anthracite mine. These results indicate that SA coal generally are low in methane content with the exception of at least one high rank coals. Whilst it is known that methane is higher in higher rank coals there is insufficient statistical data to prove this statement based on this work in South Africa. The reason for this lies in the fact that many coal of an original bituminous level of rank have been heat affected by igneous sills and/or dykes. Thereby superimposing a further factor on the reason for increased methane content in coals.

- Gas content increases with depth($r = 0.72$) although this is a weak to moderate relationship. In SA coal seams, the one exception to this relationship is the anthracite where gas content was shown to be higher at shallow depths. The reason for the anomally in this anthracite is due to the temperature and pressure

of igneous sills and dykes as described above which would have devolatilised the original coals, and increased the rank of the bituminous coal to anthracite.

- No significant relationships were established between gas content and petrographic analyses (maceral and rank). The reason is likely to be because sampling was limited to small samples hand selected after mining in the case of methane emissions testing whereas the petrographic analyses were conducted on averages of full seam or colliery samples as reported in Bulletin 113.

- Emission ranges within each colliery are scattered with a diverse histogram for each and no clear pattern or trend in any of the collieries was obvious as no further details were provided. However, the extended ranges of values in most of the collieries as illustrated in Twisdraai (fig4.5) and Bosjesspruit (fig.A1) examples indicate the presence of limited areas where sills and dykes may have increased the gas content in normally low gas-bearing bituminous coals. These extended ranges could be of value to mining operations as those areas would present higher exposure to danger and explosions.

- Prediction of methane content and emissions therefore remains difficult in South Africa apart from depth or proximity to igneous intrusions. Lloyd and Cook who originally defined the formula for the predictions of methane from mines in SA during the 1990's for the first IPCC global report, amended the formula in 2010 in order to obtain more realistic values. However, the task is still having its complications.

The limited data (quality of coal and of gas composition) precluded the reaching of any further significant conclusions in this Project Report. It is important to note that, unlike the coals in Europe, the source of methane emissions in South Africa is highly variable due to the highly variable nature and composition of the coals and to the variable proximity to igneous intrusions.

The potential for the utilisation of methane from coal mines is considerable, subject to the quantities and qualities obtained and the ability of process technologies to utilise this form of fossil fuel. Such user processes include power generation in boilers, and/or gas turbines, gas-to-liquid production and metallurgical reductions technologies.

A further use in terms of storage capacity for the CO_2 greenhouse gas is also under consideration. In this process Enhanced Coalbed Methane (ECBM) is envisaged wherein CO_2 is pumped into the coal seam thereby replacing CBM and forcing it to the surface for capture and use. This process whilst highly desirable, has yet to be proven in South Africa.

6 RECOMMENDATIONS

Further in depth investigations in methane gas emissions in South African collieries is strongly recommended for safety and potential capture and commercialisation purposes. In order to do this, it is recommended that more detailed studies in situ in mines and advancing boreholes should be undertaken along with more comprehensive associated geological and analytical data. Unless this is done, little true correlations or predictions of methane potential are possible.

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APPENDIX A: HISTOGRAMS FOR OTHER MINES

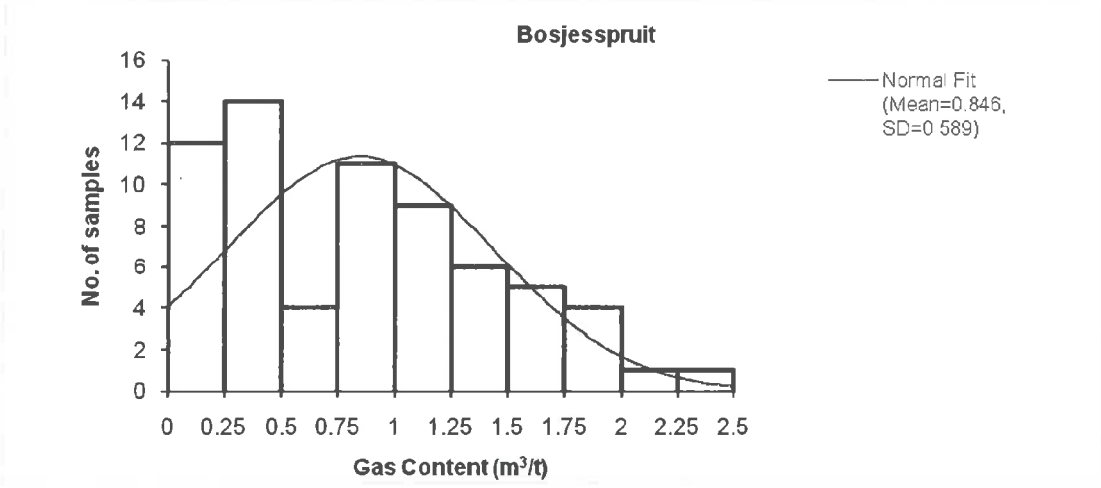

Figure A1: Bosjesspruit samples histogram

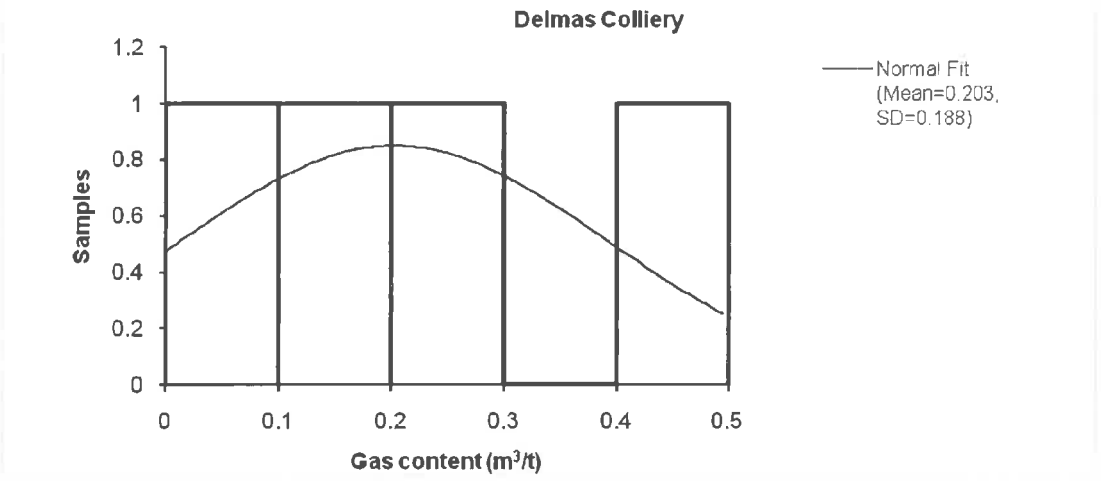

Figure A2: Delmas samples histogram

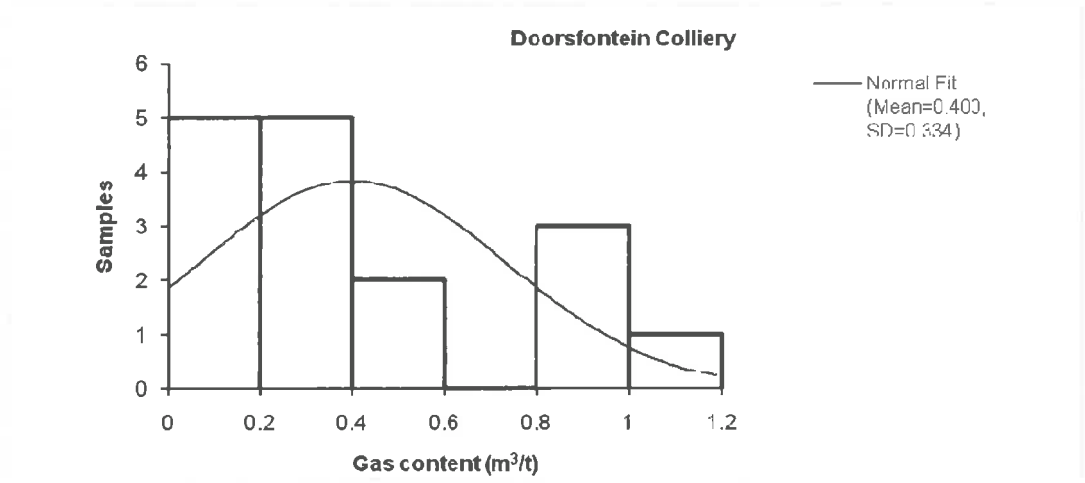

Figure A3: Doorsfontein samples histogram

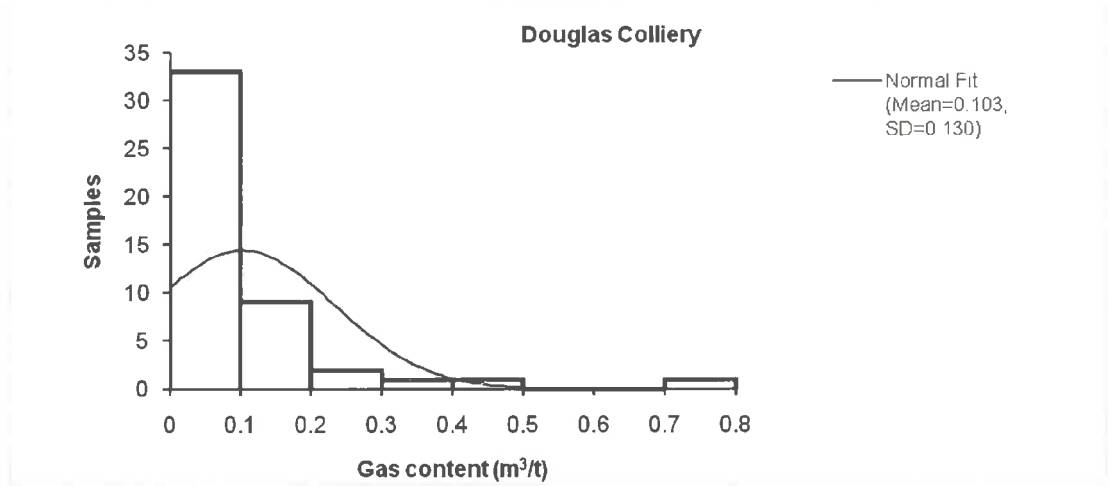

Figure A4: Douglas samples histogram

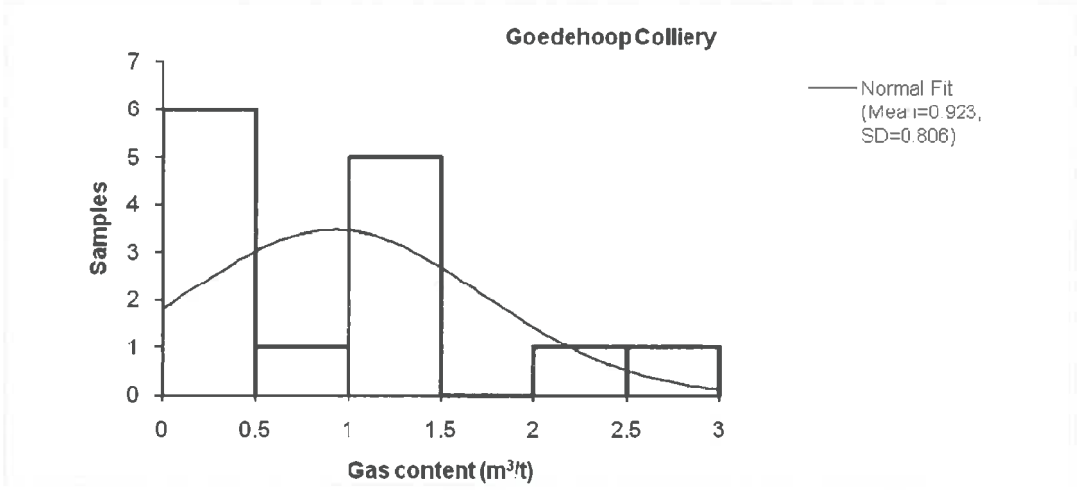

Figure A5: Goedehoop samples histogram

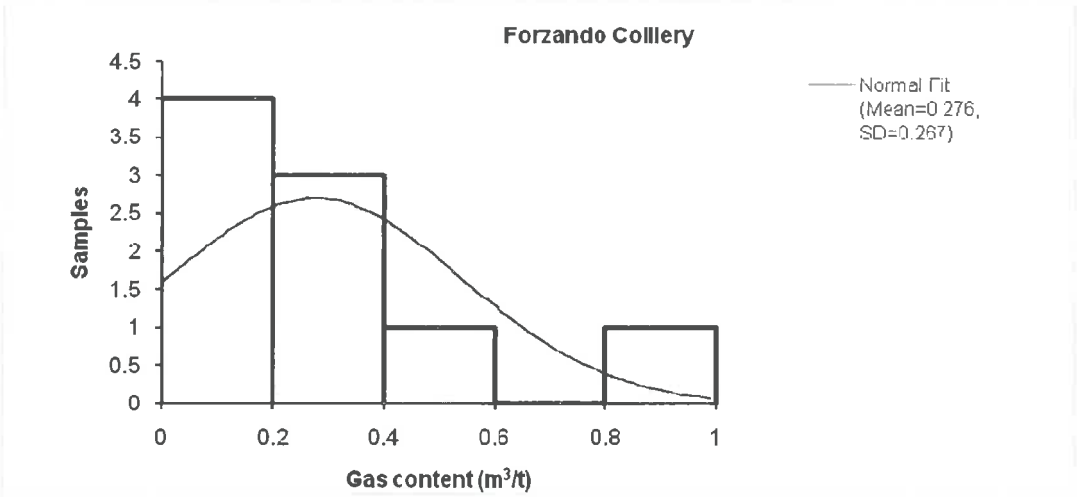

Figure A6: Forzando samples histogram

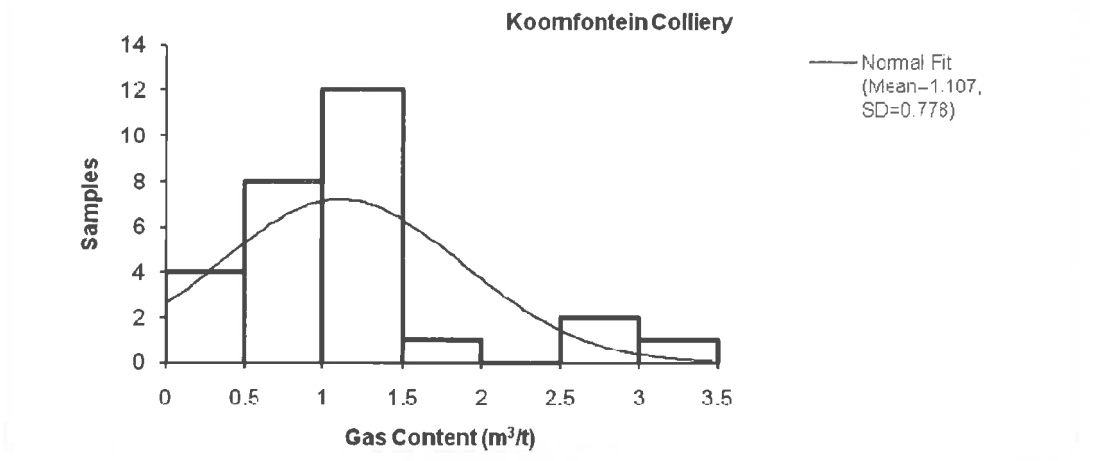

Figure A7: Koornfontein samples histogram

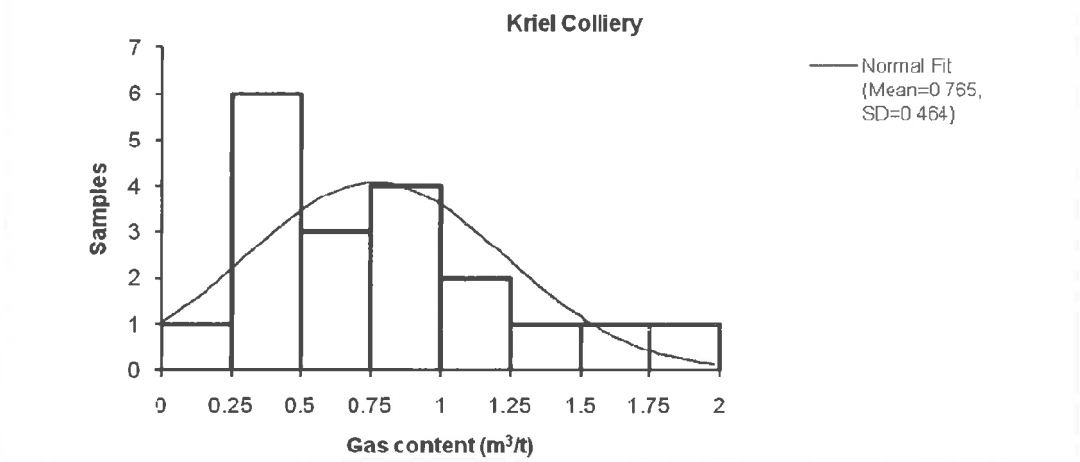

Figure A8: Kriel samples histogram

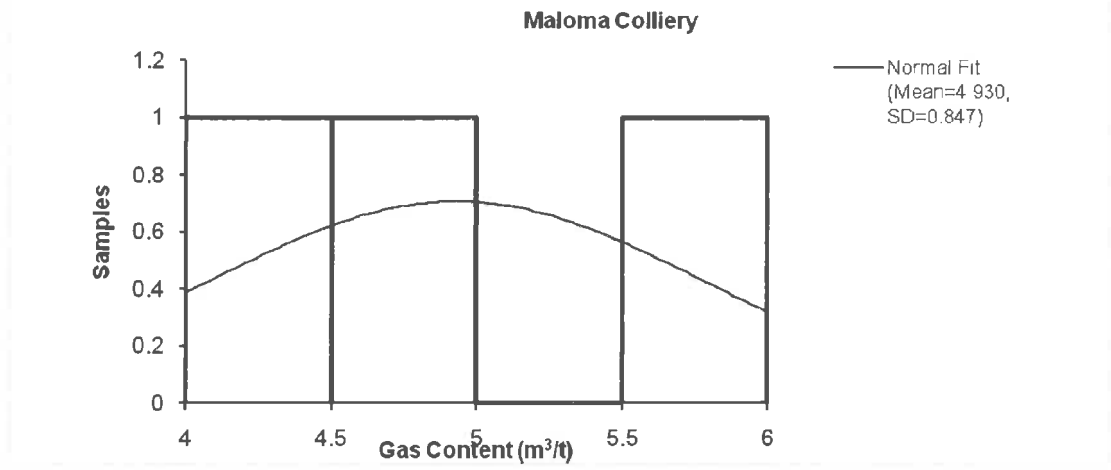

Figure A9: Maloma samples histogram

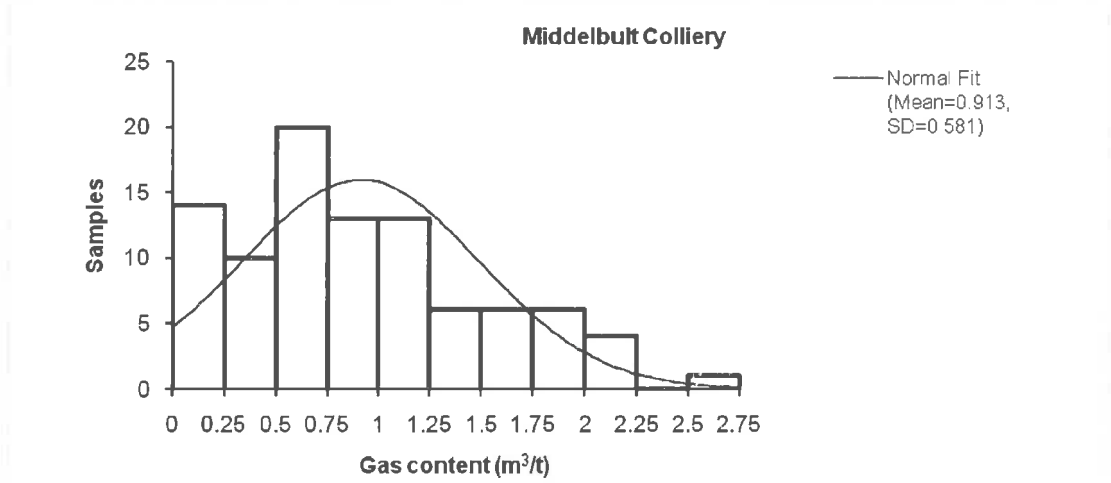

Figure A10: Middelbult samples histogram

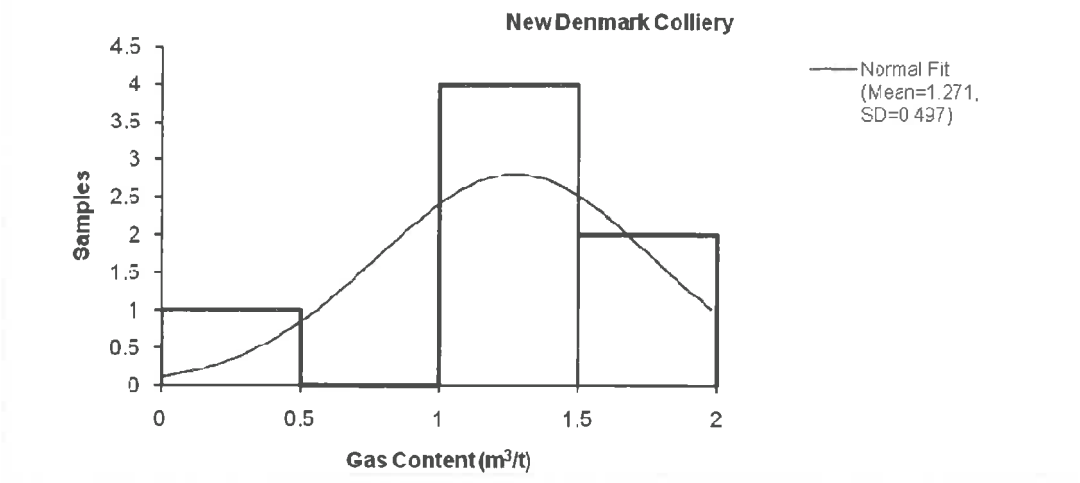

Figure A11: New Denmark samples histogram

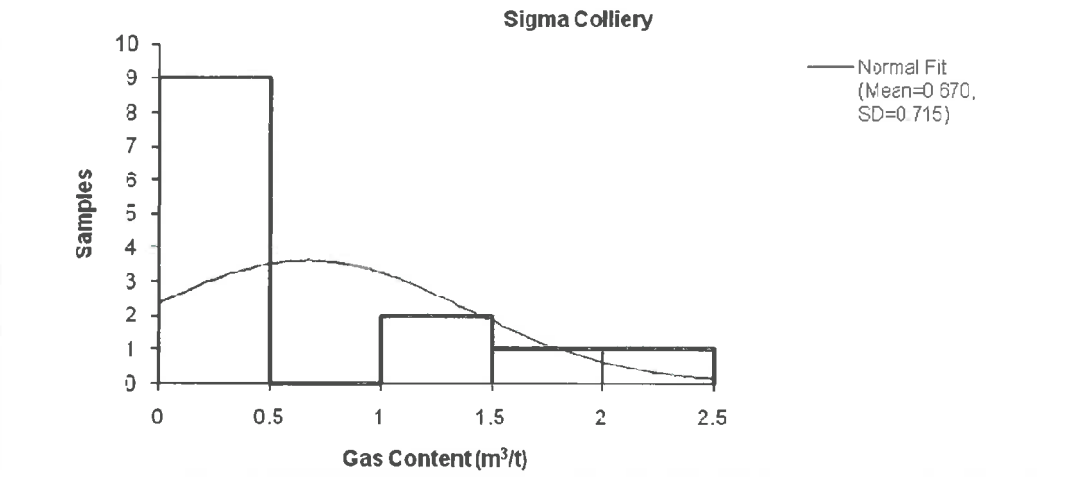

Figure A12: Sigma samples histogram

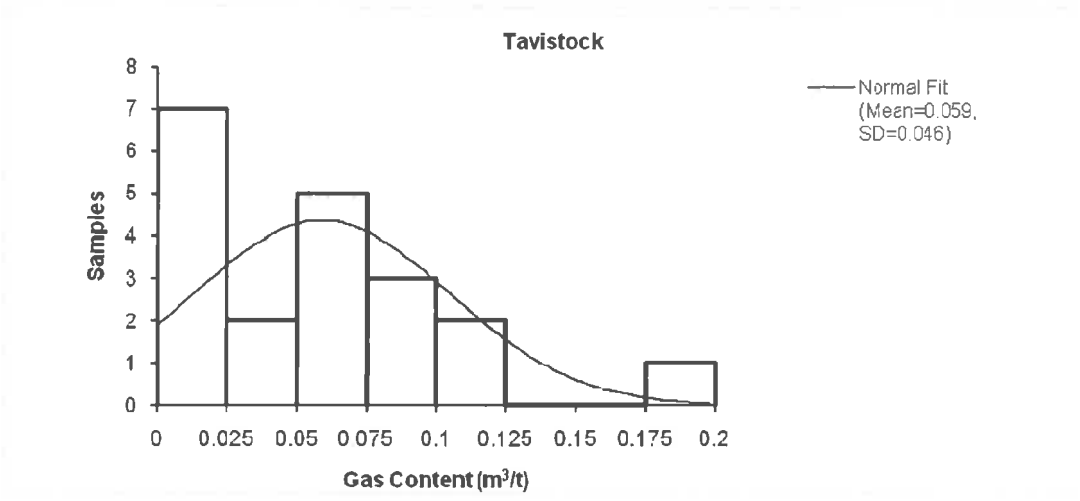

Figure A13: Tavistock samples histogram

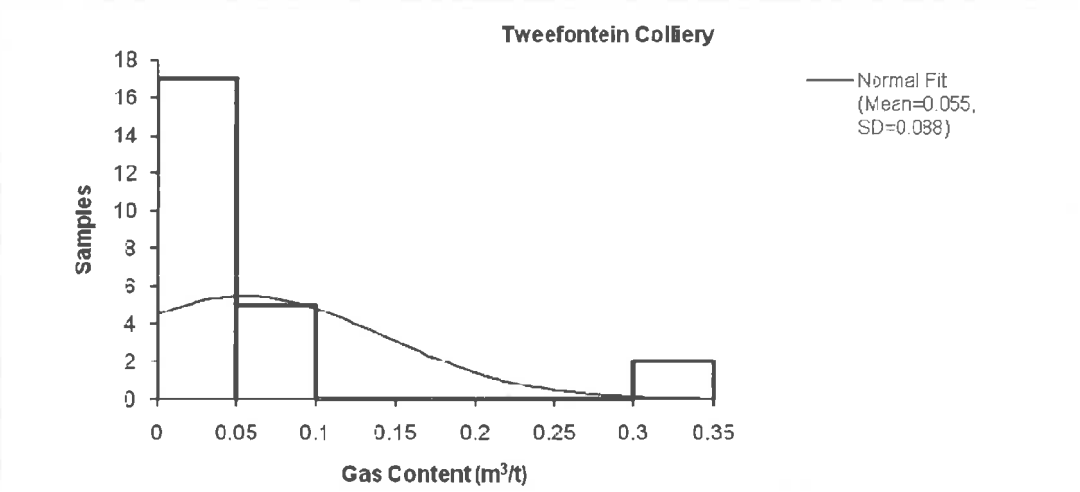

Figure A14: Tweefontein samples histogram

APPENDIX B: South African coal mines database

Table B1: Arnot samples

				AIR DRY			
	Gas Content	DAF Gas cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
			20.66	3.4	30.5	24.7	41.4
			24.28	4.1	18.4	25.3	52.2
			24.07	4.6	19.5	24	51.9
	0.01	0.02	18.74	4.4	34.5	36.1	25
	0.03	0.04	25.37	5.7	14.2	23.7	56.4
	0.02	0.02	25.67	4.3	15.4	26.4	53.9
			24.85	4.6	16.9	24.4	54.1
			26.8	3.8	14.3	31.5	50.4
			26.98	4.2	11.8	27.7	56.3
MIN	0.01	0.02	18.74	3.4	11.8	23.7	25
MAX	0.03	0.04	26.98	5.7	34.5	36.1	56.4
AVE	0.02	**0.03**	24.16	4.3	19.5	27.1	49.1
STDEV	0.01	0.01	2.76	0.64	7.79	4.16	10.08

Table B2:Bank samples

				AIR DRY			
	Gas Content	DAF Gas cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.97	1.37	22.73	2.1	27.1	22.5	48.3
	0.52	0.63	27.7	2.3	15.1	29.7	52.9
	0.01	0.01	26.04	2.5	18.7	24.9	53.9
	1.22	1.38	29.88	2.4	9.5	27.5	60.6
	1.65	1.86	30.1	2.5	8.6	32.1	56.8
	1.76	1.98	30.1	2.5	8.6	32.1	56.8
			29.08	2.2	12.7	28.5	56.6
			28.28	2.8	11.8	29.8	55.6
			29.74	2.8	10	34.5	52.7
MIN	0.01	0.01	22.73	2.1	8.6	22.5	48.3
MAX	1.76	1.98	30.1	2.8	27.1	34.5	60.6
AVE	1.02	**1.21**	28.18	2.5	13.6	29.1	54.9
STDEV	0.67	0.75	2.45	0.24	6.07	3.74	3.47

TableB3:Brandspruit samples

			AIR DRY			
Gas Content	Gas Cont.(daf)	CV	Moisture	Ash	Volatiles	Fixed Carbon
0.42						
1						
0.82						
0.66	0.93	21.8	5.7	23.2	24.3	46.8
1.28	1.65	24.27	4.8	17.8	23.2	54.2
0.47						
0.54						
0.14						
0.7						
1.12						
0.62						
0.09						
0.24						
1.35	1.68	25.49	6.2	13.4	23.1	57.3
1.28	1.63	24.53	5	16.4	24	54.6
1.75	2.14	25.62	3.2	14.9	29.6	52.3
0.37						
0.51						
0.7						
0.67						
0.38	0.52	22.41	6.1	20.6	21.1	52.2
0.34	0.47	22.22	5.1	22.3	21.7	50.9
0.41						
0.78						
0.1						
0.44						
0.3	0.51	17.92	4.8	36	18.1	41.1
1.1	1.47	22.71	5.2	20.1	23.5	51.2
1.17						
0.7						
0.47						
0.1						
0.2						
0.4						
0.21	0.34	19.36	4.6	33	18.6	43.8
0.29	0.45	20.53	3.8	31.5	19.5	45.2
0.05	0.08	20.53	3.8	31.5	19.5	45.2
0.19						
0.26						
0.31	0.43	22.28	4.5	23.6	23.8	48.1
0.17	0.24	21.68	4.9	22.9	22.2	50

Gas Content	Gas Cont.(daf)	CV	Moisture	Ash	Volatiles	Fixed Carbon
0.2						
0.12	0.17	22.68	6.1	21.5	22.4	50
0.94	1.23	23.66	3.7	19.9	23.3	53.1
0.17						
0.11						
0.89	1.23	23.21	5.6	22.1	23.6	48.7
1.68	2.28	22.74	3.6	22.8	22.7	50.9
0.03						
0.38	0.55	21.99	3.8	26.8	24.8	44.6
0.19						
0.14	0.19	23.64	6.1	18.3	20.6	55
0.08	0.12	19.55	3.6	30.1	19.7	46.6
0.14						
0.3	0.38	25.93	5.6	15.1	30.3	49
0.18	0.27	20.84	4.1	29	20.4	46.5
0.25	0.31	26.1	3.6	14.5	28.9	53
0.45						
0.5	0.63	25.04	6.1	14.9	25.6	53.4
0.28	0.35	25.5	3.6	15.8	28.4	52.2
0.67						
0.76	0.96	24.56	5.1	15.9	23.4	55.6
2.04	2.69	24.42	3.7	20.4	17.4	58.5
0.11						
1.25	1.59	24.7	4.4	17.2	23.7	54.7
2.18	2.74	25.12	7.4	13	24.8	54.8
2.79	3.61	23.99	4.1	18.7	23.4	53.8
1.84						
1.11						
0.63						
0.24						
0.12						
2.18	2.67	25.98	7	11.5	26.8	54.7
2.73	3.50	24.67	5.1	17	23.6	54.3
1.7						
0.27						
1.25						
0.35						
0.19						
0.37						
0.33						
0.21						
0.3						
0.18						
0.28						
0.03	0.08	17.92	3.2	11.5	17.4	41.1
2.79	3.61	26.1	7.4	36	30.3	58.5
0.64	**1.15**	23.20	4.8	21.0	23.2	51.0
0.62	1.02	2.12	1.09	6.34	3.17	4.22

Table B6: Douglas samples

			AIR DRY BASIS			
Gas Content	Gas Cont.(daf)	CV	Moisture	Ash	Volatiles	Fixed Carbon
0.01	0.01	21.55	2.1	30.2	21.6	46.1
0.15	0.23	21.18	1.9	32.3	19.1	46.7
0.08	0.12	21.33	2.1	30.6	20.5	46.8
0.02	0.02	27.24	2.1	16.9	29.7	51.3
0.03	0.04	27.53	1.6	17.5	32.3	48.6
0.07						
0.1						
0.08	0.21	9.95	1.3	61.3	16.9	20.5
0.02	0.03	22.15	2.3	28	23.6	46.1
0.3	0.37	27.3	2.6	15.7	21.8	59.9
		24.23	1.7	21.5	24.4	52.4
0.03						
0.02	0.02	27.79	1.8	15.8	26.6	55.8
0.03	0.04	27.23	2	16.8	18.1	63.1
		26.86	1.2	19.1	27.8	51.9
0.06	0.08	26.51	2.2	19.3	22.7	55.8
0.08	0.10	26.5	1.5	19	25.7	53.8
0.03	0.04	26.28	1.2	19	20.9	58.9
0.08	0.10	26.48	2.3	18.2	23.4	56.1
0.16	0.25	20.05	2	34.5	20.1	43.4
0.17	0.21	27.17	1.9	17.1	25.5	55.5
0.14	0.24	18.31	2.6	38.5	18.5	40.4
		24.22	1.6	22.7	26	49.7
0.19	0.24	27.49	1.9	18.6	27.7	51.8
0.05	0.07	24.03	1.1	24.8	24.8	49.3
0.16	0.20	26.05	1.6	20.1	25.8	52.5
0.02						
0.09	0.12	24.86	1.7	23.2	26.1	49
0.4	0.53	25.56	1.9	22.2	24	51.9
		27.43	1.5	16.8	25.7	56
0.05	0.07	25.25	1.8	22.5	30.2	45.5
0.03	0.05	19.46	1.8	37.8	19.1	41.3
		42	20.78	2.6	33.8	42.82
		25.4	2.8	17.8	26.7	52.7
0.01	0.01	26.02	1.5	21.1	28	49.4
		24.38	2.4	23.3	22.5	51.8
0.07	0.15	12.89	1.1	52.3	17.3	29.3
0.07	0.10	22.62	2	26.7	19.6	51.7
0.09	0.11	27.9	2.4	14.2	27.2	56.2
0.24	0.29	27.96	2.1	13.7	22.7	61.5
		24.21	2.5	21.7	23.1	52.7
		24.35	1.4	24	27.5	47.1
0.01	0.01	23.99	1.9	25.3	26	46.8

Gas Content	Gas Cont.(daf)	CV	Moisture	Ash	Volatiles	Fixed Carbon
		24.16	1.2	23.2	22.4	53.2
0.04	0.06	21.15	1.4	31.3	23.9	43.4
0.02	0.03	23.7	1.7	25.8	24.9	47.6
0.02	0.03	25.56	2.3	20	27.3	50.4
		23.86	2	24.4	20.1	53.5
0.07	0.10	22.36	1.4	26.7	20.9	51
0.14						
0.04						
0.73	0.95	25.67	1.8	21.3	28.1	48.8
		26.03	2.7	19.7	29.5	48.1
0.38	0.49	24.91	1.8	20.4	26	51.8
0.03	0.04	23.23	2.3	27	25.5	45.2
0.15	0.18	27.49	1.6	16.1	27.3	55
0.02	0.03	23.54	3.2	25.3	19.7	51.8
0.05	0.07	23.21	1.5	25.6	29	43.9
0.01	0.03	9.63	0.8	63.8	26.8	8.6
0.01	0.01	9.63	0.8	2.6	16.9	8.6
0.73	0.95	42	20.78	63.8	33.8	63.1
0.10	**0.15**	24.27	2.2	24.4	24.4	49.0
0.13	0.18	4.70	2.64	10.68	3.84	9.02

Table B7: Goedehoop samples

				AIR DRY			
	Gas Content	DAF Gas Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	1	1.19	28.69	2.3	13.9	22.5	61.3
	1.47	1.85	25.9	2.6	18.1	22.1	57.2
	1.47	1.85	25.9	2.6	18.1	22.1	57.2
	1.25	1.59	25.43	2.8	18.6	21.4	57.2
	2.16	2.73	26.19	3.4	17.5	22.1	57
	1.22						
	0.39						
	0.66	0.89	24.01	3.7	21.9	21.2	53.2
	2.56	3.32	24.3	3	19.9	23.2	53.9
	0.08	0.12	21.54	2.4	31.3	22.2	44.1
	0.09	0.11	27.09	2.3	16.4	27.6	53.7
	0.11	0.13	28.39	2	14.2	27.8	56
	0.41	0.47	30	2.1	10	31.7	56.2
			27.71	3	15.2	22.6	59.2
	0.05	0.06	24.72	3	15.7	21.5	59.8
MIN	0.05	0.06	21.54	2	10	21.2	44.1
MAX	2.56	3.32	30	3.7	31.3	31.7	61.3
AVE	0.92	**1.19**	26.14	2.7	17.8	23.7	55.8
STDEV	0.81	1.10	2.26	0.50	5.05	3.23	4.25

Table B8: Golfview samples

				AIR DRY			
	Gas Content	DAF Gas cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.03	0.04	26.52	3.9	15.9	28.3	51.9
	0.03	0.04	25.22	3.9	10.5	20.6	65
	0.03	0.04	28.38	3.9	10.5	34.4	51.2
			15.5	2.2	48.1	21	28.7
MIN	0.03	0.04	15.5	2.2	10.5	20.6	28.7
MAX	0.03	0.04	28.38	3.9	48.1	34.4	65
AVE	0.03	0.04	23.9	3.5	21.3	26.1	49.2
STDEV	0.00	0.00	5.75	0.85	18.08	6.58	15.07

Table B9: Greenside samples

				AIR DRY			
	Gas Content	DAF Gas Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	1.31	2.36	24.74	23.6	20.9	18.1	37.4
	0.2	0.42	24.16	28.57	23.5	21.4	26.53
	0.03	0.06	26.21	28.57	17.6	22.8	31.03
	0.26	0.49	25.18	27.3	19.9	21.4	31.4
	1.01	2.59	22.14	31.08	29.9	21.1	17.92
	0.34	0.61	25.97	25.69	18.4	20.5	35.41
	0.15	0.31	24.52	29.46	22.5	22.3	25.74
			25.81	30.57	18	24.3	27.13
			25.74	27.35	19.4	21.5	31.75
			26.8	28.22	15.1	23.2	33.48
	0.01	0.01	26.27	4.9	15.4	30.5	49.2
			28.61	3.2	11	34.5	51.3
	0.28	0.37	25.1	2.6	21.9	24.7	50.8
MIN	0.01	0.01	22.14	2.6	11	18.1	17.92
MAX	1.31	2.59	28.61	31.08	29.9	34.5	51.3
AVE	0.40	0.80	25.48	22.39	19.50	23.56	34.55
STDEV	0.45	0.97	1.52	10.92	4.62	4.39	10.30

Table B10: Khuthala samples

Coal type:3

					AIR DRIED BASIS			
Emission Index	Gas Content	Mining Height	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
21.55	0.06	2.8	21.73	31.36	4	28.4	21.2	46.4
		4.5	20.02	34.33	3.3	30	22.9	43.8
15.3		4	17.25	30.1	3.6	38.6	17.4	40.4
6.16	0.11	2.8	14.3	30.38	2.8	29.4	20.6	47.2
		2.8	22.42	36.77	2.4	25.8	26.4	45.4
7.23	0.17	4	18.12	34.27	2.9	36.7	20.7	39.7
		4.5	14.8	34.71	3.8	45.5	17.6	33.1
4.39	0.10	2.8	22.86	36.14	2.7	23.7	26.6	47
		4.5	16.16	32.97	2.9	41.3	18.4	37.4
3.39	0.06	4.5	13.16	45.7	2.4	49.9	21.8	25.9
		4.8	20.94	33.43	4.6	27.2	22.8	45.4
6.97	0.05	4	13.8	36.09	2.8	47.6	17.9	31.7
		4.5	22.26	30.75	3.6	22.9	22.6	50.9
1.05		4	17.45	33.11	3.2	36.1	20.1	40.6
		4.3	16.97	32.76	3.6	38.1	19.1	39.2
5.66		4	19.19	38.53	3.7	32.2	24.7	39.4
		2.8	11.6	39.57	2.2	55.6	16.7	25.5
19.24	0.05	2.8	18.5	32.9	3.8	34.2	20.4	41.6
		4.5	22.1	35.72	2.3	25.2	25.9	46.6
		4	23.53	32.28	4	20.4	24.4	51.2
		4.5	19.43	33.96	2.5	33.9	21.6	42

	Emission Index	Gas Content	Mining Height	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
			4	20.36	34.29	2.9	30.6	22.8	43.7
	2.48		4	16.68	34.49	3.3	39.3	19.8	37.6
	3.98		4.3	21.2	35.51	3.4	29.3	23.9	43.4
			2.8	20.16	34.38	2.1	31.3	22.9	43.7
			4.2						
			4	21.59	38.27	3.4	27.1	26.6	42.9
	1.06		4	18.73	31.97	3.6	32.6	20.4	43.4
			4.5	24.72	37.11	3.7	18.7	28.8	48.8
			4.5	21.95	30.92	3.8	24.4	22.2	49.6
			4.3	21.62	30.94	4.2	26.3	21.5	48
			2.8	18.27	35.32	2.4	35.6	21.9	40.1
			4	18.2	37.48	4.2	34.7	22.9	38.2
		0.10	4.3	22.65	34.35	4.2	23.6	24.8	47.4
			4.3	23.54	31.2	4.1	20.9	23.4	51.6
			4	19.19	33.85	4.1	44.2	17.5	34.2
			4	24.25	38.06	3.6	18.9	29.5	48
			4	15.51	41.19	2.7	41.7	22.9	32.7
			4	16.8	34.78	3.3	38.9	20.1	37.7
			4	19.33	33.99	3.4	31	22.3	43.3
			4	23.73	36.38	4	20.4	27.5	48.1
			5	22.18	34.71	4.2	25.5	24.4	45.9
4 seam	1.93		4.8	29.08	29.21	0.4	18.8	23.6	57.2
			4.5	15.34	36.03	3.1	42.5	19.6	34.8
			2.8	23.25	33.2	2.9	22.4	24.8	49.9
	7.74	0.13	4	22.68	31.58	3.8	22.1	23.4	50.7
			4	22.57	30.96	3.9	23.1	22.6	50.4
	0.02		4.5						
	0.02		4.5						
			4.3						
			4	18.38	35.45	3	35.5	21.8	39.7

	Emission Index	Gas Content	Mining Height	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	37.44	0.19	4.5	18.43	35.79	2.9	34.8	22.3	40
			4.5	20	32.37	3.6	30.6	21.3	44.5
			4.5	16.46	38.62	1.7	40.3	22.4	35.6
			4	18.52	33.49	3.4	34.2	20.9	41.5
			4	20.84	30.32	3.3	28.1	20.8	47.8
			2.8						
			2.8						
2seam	3.1		2.8	23.58	31.21	3.2	21.5	23.5	51.8
Coal type:6	14.06	0.06	2.8	9.38	39.95	2.2	57	16.3	24.5
	5.2		3.5	21.83	39.04	3.2	13.3	32.6	50.9
	13.63		2.8	12.11	32.75	2.6	51.6	15	30.8
	7.84		2.8						
	9.38	0.32	4.5	27.81	34.46	3	11.4	29.5	56.1
			2.8	14.14	35.29	2.2	48.5	17.4	31.9
			2.8	22.76	34.78	3.6	25.1	24.8	46.5
			4	22.16	27.83	3.6	24.9	19.9	51.6
			3						
			2.8						
	13.9	0.11	2.8	19.41	30.36	2.8	33.3	19.4	44.5
	2.44	0.05	2.8	5.4	53.54	1.6	65.9	17.4	15.1
	2.37	0.19	4	25.66	32.67	3.4	16.4	26.2	54
		0.35	40	24.13	33.42	2.9	20.5	25.6	51
	19.33	0.13	2.8	25	32.58	2.2	18.3	25.9	53.6
	6.58	0.07	2.8	18.51	33.39	2.5	35.5	20.7	41.3
	4.58	0.23	3.5	25.21	32.51	4.2	18.6	25.1	52.1
			4.5	25.67	36.52	3.8	16.8	29	50.4
	22.69	0.14	2.8	22.85	35.29	3	25.3	25.3	46.4
			5.1	24.95	31.2	4.6	15.6	24.9	54.9
	9.28	0.19	2.8	22.72	31.56	3.2	25.2	22.6	49
			2.8	24.43	29.74	1.9	22.1	22.6	53.4

Emission Index	Gas Content	Mining Height	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
55.84	0.23	4.2	19.25	34.55	3.2	34	21.7	41.1
		4.5	22.32	29.47	3.7	23	21.6	51.7
5.92	0.21	3.5	24.7	36.02	3.5	19.6	27.7	49.2
3.44	0.09	4.8	21.46	30.28	3.3	25.7	21.5	49.5
		2.8	16.69	35.71	3	39.6	20.5	36.9
		3.9	21.02	36.23	3.3	29.9	24.2	42.6
9.45	0.75	4.5	24.89	32.99	3.4	19.9	25.3	51.4
19.61	0.31	2.8	21.74	36.87	2.7	30.3	24.7	42.3
3.21	0.08	4	24.41	27.93	3.6	18	21.9	56.5
3.69	0.10	4.5	15.86	31.33	2.9	40.6	17.7	38.8
5.69	0.13	2.8	25.59	32.33	2.9	17	25.9	54.2
4.29	0.06	3.5						
2.61	0.20	3.5						
		4						
5.91	0.11	4.5	17.38	29.13	2.9	38.4	17.1	41.6
		2.8	14.46	36.18	3	43.1	19.5	34.4
		4	10.39	22.4	3.4	23.4	16.4	56.8
25.75	0.12	4.5	23.04	32.73	2.6	25.6	23.5	48.3
		2.8						
		2.8	25.82	34.09	3.6	16.6	27.2	52.6
4.95		4						
3.03		4						
15.93		2.8	24.53	35.09	2.8	21.1	26.7	49.4
		4						
4.18	0.13	4	13.31	35.88	2.9	48.6	17.4	31.1
		2.8	22.91	33.99	3.8	25	24.2	47
7.49	0.09	2.8	16.9	28.6	3.8	41.3	15.7	39.2
		2.8	18.47	31.84	3.5	34	19.9	42.6
2.22		2.8	18.3	30.81	3.6	34.4	19.1	42.9
10.8	0.12	4	14.29	34.48	2.5	48.2	17	32.3

	Emission Index	Gas Content	Mining Height	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
			2.8	18.18	28.8	2.3	35.9	17.8	44
	13.3	0.08	4.5	16.93	33.68	2.6	40.4	19.2	37.8
			2.8	18.7	29.56	3.1	35	18.3	43.6
			2.8						
			2.8						
MIN	0.02	0.05	2.8	5.4	22.4	0.4	11.4	15	15.1
MAX	55.8	0.75	40.0	29.1	53.5	4.6	65.9	32.6	57.2
AVE	9.4	0.15	4.0	19.9	33.9	3.2	30.9	22.2	43.8
STDEV	10.0	0.13	3.4	4.2	3.8	0.7	10.6	3.5	7.9

Table B11: Matla samples

type 3 coal						AIR DRY			
	Emission Index	Gas Content	Mining Height	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	32.1	0.87	4	22.2	25.4	2.1	29.3	17.4	51.2
	13.5	0.13	4	15.1	37.6	4.4	42.6	19.9	33.1
	20.4	0.36	4.1	23.6	33.5	6.1	16.8	25.8	51.3
	21.2	0.13	4	24.2	35.0	7.2	14.3	27.5	50.9
	14.5		4	19.9	36.4	5.7	26.8	24.6	42.9
	19.3	0.40	4	22.0	30.5	6.9	20.6	22.1	50.4
	12.1	0.16	4.3	23.5	32.0	6.6	16.1	24.7	52.6
	3.0	0.15	4.2	23.7	31.0	6.5	16.4	23.9	53.2
			4	20.0	33.7	6	26.4	22.8	44.8
	15.0	0.20	3.7	23.2	41.6	5.9	33.47	25.2	50.1
	23.6	0.37	4	23.6	36.7	6.7	17.6	27.8	47.9
			4.2	22.9	0.0	6	18.7	24.3	51
	11.0	0.14	4	20.3	34.9	6.6	25.1	23.8	44.5
	18.6		4	15.8	37.7	4.5	38.4	21.5	35.6
	37.1	0.59	4	23.8	33.6	6.3	18.8	25.2	50.1
	9.9	0.63	4	23.5	34.7	7.5	15.8	26.6	50.1
	13.9	0.46	4.5	22.9	33.7	6.1	18	25.6	58.3
	7.8	0.07	4.1	22.6	32.8	6.2	19.1	24.5	50.2
6&3 type	13.7	0.19	4	27.2	31.6	4.3	11.2	26.7	57.8
	9.2	0.12	4.5	24.9	29.6	3.9	18.1	23.1	54.9
	3.9		4	24.9	31.8	4.1	16.1	25.4	54.4
	15.4	0.11	4.3	23.8	34.9	3.3	21.1	26.4	49.2

	Emission Index	Gas Content	Mining Height	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	2.7		4	17.5	32.7	3.5	35.6	19.9	41
	8.7	0.05	4	21.7	35.2	4.2	26.2	24.5	45.1
	2.7		4	25.1	34.6	3.7	17.4	27.3	53.3
	8.2	0.28	4	26.4	36.0	5.2	12.4	29.7	52.7
	7.1	0.07	4	16.6	44.3	3.8	40.2	24.8	31.2
		0.05	4	20.8	36.7	3.8	29.7	24.4	42.3
		0.12	4	20.5	34.8	4.8	28.6	23.2	43.4
MIN	2.7	0.05	3.7	15.1	0.0	2.1	11.2	17.4	31.2
MAX	37.1	0.87	4.5	27.2	44.3	7.5	42.6	29.7	58.3
AVE	13.8	0.26	4.1	22.1	33.2	5.2	23.1	24.4	48.1
STDEV	8.6	0.22	0.2	3.0	7.3	1.4	8.6	2.6	6.7

Table B12: Mooifontein samples

				AIR DRY			
	Gas Content	DAF Gas cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.04	0.05	27.58	2	16	25	57
	0.03	0.04	27.58	2	16	25	57
MIN	0.03	0.04	27.58	2	16	25	57
MAX	0.04	0.05	27.58	2	16	25	57
AVE	0.04	0.04	27.58	2	16	25	57

Table B13: New Clydesdale samples

N/CLYCEDALE				AIR DRY			
	Gas Content	DAF Gas Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.13	0.15	29.37	2.3	12.2	28	57.5
	0.2	0.23	29.74	2	11	31.4	55.6
	0.05	0.06	28.39	2.7	13.1	26.4	57.8
	0.47	0.56	28.2	2.6	14	23.1	60.3
MIN	0.05	0.06	28.2	2	11	23.1	55.6
MAX	0.47	0.56	29.74	2.7	14	31.4	60.3
AVE	0.21	0.25	28.93	2.4	12.6	27.2	57.8

Table B14: Rietspruit samples

				AIR DRY			
	Gas Content	DAF Gas. Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.01	0.01	22.27	2.4	28.4	23.9	45.3
	0.02	0.03	23.36	2.6	25.5	22.8	49.1
	0.02	0.03	20.91	2.5	32.1	22.9	42.5
	0.01	0.02	21.53	2	32.1	23.9	42
	0.03	0.04	27.3	2.1	18	31	48.9
	0.01	0.01	27.43	2.2	16.4	32.1	49.3
MIN	0.01	0.01	20.91	2	16.4	22.8	42
MAX	0.03	0.04	27.43	2.6	32.1	32.1	49.3
AVE	0.02	0.02	23.8	2.3	25.4	26.1	46.2
STDEV	0.01	0.01	2.88	0.24	6.85	4.26	3.39

Table B15: Spitzkop samples

				AIR DRY			
	Gas Content	DAF Gas Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
			25.5	3.2	20.8	28.8	47.2
	0.05	0.06	30.52	3.9	6.4	30.6	59.1
	2.12	2.60	27.41	3.6	14.9	30.8	50.7
			14.71	1.4	52.3	22.1	24.2
			27.58	2.1	15.7	30.8	51.4
			23.64	2.5	25.7	28.8	43
MIN	0.05	0.06	14.71	1.4	6.4	22.1	24.2
MAX	2.12	2.60	30.52	3.9	52.3	30.8	59.1
AVE	1.09	1.33	24.9	2.8	22.6	28.7	45.9

Table B16: Strathrae samples

				AIR DRY			
	Gas Content	DAF Gas Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.11	0.11					
	0.13	0.16	25.89	6.2	14.2	20.9	58.7
			24.27	6.1	18.2	22.2	53.5
	0.02	0.02	26.42	6.1	12.9	22.1	58.9
MIN	0.02	0.02	24.27	6.1	12.9	20.9	53.5
MAX	0.13	0.16	26.42	6.2	18.2	22.2	58.9
AVE	0.09	0.10	25.5	6.1	15.1	21.7	57.0

Table B17: Tavistock samples

Tavistock

			AIR DRY			
Gas Content	DAF Gas cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
		21.72	2.9	28.2	23.4	45.5
		25.36	3.5	17.4	24.5	54.6
0.02	0.03	25.12	3.4	18.7	26.5	51.4
		20.57	2.7	31.1	21.5	44.7
0.04	0.05	22.45	2.5	23.4	28	46.1
		19.66	2.7	33.3	22.4	41.6
0.01	0.01	24.84	2.6	20.8	21.2	55.4
0.07	0.09	24.3	3.2	20.5	25.9	50.4
0.02	0.03	19.8	2.4	34.1	24.5	39
		26.93	3.9	18.6	25.8	51.7
		25.04	2.6	18.9	25.7	52.8
0.01	0.01	24.82	3.8	21.8	24.3	50.1
0.01	0.01	25.91	3.3	17.5	28.6	50.6
		19.03	2.5	34.8	22.5	40.2
0.08	0.12	20.25	2.8	32.1	24.4	40.7
0.07	0.09	23.93	3.5	20.8	25	50.7
		23.42	2.9	25.1	25.9	46.1
0.07	0.11	19.56	2	35.1	24.1	38.8
0.08	0.11	22.97	3.1	24.1	26.7	46.1
0.06	0.08	23.64	2.5	22.6	25.8	49.1
		26.44	3.1	15	29.2	52.7
		23.33	2.9	24.5	27.7	44.9
0.02	0.03	25.65	3.2	18.4	29.2	49.2
0.08	0.11	21.2	2.4	25.6	29.4	42.6
0.03	0.04	23.5	3.4	22.1	25.9	48.6
		22.7	2.3	26.6	25.5	45.6
0.02	0.02	26.67	2.6	15.3	31.6	50.5
		23.49	3.5	22.4	25.3	48.8
0.12	0.16	22.59	2.9	24.3	23.9	48.9
0.11	0.17	20.44	2.2	31.8	24.4	41.6
		24.3	3.8	19.6	25.8	50.8
0.19	0.30	20.01	2.4	33.3	23.2	41.1
0.07	0.09	23.52	2.8	22.3	22.2	52.7
		22.88	2.9	25.3	27.4	44.4
		22.56	2.6	25.5	26	45.9

	Gas Content	DAF Gas cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
			16.59	2.5	43.9	23.8	29.8
			26.86	3.6	15.1	31.8	49.5
MIN	0.01	0.01	16.59	2	15	21.2	29.8
MAX	0.19	0.30	26.93	3.9	43.9	31.8	55.4
AVE	0.06	0.08	23.0	2.9	24.6	25.6	46.8
STDEV	0.05	0.07	2.49	0.49	6.69	2.55	5.31

Table B18: Tselentis samples

				AIR DRY			
	Gas Content	DAF Gas Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
			26.63	3.4	16.4	23	57.2
			21.73	2.2	30.9	21	45.9
	0.03	0.04	25	5.7	14	23	57.3
	0.02	0.02	27.7	2.6	15.4	31.3	50.7
MIN	0.02	0.02	21.73	2.2	14	21	45.9
MAX	0.03	0.04	27.7	5.7	30.9	31.3	57.3
AVE	0.03	0.03	25.3	3.5	19.2	24.6	52.8
STDEV	0.01	0.01	2.61	1.56	7.88	4.58	5.53

Table B19: Tshikondeni samples

				AIR DRY			
	Gas Content		CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.03	0.06	18.05	0.80	46.10	15.80	37.30
	0.05	0.08	21.98	0.80	35.60	20.10	43.50
	0.03						
	0.02	0.03	18.58	4.60	33.20	20.00	42.20
	1.03						
MIN	0.02	0.03	18.05	0.8	33.2	15.8	37.3
MAX	1.03	0.08	21.98	4.6	46.1	20.1	43.5
AVE	0.23	0.06	19.5	2.1	38.3	18.6	41.0
STDEV	0.45	0.02	2.13	2.19	6.86	2.45	3.27

Table B20: Twisdraai samples

TWISDRAAI

			AIR DRY			
Gas Content	DAF Gas Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
0.76	0.76					
0.63	0.63					
1.76	1.76					
1.8	2.57	22.52	3.30	26.60	30.80	39.30
1.33	1.63	26.32	4.10	14.30	32.90	48.70
0.29	0.42	22.37	3.40	27.10	29.30	40.20
0.18	0.70	5.48	1.20	73.00	13.30	12.50
1.52						
1.18	2.39	15.21	2.40	48.30	20.70	28.60
0.5	0.91	16.84	3.00	41.80	22.70	32.50
0.14	0.21	20.3	4.10	27.70	24.40	43.80
0.02	0.03	18.98	3.00	34.80	23.90	38.30
1.42						
1.7						
1.3	1.77	23.42	4.30	22.30	24.70	48.70
0.65	0.94	22.13	3.40	27.70	30.50	38.40
1.7	1.95	28.77	3.40	9.20	36.40	51.00
0.45	0.60	24.2	3.40	21.10	28.80	46.70
1.37						
1.12						
1.51						
1.35						
1.11	1.62	21.78	3.50	28.00	27.00	41.50
1.53	2.02	24.4	4.00	20.20	28.10	47.70
0.62						
1.27						
1.95						
1.22	1.73	22.69	4.00	25.40	27.40	43.20
1.64	2.16	24.4	4.00	20.20	28.10	47.70
0.3	0.42	22.57	3.50	24.60	30.90	41.00
0.23	0.28	26.68	3.60	13.30	32.30	50.80
1.66	2.24	23.5	4.00	22.00	29.50	44.50
1.47	2.12	22.43	3.20	27.40	29.40	40.00
0.64	0.92	21.42	4.00	26.20	28.00	41.80
0.07	0.14	14.64	2.60	47.90	19.60	29.90
0.42	0.60	21.79	3.30	27.00	27.60	42.10
0.55	0.80	21.48	3.20	27.90	26.60	42.30
0.82						
0.34	0.61	16.94	3.10	41.30	19.10	36.50
0.2	0.35	17.69	2.60	39.70	23.70	34.00
0.64	0.86	23.21	3.20	22.40	24.70	49.70

Gas Content	DAF Gas Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
0.75	0.98	24.48	4.20	19.10	29.50	47.20
0.24	0.42	16.91	2.80	40.60	18.70	37.90
1.24	1.65	21.9	4.10	20.70	32.10	43.10
0.19						
2.35						
2.16						
1.4	1.73	26.69	4.10	15.20	33.30	47.40
1.06	1.34	25.43	3.80	17.20	32.50	46.50
0.64						
1.45						
1.23						
0.64						
1.57	2.09	23.52	3.80	21.10	28.80	46.30
0.09						
0.61						
1.14						
1.72	2.40	23.1	3.70	24.70	25.00	46.60
1.13	2.16	16.18	3.10	44.60	19.20	33.10
1.12	1.38	26.1	4.40	14.50	32.00	49.10
0.98						
0.48	0.73	19.7	3.70	30.60	21.70	44.00
0.42	0.61	21.4	3.50	27.80	23.40	45.30
0.19						
0.36						
1.27						
0.31						
1.72						
1.57	2.41	20.63	3.50	31.40	24.30	40.80
1.1						
1.4	1.99	21.78	4.50	25.00	23.20	47.30
0.93	1.43	19.83	4.00	30.90	21.70	43.40
1.38	1.81	24.04	4.40	19.40	22.60	53.60
1.46	1.94	23.77	4.90	20.00	24.60	50.50
2.15	2.55	28.17	5.00	10.70	33.30	51.00
0.89	1.24	22.19	4.30	23.90	23.70	48.10
0.75	1.30	16.99	3.70	38.80	22.10	35.40
1.27						
0.62						
0.29						
2.26	2.90	25.09	4.80	17.40	26.80	51.00
1.17	1.73	20.26	4.80	27.70	19.90	47.60
0.96	1.26	24	3.60	20.20	29.80	46.40
0.77	0.97	24.91	3.00	17.60	24.80	54.60
0.65	0.92	22.17	3.60	25.60	30.10	40.70
0.32	0.41	24.47	3.80	18.80	24.20	53.20
0.89						
1.12	1.59	22.01	3.60	25.90	24.10	46.40
0.83	1.15	22.57	4.30	23.60	25.40	46.70
0.22	0.49	12.61	2.80	52.60	16.90	27.70

	Gas Content	DAF Gas Cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.47	0.69	21.11	3.00	29.30	20.00	47.70
	2.62						
	0.9	1.22	23.15	4.50	21.50	21.80	52.20
	0.9	1.17	23.99	4.40	18.80	29.00	47.80
	0.88	1.16	23.46	4.80	19.60	23.00	52.60
	2.83						
	2.53						
	0.13						
	0.45						
	0.42						
	1.78						
	0.79	1.08	23.14	4.20	22.70	23.40	49.70
	1.16	1.45	25.19	5.20	14.80	24.30	55.70
	0.46						
	1.39	1.95	22.73	3.60	25.30	25.40	45.70
	1.03	1.32	24.69	5.00	16.80	23.80	54.40
	1	1.36	22.24	4.60	21.60	21.70	52.10
	2.29						
	1.46	1.87	24.98	4.10	18.00	25.20	52.70
	0.66	0.85	24.29	5.20	17.50	25.00	52.30
	0.36	0.49	22.8	4.50	22.70	24.00	48.80
	1.32						
	1.94	2.37	27.57	3.90	14.20	32.60	49.30
	1.69	2.19	24.57	3.90	19.10	31.70	45.30
	0.06	0.08	24.34	4.80	17.90	23.20	54.10
	0.41	0.73	17.36	3.60	40.00	22.30	34.10
	0.63	0.83	24.1	3.10	21.20	24.40	51.30
	0.48	0.69	21.96	4.20	26.20	21.60	48.00
	0.13	0.16	25.07	4.10	16.10	24.40	55.40
	1.46	1.80	25.72	3.80	15.30	24.30	56.60
	0.61						
	0.09						
	1.74						
	1.71	2.12	25.48	4.00	15.20	25.60	55.20
	1.15	1.43	25.89	4.80	14.80	22.50	57.90
	1.12						
	1.16	1.50	24.55	4.80	18.10	25.40	51.70
	0.86	1.14	24.02	5.00	19.30	24.50	51.20
	0.25	0.32	24.38	5.20	16.90	21.10	56.80
	0.08	0.10	25.12	5.60	16.70	26.80	50.90
	0.71	1.00	21.1	2.70	26.20	28.80	42.30
	0.34	0.43	25.29	4.70	15.50	24.20	55.60
	0.42	0.61	21.79	3.50	27.50	22.00	47.00
MIN	0.02	0.03	5.48	1.2	9.2	13.3	12.5
MAX	2.83	2.90	28.77	5.6	73	36.4	57.9
AVE	0.99	1.24	22.4	3.9	24.8	25.5	45.8
STDEV	0.62	0.71	3.60	0.76	10.34	4.26	7.71

Table B21:Vlaklaagte samples

				AIR DRY			
	Gas Content	DAF Gas cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.04	0.06	19.1	2.7	33	20.2	44.1
	0.01	0.01	23.11	3.4	19.3	9.6	67.7
	0.08	0.12	22.3	3	29.8	18.3	48.9
	0.06	0.08	24.67	2.4	23	18.3	56.3
MIN	0.01	0.01	19.1	2.4	19.3	9.6	44.1
MAX	0.08	0.12	24.67	3.4	33	20.2	67.7
AVE	0.05	0.07	22.3	2.9	26.3	16.6	54.3
STDEV	0.03	0.04	2.35	0.43	6.25	4.75	10.28

Table B22: Tweefontein samples

TWEEFONTEIN				AIR DRY			
Gas Content	DAF Gas cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
		25.4	2.5	20.1	24	53
		27.35	3	14.6	22.2	60.2
		27.28	3.1	13.8	26	57.1
0.01	0.01	26.35	2.6	17	25.2	55.2
0.02	0.03	26	2.7	18.8	24.2	54.3
		25.98	2.5	16.1	25.2	56.2
		25.05	3.4	19.8	24.8	52
		23.9	2.4	23.5	19.6	54.5
0.06	0.07	26.41	3.1	16.6	22.3	58
		27.26	2.4	15.5	22.4	59.7
0.08	0.10	26.56	2.6	15.2	23.4	58.8
0.01	0.01	25.62	3	18.4	23	55.6
0.02	0.02	26.63	2.7	17.1	25.5	54.7
		24.08	2.7	22.7	20.9	53.7
0.07	0.09	23.85	2.4	22.7	29.3	45.6
		23.58	3.5	23.6	20	52.8
0.03	0.04	25.84	2.9	18.7	28.2	50.2
		27.44	3.1	14.8	25.3	57
0.08	0.10	26.46	2.6	17.2	29.2	51
		22.12	2.8	26.8	21.7	48.7
0.02	0.03	24.28	3.2	21.3	20.6	54.9
		26.31	2.8	16	22.8	58.4
0.04	0.05	26.28	3.4	15.6	21.4	59.6
0.02	0.02	26.29	2.4	17.5	25.1	55
		24.25	2.1	21.1	22.6	54.2
0.03	0.03					
0.01	0.01	24.42	2.6	21.5	17.9	58

	Gas Content	DAF Gas cont.	CV	Moisture	Ash	Volatiles	Fixed Carbon
	0.01	0.01	23.51	2.3	25	22.5	50.2
			24.85	2.1	34.4	23.2	43.8
			20.14	1.9	35	19.9	43.8
	0.03	0.04	27.75	2.2	14.1	31.5	52.2
			21.65	2.1	32	21.8	44.1
			25.76	1.8	19.3	26.5	52.7
			26.28	2.7	17.7	25.3	54.3
			20.7	2	30.6	22.3	45.1
			18.13	1.7	39.3	20.8	38.2
			24.32	1.9	21.9	24.3	51.9
			22.55	2	25.7	20.8	51.5
	0.01	0.01	25.99	2.2	17.5	23.7	56.6
			25.5	2.4	18.7	22.8	56.1
	0.01	0.01	23.78	2.6	23.1	19.7	54.6
	0.33	0.41	26.01	2.2	17.7	24.6	55.5
	0.06	0.08	23.89	2.1	23	21.4	53.5
			21.59	2.7	28.6	18.01	50.6
			24.09	2.8	22.7	18.9	55.6
			25.22	2.6	17.8	22.1	57.5
			24.54	2.7	19.2	19.1	59
	0.01	0.01	25.29	2	20.8	24.9	52.7
			23.92	2.5	22.9	19.2	55.4
	0.03	0.04	24.09	2.6	23.9	23.9	49.6
			25.52	3.2	18.9	19.5	58.4
			22.94	3	23.3	20.3	53.4
	0.01	0.01	23.18	2.4	23.2	21.6	52.8
	0.33	0.43	24.74	2.3	21.8	17.1	59.3
			19.41	2.7	36.2	19.3	43.4
			11.92	2.3	54.6	15.3	29.5
			16.78	2.9	41	18.8	39
MIN	0.01	0.01	11.92	1.70	13.8	15.30	29.5
MAX	0.33	0.43	27.75	3.50	54.6	31.50	60.2
AVE	0.06	0.07	24.27	2.56	22.43	22.53	52.66
STDEV	0.09	0.11	2.84	0.42	7.66	3.16	5.99

Table B23 Kriel samples

N-W SHAFT

					AIR DRY			
	Emission Index	Gas Content	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	40.59	0.69	21.9	25.9	2.6	21.2	19.7	56.5
	14.91	0.18	21.9	33.8	3.7	24.7	24.2	47.4
	45.37	0.25	19.6	32.9	4	31	21.4	43.6
	14.44	0.44	22.1	28.3	4.7	21.9	20.8	52.6
	33.19	0.33						
	56.46	0.85						
	45.89	1.07						
	29.06	0.27						
	49.20	0.65						
	27.78	0.38						
	57.29	1.05						
	49.95	0.76						
	27.75	0.44						
	54.90	0.83						
	52.75	0.84	18.0	36.6	5.3	32.4	22.8	39.5
	73.91	1.26	22.2	28.3	4.4	23.4	20.4	51.8
	81.23	1.61	25.1	30.7	3.7	17.9	24.1	54.3
	66.54	1.91	23.5	32.2	4	22.5	23.7	49.8
	58.56	0.73	19.1	31.6	4.7	31	20.3	44
MIN	**14.4**	**0.18**	**18.0**	**25.9**	2.6	17.9	19.7	39.5
MAX	**81.2**	**1.91**	**25.1**	**36.6**	**5.3**	**32.4**	**24.2**	56.5
AVE	**46.3**	**0.77**	**21.5**	**31.1**	**4.1**	**25.1**	**21.9**	**48.8**

TableB24: Syferfontein samples

						AIR DRY BASIS			
	Emission Index	Gas Content	Mining Height	CV	DAFVols	H2O	Ash	Volatiles	Carbon
	526.6	4.89	3.8						
	153.4	2.15	3.8						
	24.8	0.44	3.8						
	15.3	0.27	3.8						
	45.8	1.31	4.8	24.0	33.2	6.1	17.3	25.4	51.2
	71.9	1.29	3.8						
	36.9	1.02	3.8						
	43.3	0.40	4.8	23.1	31.3	6.7	17.9	23.6	51.8
	28.4	0.89	3.8						
	12.0	1.09	3.8						
	19.7	0.91	4.4	24.2	32.0	7.4	14.5	25	53.1
	4.1	0.94	3.8						
	82.6	1.62	4.8	24.2	33.3	5.4	16.5	26	52.1
MIN	**4.1**	**0.27**	**3.8**	**23.14**	**31.3**	**5.4**	**14.5**	**23.6**	**51.2**
MAX	**526.6**	**4.89**	**4.8**	**24.2**	**33.3**	**7.4**	**17.9**	**26**	**53.1**
AVE	**81.9**	**1.32**	**4.1**	**23.9**	**32.4**	**6.4**	**16.6**	**25**	**52.05**
STDEV	**139.4**	**1.19**	**0.4**	**0.5**	**1.0**	**0.9**	**1.5**	**1.0**	**0.8**

Table B25: Bosjesspruit samples

DRIEHOEK

					AIR DRY			
EmissionIndex	GasContent	DAF Gas Cont.	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
37.4	0.99	1.24	23.76	31.23	4.4	19.4	23.8	52.4
27.2	1.14	1.70	23.42	34.58	4.1	31.7	22.2	42
	0.23	0.23						
38.4	0.43	0.55	23.77	28.30	4.2	20.9	21.2	53.7
56.9	1.52	1.52						
39.3	0.97	0.97						
36.1	1.54	2.20	20.68	33.88	4.3	28.7	22.7	44.3
37.9	1.87	2.31	24.43	36.12	4.1	18.1	28.1	49.7
48.1	0.41	0.55	22.59	34.08	3.5	24.6	24.5	47.4
34.2	0.68	0.68						
2.0	0.12	0.23	14.91	35.66	3.1	45.3	18.4	33.2
34.3	1.44	1.44						
31.8	1.43	2.02	20.62	34.02	4.1	28	23.1	44.8
	0.94	0.94						
74.1	1.84	2.35	23.36	29.32	4.6	20.7	21.9	52.8
36.7	1.58	1.92	24.31	31.11	4.9	17	24.3	53.8
53.7	1.23	1.23						
30.9	1.39	1.39						
41.1	1.12	1.62	20.37	29.07	4.8	29.5	19.1	46.6
32.8	1.07	1.32	24.67	35.96	4.5	18.2	27.8	49.5
71.9	1.83	1.83						
56.9	1.17	1.17						
65.3	2.25	2.80	24.21	29.51	5.5	18.6	22.4	53.5
28.1	1.12	1.76	18.16	31.37	3.8	35	19.2	42
35.1	0.26	0.26						
82.8	0.58	0.58						
23.3	0.45	0.45						
61.5	1.77	1.77						

Emission Index	GasContent	DAF Gas Cont.	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
67.9	2.23	2.23						
52.8	1.40	1.90	21.01	30.18	3.6	25.5	21.4	49.5
22.5	0.53	0.61	26.24	32.89	4.9	13	27	55.1
15.2	0.30	0.30						
77.6	0.77	0.97	24.94	29.02	4.1	19.4	22.2	54.3
	0.08	0.08						
29.1	0.76	0.76						
	0.07	0.07						
	0.23	0.23						
24.2	0.13	0.17	22.29	30.93	4.7	23.2	22.3	49.8
56.2	1.57	1.92	24.69	30.52	4.2	17.5	23.9	54.4
12.8	0.25	0.30	25.10	30.97	3.9	17	24.5	54.6
18.0	0.13	0.16	24.63	32.11	3.7	20	24.5	51.8
15.2	0.32	0.32						
55.9	0.76	0.98	23.48	29.80	4.1	21.4	22.2	52.3
49.4	0.84	0.84						
30.7	0.90	1.10	25.26	31.29	4.2	17.5	24.5	53.8
19.3	0.45	0.66	20.21	31.06	3.7	30.3	20.5	45.5
8.7	0.33	0.41	24.94	31.32	3.8	18.3	24.4	53.5
33.0	0.41	0.41						
20.5	0.84	1.00	25.79	29.43	4.2	15.6	23.6	56.6
33.0	0.91	1.12	25.05	35.52	4.7	17.6	27.6	50.1
14.8	0.15	0.21	20.71	31.49	2.7	28.7	21.6	47
27.6	0.61	0.75	24.75	31.15	4	18	24.3	53.7
34.5	1.07	1.40	23.11	31.97	3.5	23	23.5	50
11.4	1.09	1.51	21.64	32.18	3.9	26.5	22.4	47.2
	0.32	0.43	22.03	27.14	3.8	25.1	19.3	51.8
10.0	0.43	0.51	25.89	31.77	3.7	15.4	25.7	55.2
28.9	0.77	1.12	20.72	37.65	3.4	30.2	25	41.4

	Emission Index	GasContent	DAF Gas Cont.	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	11.1	1.18	1.50	23.34	27.13	4.2	20.6	20.4	54.8
	54.2	1.56	1.87	24.98	29.36	4.7	15.6	23.4	56.3
	4.5	0.13	0.17	23.00	27.49	4.2	20.5	20.7	54.6
	33.3	0.29	0.29						
	3.1	0.15	0.22	19.66	39.51	3.6	31.6	25.6	39.2
	24.0	0.38	0.53	21.74	35.01	3.4	27.2	24.3	45.1
				22.86	30.81	3.9	23.4	22.4	50.3
	38.7	0.07	0.10	25.82	37.75	4.3	31.6	24.2	39.9
	11.3	0.05	0.08	17.25	41.88	2.8	39.9	24	33.3
		1.39	1.81	22.70	29.99	4	22.3	22.1	51.6
	4.3			21.94	31.04	4.1	26	21.7	48.2
	49.5	1.46	1.70	26.73	29.25	4.3	13.3	24.1	58.3
MIN	**2.0**	**0.05**	**0.07**	**14.91**	**27.13**	**2.7**	**13**	**18.4**	**33.2**
MAX	**82.8**	**2.25**	**2.80**	**26.73**	**41.88**	**5.5**	**45.3**	**28.1**	**58.3**
AVERAGE	**34.8**	**0.85**	**1.01**	**22.93**	**32.04**	**4.0**	**23.4**	**23.2**	**49.4**
STDEV	**19.8**	**0.59**	**0.71**	**2.48**	**3.24**	**0.5**	**7.0**	**2.3**	**5.9**

Table B26: Middelbult

MIDDELBULT

			AIR DRY			
GasContent	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
1.10						
1.16						
2.03						
2.04						
1.07	23.9	32.24	5.7	18.3	24.5	51.5
1.12	26.2	31.84	3.9	16	25.5	54.6
1.98	26.39	27.18	5	12.6	22.4	60
1.97						
0.73	22.43	30.17	5.7	22.7	21.6	50
0.94	21.42	29.64	5.9	24.6	20.6	48.9
1.92						
1.29	25.15	34.3	5.8	14.6	27.3	52.3
1.18	24.19	35.94	5.7	17.5	27.6	49.2
0.96	24.71	33.5	5.5	16.6	26.1	51.8
1.37						
1.37	22.17	27.13	4.9	23.6	19.4	52.1
1.64	25.05	31.73	4.9	16.3	25	53.8
1.65	24.23	30.18	4.6	18.2	23.3	53.9
1.06						
0.70	24.73	31.31	5	16.1	24.7	54.2
0.23	13.36	34.97	3.5	47.6	17.1	31.8
0.85						
1.94						
1.16	24.09	34.05	4.7	20.4	25.5	49.4
0.51		42.09	2.7	63.8	14.1	19.4
1.51						
0.65	24.37	31.23	3.9	17	24.7	54.4
0.59	23.55	33.07	3	22.3	24.7	50
0.58	26.01	30.4	4.1	14	24.9	57

Gas Content	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
0.40						
	22.31	29.42	4	18.5	22.8	54.7
0.55						
2.24	25.24	33.33	4.9	15.3	26.6	53.2
1.23						
0.68	22.49	30.72	3.8	22.3	22.7	51.2
0.49	19.68	30.41	3.8	31.1	19.8	45.3
0.29	21.67	28.17	4.3	24.7	20	51
0.44						
	15.33	35.2	2.5	45.8	18.2	33.5
0.17						
0.23	15.92	31.44	3	42.3	17.2	37.5
0.91	25.05	35.16	3.2	16.3	28.3	52.2
1.29	25.4	34.01	3.9	12.3	28.5	55.3
0.24						
0.59	25.74	29.9	4.2	14.2	24.4	57.2
0.17						
0.85	22.58	31.38	5.1	21.6	23	50.3
0.57	20.02	32.29	4.4	28.4	21.7	45.5
0.12						
1.07	20.27	29.96	3.6	26.3	21	49.1
0.89	25.35	33.08	3.7	16.2	26.5	53.6
0.11	24.65	27.47	4.7	16.3	21.7	57.3
0.88	24.4	31.15	4.2	16.5	24.7	54.6
1.16						
0.20	24.53	63.13	38	20.5	26.2	15.3
1.55						
2.58	25.85	35.13	4.6	15.7	28	51.7
0.81	22.13	28.15	4.2	24.4	20.1	51.3
1.90						
1.65	22.98	29.46	4	16.9	23.3	55.8

Gas Content	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
0.13	17.89	31.86	3.4	37.9	18.7	40
1.54						
0.77	16.67	30.66	2.1	41.8	17.2	38.9
0.57	18.7	29.92	4.2	32.3	19	44.5
0.39						
0.21	23.87	27.92	4.4	19.3	21.3	55
1.07	27.31	36.85	5.1	10.5	31.1	53.3
0.35						
2.04						
1.75						
0.48						
0.32	17.38	29.85	4.4	35.3	18	42.3
0.53						
0.44						
0.48						
1.22						
0.53	22.9	32.2	4	21.2	24.1	50.7
0.67						
0.92						
0.24	24.0	29.0	4.8	18.7	22.2	54.3
0.65						
1.28						
0.65	24.2	29.7	4.8	18.5	22.8	53.9
0.90						
0.06						
1.22						
0.53	22.9	32.2	4	21.2	24.1	50.7
0.67						
0.92						
0.24	24.0	29.0	4.8	18.7	22.2	54.3

	Gas Content	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	0.65						
	1.28						
	0.65	24.2	29.7	4.8	18.5	22.8	53.9
	0.90						
	0.06						
MIN	**0.06**	**13.4**	**27.1**	**2.1**	**10.5**	**14.1**	**15.3**
MAX	**2.58**	**27.3**	**63.1**	**38**	**63.8**	**31.1**	**60**
AVE	**0.91**	**22.8**	**32.2**	**5.0**	**22.8**	**22.9**	**49.2**
STDEV	**0.58**	**3.1**	**5.3**	**4.8**	**10.5**	**3.5**	**8.8**

TableB27 : New Denmark samples

	Gas Content	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	1.89						
	1.85						
	1.13	22.6	34.2	4.3	24.7	24.3	46.7
	1.40	21.7	29.0	4.6	25.7	20.2	49.5
	1.11	22.0	35.7	3.4	25.5	25.4	45.7
	0.46	22.4	33.5	3.2	25.1	24	47.7
	1.06	21.9	31.2	3.2	26.2	22	48.6
		24.9	29.8	4.4	17	23.4	55.2
MIN	**0.46**	**21.7**	**29.0**	**3.2**	**17**	**20.2**	**45.7**
MAX	**1.89**	**24.9**	**35.7**	**4.6**	**26.2**	**25.4**	**55.2**
AVERAGE	**1.27**	**22.6**	**32.2**	**3.9**	**24.0**	**23.2**	**48.9**
STDEV	**0.50**	**1.2**	**2.7**	**0.7**	**3.5**	**1.9**	**3.4**

Table B28 : Forzando samples

					AIR DRY			
	Emission Index	Gas Content	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	47.1	0.23	22.6	36.2	1.5	29.5	25	44
	46.0	0.40	22.2	34.1	3.6	23.7	24.8	47.9
	2.6	0.93	24.5	16.4	2.3	25.9	11.8	60
	5.8	0.12	20.5	40.9	2.2	32.1	26.9	38.8
	17.5	0.09	23.6	41.2	3.9	24.5	29.5	42.1
	61.3	0.16	17.4	32.8	2.6	40.7	18.6	38.1
	14.7	0.21	25.9	39.6	3.8	16.3	31.6	48.3
		0.06	24.3	40.3	3.8	20.1	30.7	45.4
	19.6	0.28	22.6	40.8	3.4	26.3	28.7	41.6
MIN	**2.6**	**0.06**	**17.4**	**16.4**	**1.5**	**16.3**	**11.8**	**38.1**
MAX	**61.3**	**0.93**	**25.9**	**41.2**	**3.9**	**40.7**	**31.6**	**60.0**
AVE	**26.8**	**0.28**	**22.6**	**35.8**	**3.0**	**26.6**	**25.3**	**45.1**
STDEV	**21.7**	**0.27**	**2.5**	**7.9**	**0.9**	**7.1**	**6.4**	**6.6**

TableB29 : sigma samples

						AIR DRIED BASIS			
	Emission Index	Gas Content	Mining Height	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	9.9	0.13	4	15.5	32.0	5.3	39.1	17.8	37.8
	19.6	0.26	4	12.7	33.2	5.3	46.8	15.9	32
	9.9	0.29	4	18.6	34.4	6.1	31.3	21.5	41.1
	9.0	0.19	4	20.2	33.3	7.3	25.8	22.3	44.6
	14.4	0.27	1						
	140.3	0.34	1						
	7.1	1.36	4						
	15.6	2.16	4						
	23.5	1.35	4						
	15.0	1.74	4						
			3	14.6	35.8	4.4	43.1	18.8	33.7
			3	17.1	36.5	4.9	35.7	21.7	37.7
			3	13.7	35.8	4.4	44.8	18.2	32.6
	27.0	0.13	3	23.3	31.1	3.6	20.3	23.7	52.4
	65.4	0.44	3						
		0.05	3	19.4	31.7	2.8	31.6	20.8	44.8
	14.3		3	17.8	32.3	2.7	35.4	20	41.9
MIN	**7.1**	**0.05**	**1**	**12.7**	**31.1**	**2.7**	**20.3**	**15.9**	**32**
MAX	**140.3**	**2.16**	**4**	**23.3**	**36.5**	**7.3**	**46.8**	**23.7**	**52.4**
AVE	**28.5**	**0.67**	**3.2**	**17.3**	**33.6**	**4.7**	**35.4**	**20.1**	**39.9**
STDEV	**36.8**	**0.72**	**1.0**	**3.3**	**1.9**	**1.4**	**8.5**	**2.4**	**6.4**

Table B30 : Springlake samples

	Emission Index	Gas Content	Mining Height	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
		0.08	2						
	6.3	2.01	2						
		1.70	2						
	49.9	5.04	2	31.2	7.6	1.3	9.9	6.7	82.1
	7.8	2.55	2	18.2	10.5	1.3	41.5	6	51.2
MIN	**6.3**	**0.08**	**2**	**18.2**	**7.6**	**1.3**	**9.9**	**6**	**51.2**
MAX	**49.9**	**5.04**	**2**	**31.2**	**10.5**	**1.3**	**41.5**	**6.7**	**82.1**
AVE	**21.3**	**2.28**	**2**	**24.7**	**9.0**	**1.3**	**25.7**	**6.4**	**66.7**

Table B31 Maloma samples

					AIR DRY			
	Emission Index	Gas Content	CV	DAFVols	Moisture	Ash	Volatiles	Fixed Carbon
	8.7	5.89	31.2	6.5	1.8	10.8	5.7	81.7
	7.6	4.29	27.3	6.5	2.2	18.1	5.2	74.5
	8.1	4.61	22.5	6.9	1.8	28.6	4.8	64.8
MIN	**7.6**	**4.29**	**22.5**	**6.5**	**1.8**	**10.8**	**4.8**	**64.8**
MAX	**8.7**	**5.89**	**31.2**	**6.9**	**2.2**	**28.6**	**5.7**	**81.7**
AVE	**8.1**	**4.93**	**27.0**	**6.6**	**1.9**	**19.2**	**5.2**	**73.7**
STDEV	**0.6**	**0.85**	**4.3**	**0.2**	**0.2**	**8.9**	**0.5**	**8.5**