Characterization of the coal resources of South Africa

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Synopsis

Estimates for South Africa's coal recoverable reserves made in 1999 range from nine to 59 billion tons; latest estimates by the Minerals Bureau suggest that 33 billion tons is a more likely figure. As much as 70% of that coal is located in the Waterberg, Witbank, and Highveld coalfields, as well as lesser amounts in the Ermelo, Free State and Springbok Flats coalfields. However, the Witbank and Highveld coalfields are approaching exhaustion (estimated 9 billion tons of recoverable coal remaining in each), while the coal quality or mining conditions in the Waterberg, Free State and Springbok Flats coalfields are significant barriers to immediate, conventional exploitation. New extraction technologies, technologies exploiting the energy content of the coal *in situ*, as well as suitable uses and markets for low-grade, high-ash coal are required before the country can utilize its admittedly vast coal resources.

Major challenges for exploiting some Limpopo province coalfields are severe water shortages, insufficiently developed infrastructure, fragile environments and poor roof conditions due to the depth and complex geology. In the Central Basin (Witbank, Highveld and Ermelo coalfields) technical innovations for thin seam extraction, economic mining of both pillar coal and intrusion-fragmented resource blocks and the utilization of lower-grade coals are required. The success of the fluidized bed combustion technology is necessary to utilize the low-grade coals of the Free State and Molteno coalfields, while environmental exemption for past problems, together with strategies for mining small, disjointed thin-seam resource blocks, is required in KwaZulu-Natal. Clean coal technologies, coal cost and quality, environmental considerations, sustainable development, the growth of the South African economy and Government's regulation of the electricity industry are the main challenges to the continued use of coal as South Africa's primary energy source.

Introduction

Coal currently provides 73% of South Africa's primary energy; 95% of the country's electricity is coal-fired thermal generation, while Sasol's coal conversion technology provides half South Africa's liquid fuels requirement. Although natural gas, renewable energy sources and nuclear energy are forecast to increasingly contribute to the primary energy supply, coal will remain our major energy source into the foreseeable future, due to its relative abundance and low cost.

Geology and coal quality of the South African coalfields

Coal is found in South Africa in 19 coalfields (Figure 1), located mainly in KwaZulu-Natal, Mpumalanga, Limpopo, and the Free State, with lesser amounts in Gauteng, the North West Province and the Eastern Cape. Table I summarizes pertinent geological information about the coal seams in each of the 19 coalfields, while Table II contains coal quality information.

South African coal resources and reserves

The main coal mining areas are presently in the Witbank-Middelburg, Ermelo and Standerton-Secunda areas of Mpumalanga, around Sasolburg-Vereeniging in the Free State/Gauteng and in northwestern KwaZulu-Natal where smaller operations are found. Single, although large, collieries are found near Ellisras and Tshipise. The coal resource and reserve estimates vary widely (Table III). In 1983 F.S.J. de Jager[15] estimated the reserves at 58.4 billion tons; J.H. Bredell[16] reassessed them in 1987 to 55.3 billion tons and X.M. Prevost[14] of the Minerals Bureau downgraded the reserves again to 39.1 billion tons in 2000. The latest Minerals Bureau estimate sets the reserves at 33.8 billion tons, considered to last until around 2050 (Prevost[17]). Bredell[16] defined coal reserves as referring 'only to that portion of the total coal resources of which the nature and distribution have been fairly well established and which is at present economically recoverable or borders on economic recoverability'. Since each value of the reserves was estimated under a different set of circumstances, using different criteria (e.g. depth,

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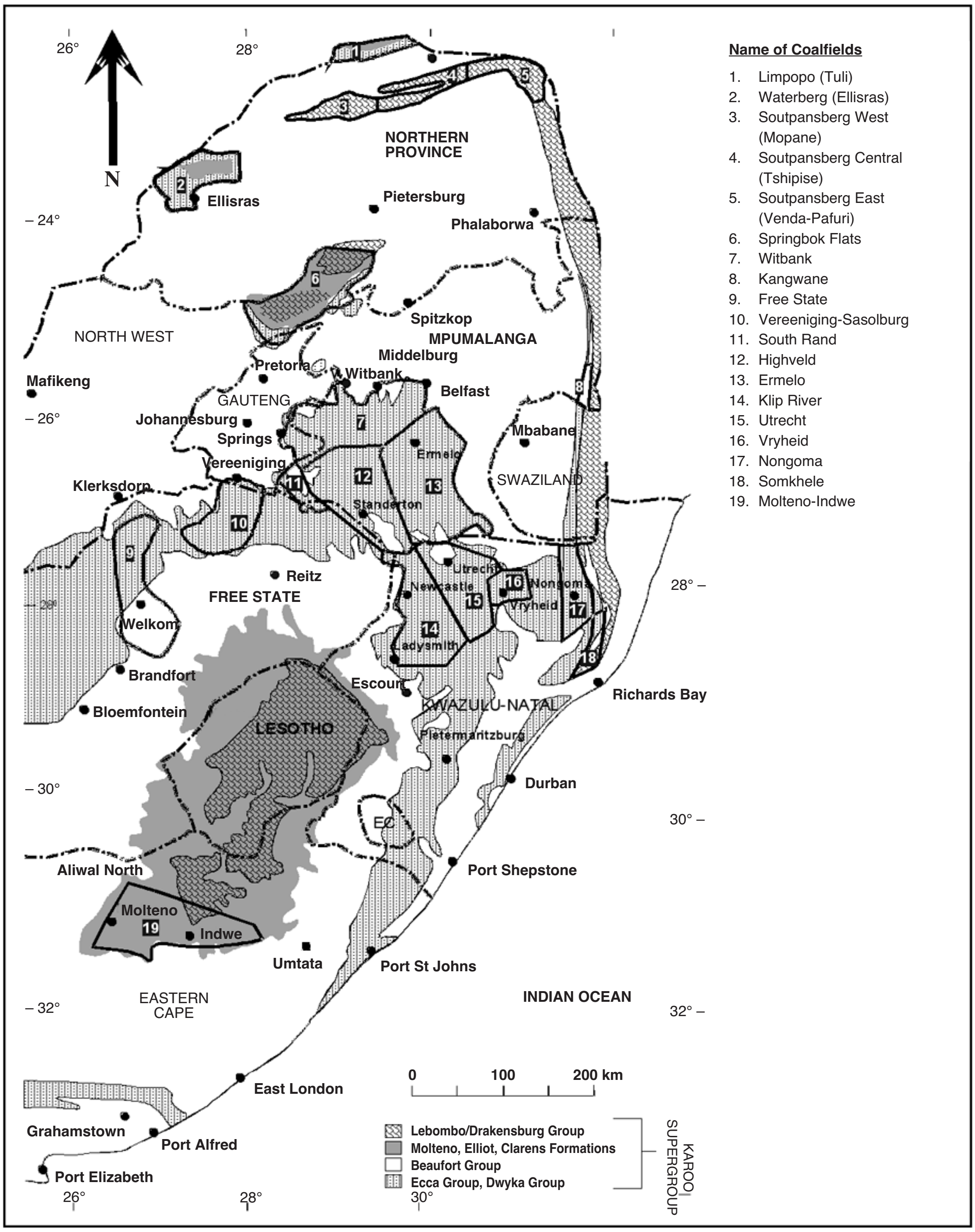

Figure 1—Coalfields of South Africa

seam thickness and grade cut-offs), different classification systems and at different times with different sets of economic constraints, the variation in the estimates is explicable. Also of important consideration is the distribution and quality of these reserves, the technologies that are being used and that could be used in the future to exploit them, and the alternative resources that could act as viable economic replacements.

The total remaining recoverable reserves are estimated at 51 billion tons (Table IV). This current distribution of the remaining reserves among various coalfields is based on Bredell[16] data, which is the most recent evaluation done on South Africa's coal reserves and takes into account the amount of coal mined since the estimate was done. Considering the 290 Mt run-of-mine (ROM) production for 2001 (Prevost[14]) will further reduce the estimated reserves. From Table IV, it is evident that the Waterberg, Highveld and the Witbank coalfields contain above 70% of the total reserves.

The Witbank Coalfield is nearing depletion and additional sources for coal supply must soon be identified if the coal industry is to continue into the 21st century. The Waterberg Coalfield is a likely replacement of the Witbank Coalfield, simply because it has the potential to contain the vast majority of the country's remaining *in situ* virgin coal resources. The Highveld Coalfield reserves are important to the long-term life of Sasol's Sasol Synthetic Fuels (SSF) and Sasol Chemical Industries (SCI), which requires 40 million tons a year. It is likely that production will continue for a considerable number of years.

Table I

Geology of the South African coalfields

Coalfield	Depth	Geology
Limpopo (Tuli)	200 m	Synclinal folded basin **Vryheid Fm**: Top (Upper) and Bottom (Lower/Basal) Seams; flat lying (2° dip north & northwest); several large dykes No current exploitation (environmentally sensitive, remote); only South Central Sector prospected - majority of mineable *in situ* resources; extensive roof support needed—interlaminated mudstones, thin coal bands, siltstones, carbonaceous shales (Ortlepp[1]).
Waterberg (Ellisras)	15–> 400 m	Fault-bounded graben-type basin **Vryheid Fm**: 55 m thick; allochthonous, multiple seam deposit type; 4 coal zones, 5 seams (1.5–9.0 m thick), lateral quality variations; steam coal feedstock
		Grootegeluk Fm: 60 m thick; autochthonous, thick interbedded seam deposit type (carbonaceous mudstones interbedded with thin coal seams); 7 coal zones, multiple seams; lateral quality consistent although coking coal yield varies widely; produces greatest % ROM coal
Soutpansberg: Mopane (W); Tshipise; Venda-Pafuri (E)	> 100 m	**Mopane (shallow) and Tshipise (deep)**: coal poorly, inconsistently developed; no economic potential defined (De Jager[2]). Faulting common—resulting in small fault bounded resource blocks. Dolerite dykes and sills also common. **Venda-Pafuri:** thick interbedded seam deposit type; **No. 1 Seam** (0.55 m); **No. 2 Seam** (6.00 m)
Springbok Flats	0–> 1000 m	**Vryheid Fm**: Lower coal zone; poor lateral development **Volksrust Fm**: Upper coal zone; laterally persistent; 5–8 m thick (max. = 12 m); **Lower, Middle** (2–4 m), **Upper** (0.8–1.2 m) **Seams**; zone of potential economic interest; the majority of coal west of Warmbad-Pienaarsrivier devolatilized by dolerite intrusions. Uranium-mineralized zone (1 m thick) in the upper part of the Upper coal zone and immediate roof strata; significant mineralization of entire coal zone near pre-Karoo inliers. U_3O_8: 0.2–0.7 kg/ton (Christie[3]).
Witbank		**Volksrust Fm: No. 1 Seam** (0–3 m, patchily developed due to Pre-Karoo topography), **No. 2 Seam** (4.5–20 m, up to 6 quality zones, most economically important for export steam coal), **No. 3 Seam** (0.5 m, high quality, generally uneconomic), **No. 4 Seam** (2.5–6.5 m, commonly split into **Nos 4 A, 4 Upper, 4 Lower Seams** by mudstone/siltstone partings, economically important but lower quality than No. 2 Seam), **No. 5 Seam** (0–2 m, erosional remnants)
		Seams are flat lying to gently undulating; sills (15–50 m) transgress seams; dykes (0–1 m) common (trends east, northeast, north); most prominent dyke: Ogies dyke (15 m thick, 100 km long and strikes east-west) Transgressive sills caused tilting and displacement of seams—mining blocks at different elevations, causing major problems with mining (Smith and Whittaker[4]). The degree and extent of coal burning associated with intrusions poses a serious problem to mining and to resource estimation (Smith and Whittaker[4]).
Free State		The coal zone (50 m thinning north) divided into **Top and Bottom/Upper and Lower Seams** in north, additional **Middle and Dwyka Seams** in south. Seams interlaminated with sandstone/mudstone—predominantly dull coal with high ash content. **Bottom Seam** (widely distributed, 2.5–8 m, dull, banded coal. **Top Seam** (patchy, < 2 m). Dolerite sills (max. thickness = 150 m) common throughout the coalfield, resulting in major displacements (Gilligan[5]), rendering 40–50 % of the coal resources in this coalfield unmineable (Snyman[6] and Barker[7]).
Vereeniging-Sasolburg	25–> 250 m	Southern extension of South Rand Coalfield; subdivided into Sigma, Cornelia and Coalbrook basins. Sigma & Coalbrook basins: **No. 1 Seam** (0–5 m, sometimes split into **Nos 1A, 1B and IC** by sandstone partings), **No. 2 Seam** (split into **Nos 2A and 2B**—each up to 8m thick - by 1.5 m mudstone parting) and 3 (well developed, 0–5 m) Cornelia basin: **Bottom, Middle** and **Top Unit** Two sills transgress the seams in the Sigma Basin; numerous dolerite dykes, especially in the south; east-west striking graben, displacement 70 m in the west and 5 m in the east of Cornelia Basin.
South Rand		One main coal zone (1 m seam—20 m composite seam split by sandstone, shale and conglomerate partings). **No. 1 Seam** (> 3 m, dull lustrous coal), **No. 2 or Main Seam** (2–20 m, correlated with No. 4 Seam in Witbank/Highveld Coalfields), **No. 3 Seam** (2–11 m), **Ryder Seam** (2.5 m, irregularly developed). Major east-west trending faults (displacements up to 35 m); numerous dykes (0.1–10 m) and sills of variable orientation devolatilized the coal, most of the central part overlain by a 100 m dolerite sill. (Henderson[8] and Snyman[6]).
Highveld	0–300 m	**Vryheid Fm: No. 1 Seam** (thin, mainly discontinuous), **No. 2 Seam** (1.5–4 m on av., irregular shale partings 0.1–1.0 m thick, no zoning as per Witbank Coalfield), **No. 3 Seam** (thin, discontinuous, poor quality), **No. 4 Seam** (1–12 m, laterally continuous, most economically important, 2–15 m sandstone parting separates **No. 4 Upper Seam** (1–4 m) from **No. 4 Lower Seam** (4–12 m); thin, discontinuous **No. 4A Seam** occurs above No. 4 Upper in places), **No. 5 Seam** (1–2 m) East-west graben—downthrow of 22 m; transgressive or conformable sills (up to 80 m thick) resulted in faulting and tilting of the coal. Dykes (1–4 m) ubiquitous (major direction east-west; minor north-south, north-east), resulting in destruction and burning of the seams; poor roof and groundwater conditions due to dykes
Ermelo	0–100 m	**Vryheid Fm: E Seam** (0–3 m), **D Seam** (0.6 m), **C Lower Seam** (1.5 m, sandstone partings in upper section), **C Upper Seam** (well developed, 0.7–4 m, sandstone, siltstone or mudstone partings split seam into 2–3 plies, devolatilized/ destroyed by dolerite over large areas), **B Lower Seam, B Upper Seam** (may coalesce in south, 0–3 m), A (isolated outliers, 1 m), **A Seam** (0–1.5 m, mainly removed by erosion) Dip gently southwest, minor folding; dykes (2–5 m) common, up to 8 sills (10–250 m) transgress and uplift the seams
Klip River		**Bottom Seam** (equivalent to the Gus Seam; 1.3 m in north, 0.5 m in south), **Top Seam** (equivalent to the Alfred, better developed than Bottom Seam, 3.3 m in north, 1,5 m in south) (Snyman[6]). Gentle southerly dip; 9 dolerite sills—4 major sills (Zuinguin, Utrecht, Ingogo and Talana)—have caused major displacement (up to 137 m (Bell and Spurr[10]). Dykes (northwest-southeast, northeast-southwest) common, associated with minor displacements.
Utrecht		**Vryheid Fm**: **Coking Seam** (< 1.5 m, good quality), **Dundas Seam** (2 m mixed dull, bright and shaly coal), **Gus Seam** (well developed, economically most important, 1 m in south, split by a sandstone parting in north, **Alfred Seam** (persistent, 3–4 m south of Utrecht, bright—dull-lustrous coal (Spurr[9]), **Eland Seam**. 5 major dolerite sills (Zuinguin (> 150 m), B, Utrecht, Ingogo and No. 10) with associated faulting (throws > 15 m (Barker[7]))

Table I

Geology of the South African coalfields (continued)

Coalfield	Depth	Geology
Vryheid		9 seams within the Main Coal Zone (only 4 exploited in north, 5 in central portion). **Targas Seam** (uneconomic), **Coking Seam** (< 1 m), **Dundas Seam** (well developed, split into Upper (0.15–1.2 m, usually too thin to be mined alone, coking coal) and Lower (0.1–2.5 m, 1.5–6.5 m below Upper Dundas, interbanded bright and dull coal), **Gus Seam** extensively developed, 0.5–2 m, finely interbanded bright and lustrous coal), **Fritz Seam** (< 0.5 m, bright coal), **Alfred Seam** (< 1 m), **Eland Seam**. 5 sills: concordant: Zuinguin (oldest), transgressive: Ngwibi, Matshongololo, Nyembi, Enyati; devolatilized coal; caused major displacement (up to 150 m); dykes (up to 10 m) associated with minor faulting (Bell and Spurr[11]).
Nongoma		**Vryheid and Emakwezini Fms**: preserved within graben **Emakwezini Fm: A, B, C Zones** (Umsebe Prospect); 3 very thin coal seams of inferior quality (ZAC**) V**ryheid Fm: Main Seam** (1–3 m), **B Zone** coal occurs about 35 m above the **A Zone**. Two thinner seams occur 0.7 m above and 0.3 m below the Main Seam respectively. At the Umsebe Prospect, 2 sills (17–35 m, 15–65 m, 10 - 40 m apart above the upper coal zone). 25 m thick sill transgresses the coal zones; no major devolatilization; dykes occur throughout the coalfield (Snyman[6]).
Somkhele		**Emakwezini Fm: Lower, Main** (up to 10.6 m), **Upper Seam 1** and **Upper Seam 2**, (called the A, B, C, and D Seams respectively in the northwestern portion). Dip 15–30^0 south; numerous dolerite intrusions and intense faulting—major faults striking southwest (Snyman[6]) subdivided the area into five blocks.
Molteno-Indwe		6 coal seams, 4 lower seams more persistent. **Indwe Seam** (consistently developed, composite seam of interbedded coal/shale bands, 2–6 m), **Guba Seam** (24–30 m above Indwe, but seams rarely developed together in same locality, generally less persistent, 2.8 m thinning to south & north, bright coal at base followed by alternating bands of bright/dull coal. **Cala/Cala Pass/Molteno/Piet/Upper Seam** (Christie[3]: 2 coal bands, each 0.35–0.40 m separated by carbonaceous shale 1.2 m thick, coal medium-volatile bituminous—anthracitic with high chlorine (0.15%) content (Snyman[6]). **Ulin/Gubenxa Seam** (Snyman[6]: discontinuous band consisting of thin coal lenses, coaly silt, mud, shale; developed 20 km southwest of Elliot. Faults (few km long, displacements < 50 m but throws > 300 m) have been recorded; 200 m thick sills cover 30% of the Molteno-Dordrecht-Indwe region, erosion resistant, cap the hills; north-south and east-west vertical to subvertical dykes (up to 20m).

** ZAC: Zululand Anthracite Colliery

The Sasolburg-Vereeniging Coalfield is also a supplier to SSF and SCI, as well as supplying coal to Lethabo power station. The remaining coal reserves of the Free State Coalfield are low-grade coal suitable for power generation and possible liquid fuel production, while the remaining reserves in the South Rand Coalfield are classified as low-grade bituminous coal with a CV of less than 25.5 MJ/kg (Bredell[16]). The Limpopo (Tuli) Coalfield is reported to contain between 517–349 Mt of mineable *in situ* raw bituminous coal with the potential to provide, after washing, between 243–125 Mt of metallurgical coal. South Africa currently produces less than 0.5 Mt of saleable coking coal (Spalding[19]) per annum and therefore the Limpopo (Tuli) Coalfield will remain a potentially valuable coking coal resource for the future.

Present mining and utilization

Table V shows South African coal production, consumption and export for 2003 (Spalding[20]) while Table VI summarizes the production and utilization from each coalfield.

Possibilities for and challenges to future mining and utilization

The coal currently exported from the Waterberg Coalfield as steam coal is actually a semi-soft coking coal with less than ten per cent ash content. This coal is better suited for metallurgical purposes where it could fetch higher prices, if the local steelmaking industry was large enough. Anglo Coal has been exploring for coal bed methane (CBM) since 2001 (Anglo American plc[23]), while Kumba Resources Ltd investigated this in the past. CBM may be significant for exploiting the deep central and eastern resources. Eskom's Technology Services International has been conducting research into underground gasification for a number of years. If successful, the technique could harness the coal's energy *in situ,* thereby negating the need for extensive underground development; it would be best suited to the deeper portions of the coalfield where conventional mining will be challenging; it may also be suitable for coal around Majuba Colliery in Mpumalanga. Kumba Coal has undertaken research into coal liquefaction and believes this to be a viable option for the Waterberg Coalfield. A study conducted in 1991 looked into the potential for the Waterberg coals to be used for the production of benzene, toluene and xylene (BTX). At the time, the cost of sulphur removal made the project uneconomical; however, new technologies have allowed for a cost reduction in sulphur removal and BTX production can now be viewed as a viable utilization option. According to Spicer[24], Kumba Coal and Trade and Investment Limpopo have agreed to co-fund a R500 000 follow-up project to the 1991 study.

Although the Somkhele Coalfield in KwaZulu-Natal has been dormant for sometime, the Somkhele project undertaken by AfriOre in 2002 shows great promise. It is intended that once the Somkhele project comes to production, 70% of its output will be sold locally and 30% will be exported (*Mining Review Africa*[25]). If the Somkhele project is successful, it is envisaged that the anthracite could be used as a reductant for the metallurgical industries, especially the South African based titanium, ferrochrome, ferromanganese and steel

Table II

Coal quality of the South African coalfieds

Coalfield	Coal Quality
Limpopo (Tuli)	The washed coal characteristics (Ortlepp[1]) indicate yields of 53–47% with ash values of 12–10%, volatiles of 35.5–36.5%, sulphur of ~ 1.1% and swelling indices of 8.0–8.5.
Waterberg (Ellisras)	Little information is published regarding the overall coal qualities of the Waterberg (Ellisras) Coalfield, although it is known that the coal rank increases steadily from west to east (de Jager[2]). It must be assumed that qualities observed at GCM are potentially representative of the entire coalfield.
Soutpansberg	The Soutpansberg Coalfield is known to have some hard coking coal, but little other quality information is available.
Springbok Flats	Analysis of coal qualities in the Springbok Flats Coalfield has resulted in the establishment of a well defined CV to ash relationship. The linear relationship has been found at all fractional yields (Christie[3]) and this is very useful in terms of exploration. Down-hole geophysical methods can be used to not only identify coal seams within the Coal Zone but also to determine ash and CV values for the identified seams in each borehole. Sulphur content, in raw coal, ranges from 2% to 4% and averages ±1.5% in the beneficiated product.
Witbank	In some areas of the Witbank Coalfield, the No. 1 Seam is a source of high-grade steam coal suitable for export after beneficiation (Smith and Whittaker[4] and Snyman[6]). According to Barker[7], the No. 1 Seam frequently has very low phosphorus content and in such cases it is usually mined separately as metallurgical feedstock. The No. 2 Seam contains some of the best quality coal. It generally displays a well-defined zoning with up to seven (five in some areas) distinct coal zones of different coal quality with the three basal zones being mined mainly for the production of low-ash metallurgical coal and export steam coal. The upper part of the seam is generally shaly and unmineable; selective mining takes place within the better quality lower part of the seam (Smith and Whittaker[4]). The No. 4 Seam is generally of poor quality and consists of predominantly dull to dull lustrous coal with the upper portion being of poor quality. Thus mining is restricted to the lower 3.5 m portion of the coal-seam, which is mainly used as a power station feedstock and as domestic steam coal (Smith and Whittaker[4]). The No. 5 Seam has been mined as a source of blend coking coal and for metallurgical uses especially in the central Witbank area where it is of higher quality (Smith and Whittaker[4]).
Free State	The Free State Coalfield's Bottom Seam is of low-grade steam coal with poor washing characteristics (Gilligan[5]). The Top Seam comprises lustrous coal with bright stringers and is of better quality than the Bottom Seam (Gilligan[5]).
South Rand	The South Rand's No. 2 Seam is the composed mainly of dull coal but with fairly constant coal quality throughout the seam (Henderson[8]). The Ryder Seam is generally of low quality with a CV of about 18 MJ/kg and is prone to spontaneous combustion (Henderson[8] and Snyman[6]).
Highveld	The No. 2 Seam contains low-grade bituminous coal with an ash content of 22–35% and a CV of 20–23 MJ/kg. In areas where the No. 2 Seam is of better quality and has good washability characteristics, like in Leandra, a coal product of 27 MJ/kg at yields of greater than 70% can be produced. The No. 4 Seam generally contains mainly low-grade bituminous coal with an ash content of 20–35% and a CV of 18–25 MJ/kg. However, the ash content can increase to 40% and CV can drop to 15 MJ/kg in the upper one to two metres. In areas where the seam is much thicker the ash can be as low as 21% with the CV about 23 MJ/kg in the lower three to four metres of the seam (Jordaan[12]). The No. 4 Upper Seam quality is extremely variable but the seam generally contains low-grade bituminous coal with approximately 25% ash content and a CV of 22 MJ/kg (Jordaan[12]). The No. 5 Seam has better quality coal than the other seams, with a raw *in situ* CV of > 25 MJ/kg, ash and volatile matter contents of 19% and 32% respectively. It can be a source of metallurgical coal, such as is mined at the No. 2 Mine at Kriel Colliery (Barker[7]).
Ermelo	The Ermelo Coalfield's E Seam is of reasonable quality but the economic potential of the seam decreases southwards as it becomes torbanitic and/or shaly whereas in other areas it might be too thin to be viable for mining (Greenshields[13]). The D Seam is of good quality and has no clastic partings but has a high proportion of vitrain with minor durain bands (Greenshields[13] and Snyman[6]). The C Lower Seam is the most important seam as it is the main source of export coal (Barker[7]). The C Upper Seam is generally of poorer quality, has no in-seam partings and may be torbanitic in the upper part; however, the lower part of the seam is usually of good quality making it the main target for mining. It is typically mined to supplement the C Lower (Snyman[6] and Barker[7]). The B Seams are low quality, dull coal that contains fewer vitrain bands compared with the lower portion of the C Upper Seam (Greenshields[13]).
Klip River	The Bottom Seam in the Klip River Coalfield (equivalent to the Gus Seam) is high in sulphur and phosphorus, with sulphur usually ranging from 1.3 to 1.8% (Bell and Spurr[10] and Snyman[6]). The Top Seam (corresponding to the Alfred Seam) has a smaller bright coal proportion than the Bottom Seam (Snyman[6]), but like the Bottom Seam, the rank of the Top Seam ranges from bituminous to anthracitic with generally high sulphur and phosphorus content. In general, the Klip River Coalfield contains bright coal with the rank ranging from bituminous to anthracite; in the central part of the coalfield, good coking coal has been produced in the past.
Utrecht	In the Utrecht Coalfield, the seams have been a major source of moderately good coking coal and require little beneficiation (Spurr[9]). The Lower Dundas Seam rank varies from medium volatile bituminous to anthracitic, with the coal mined as a source of bituminous coal in the northeastern sector of the coalfield and as anthracite in the southern sector. However, the sulphur content can be high—in excess of one per cent (Spurr[9]). The Gus Seam is subdivided into three coal quality zones with the upper part comprising mainly dull coal, the central part predominantly bright coal and the bottom section mainly poor quality coal with shale partings. The seam has elevated methane gas concentration (Spurr[9] and Snyman[6]). The Alfred Seam is of better quality in the Utrecht Coalfield, particularly towards the bottom portion of the seam. The seam is generally high in ash and sulphur content but beneficiation can produce relatively high quality, low ash coal with low sulphur and phosphorus (Snyman[6]).
Vryheid	In the Vryheid Coalfield of KwaZulu-Natal, the Coking Seam is high-grade bright coal with excellent coking properties at medium rank and commonly contains very low ash of between seven and eight per cent (Bell and Spurr[11]). The Lower Dundas Seam is mined as coking or steam coal in the Vryheid Coalfield (Bell and Spurr[11]). Good quality coke has been produced from the Gus Seam in the Vryheid Coalfield where it is unaffected by dolerite intrusions and high quality anthracite where the seam has been metamorphosed (Bell and Spur[11]). The Alfred Seam (Vryheid Coalfield) is of low grade with average CV of 26–27 MJ/kg, ash content of 16–35% and poor coking properties. The Fritz Seam is generally of fairly high grade but high sulphur content (Bell and Spurr[11]) and is usually mined together with other seams in opencast operations.
Nongoma	The A coal zone in the Nongoma Coalfield has a thin A1 Seam and a thicker A2 Seam with raw ash values of between 33 and 42%. Anthracite occurs in the lower A zone (Snyman[6]). The B Zone consists of four seams with raw ash values of 25%; anthracite occurs in the upper part of the B Zone. Plant-scale wash tests on the Somkhele project indicate the anthracite is of high quality with a high reactive component, low to medium ash, low phosphorus calcium oxide in the ash and low sulphur.
Molteno-Indwe	Only the Indwe, Guba and the Molteno seams in the Molteno-Indwe Coalfield have economic potential in places; however, they are mainly of poor quality. Analyses show that the Indwe and Guba seams have high ash content of 31–51% unwashed and between 26–27% when washed, high moisture content of 7–11%, low volatile matter (VM) of 7 to 12% and a CV of 23.9–25.9 MJ/kg (Prevost[14]).

Table III

Estimates of South African coal 'reserves' (Barker[7])

Year	Reported by	*In situ* (Mt)	Recoverable (Mt)
1913	Department of Mines	56 245	
1928	W.J. Wybergh	205 723	
1948	Coal Commission		11 086
1952	F.A. Venter	67 922	
1959	Mineral Resources	72 467	
1967	D.W. Bishopp		9 071
1969	W.C.J. van Rensburg *et al*.	33 879	18 881
1975	Petrick Commission	82 018	25 290
1983	F.S.J. de Jager	115 530	58 404
1986	D.A.M. Smith and R.L.G. Whittaker	115 530	58 919
1987	J.H. Bredell—Geological Survey of SA	121 218	55 333
1998	Various Sources	194 432	54 303

Table IV

Estimated remaining recoverable reserves as at the end of 2000 (*South African Coal Statistics and Marketing Manual*[18])

Coalfield	Reserves (Mt)		
	Recoverable (Bredell[16])	ROM production (1982–2000)	Remaining (2000)
Witbank	12 460	2320.23	10139.77
Highveld	10 979	972.49	10006.51
Waterberg (Ellisras)	15 487	384.00	15103.00
Vereeniging-Sasolburg	2 233	334.91	1898.09
Ermelo	4 698	101.11	4596.89
Klip River	655	85.26	569.74
Vryheid	204	81.80	122.20
Utrecht	649	64.47	584.53
South Rand	730	22.03	707.97
Somkhele & Nongoma	98	15.18	82.82
Soutpansberg	267	6.11	260.89
Kangwane	147	0.96	146.04
Free State	4 919	0.22	4918.78
Springbok Flats	1700	0	1700.00
Limpopo (Tuli)	107	0	107.00
Total	**55333**	**4388.77**	**50944.23**

Table V

South African coal production, consumption and export for 2003

Coal type	Production (Mt)	Domestic consumption (Mt)	Export (Mt)
Steam	236.490	164.867	68.934
Coking	0.445	1.780	1.329
Anthracite	1.205	0.459	1.195
Total	**238.140**	**167.106**	**71.458**

industries (Spalding[19]). Due to its low sulphur content, the product can be used as an ideal blend with AfriOre's Springlake product, resulting in the reduction of Springlake's higher sulphur content, which ranges from 1.58% to 1.74%, thereby increasing the acceptability of the product (Spalding[20]).

Primarily due to the nature and depth of the Coal Zone in the Springbok Flats Coalfield, conventional underground mining is currently not an option. About 15% (1 210 Mt) of the coal occurs within the opencastable range (0–75 m) in small resource blocks around the edges of the basin, perhaps more suitable to opencast mining by small, medium and micro enterprises. The quality of the raw coal makes it a suitable steam coal (industrial boilers, electricity generation), while a beneficiated product may be utilized in the steel industry as a (blend) coking coal; the middlings could be a feedstock for indirect liquefaction (petrochemical industry). Major challenges facing future exploitation include water supply, transport infrastructure, environmental issues and underground mining in difficult conditions at depths in excess of 250 m. Due to the presence of intra-seam clastic partings, select seam horizon mining will not be possible and the ROM material will need some form of preparation prior to utilization. A simple destoning, e.g. jig, operation might

Table VI

Production and utilization of the South African coalfields

Coalfield	Production and utilization
Limpopo (Tuli)	No current exploitation
Waterberg (Ellisras)	The Waterberg coals are used for steelmaking (coal for the Corex process at Saldanha Steel and coking coal for Iscor's Vanderbyl Steelworks) and power generation (Eskom's Matimba power station). Some coal is exported via the Matola terminal in Mozambique for steam generation in order to make the extraction of the steelmaking coals viable. GCM* only mine (50 Mtpa ROM), CBM exploration; several techno-economic challenges to further development.
Soutpansberg	Only one operation currently exploits the resources in the Soutpansberg Coalfield—Tshikondeni Colliery—producing hard coking coal. Due to the limited exploration data available in public domain publications, one must assume that the entire Soutpansberg Coalfield contains coals that are suitable, after beneficiation, as coking coals for the metallurgical and steelmaking industries. Tshikondeni Colliery only mine (380 ktpa hard coking coal).
Springbok Flats	No current exploitation
Witbank	The majority of the coal is mined in the Witbank Coalfield; of the 71 operating collieries in South Africa at the end of 2001, 39 (55%) of these were located in the Witbank Coalfield. In 2001, the coalfield accounted for 155.132 Mt (about 52.49%) of the total 295.546 Mt ROM production (SACSMM[18]). The Witbank Coalfield seams have diverse characteristics, resulting in a range of potential markets/utilization in the power generation, export, domestic, metallurgical, liquefaction and chemical sectors. The No. 2 seam is a critical source of high-yield export quality steam coal while the No. 5 seam is the source of metallurgical coal for the local steel industry (Bell[21]). The lower grade coals are consumed domestically by Eskom for power generation.
Free State	New Vaal Colliery only operating mine
Vereeniging-Sasolburg	The operating collieries within the Sasolburg-Vereeniging Coalfield are the Sigma Colliery, incorporating the Wonderwater Strip Mine, in the Sigma Basin and the New Vaal Colliery situated in the northern portion of the Cornelia Basin. Only the No. 2B and No. 3 coal-seams are mined at Wonderwater Strip Mine with the soft overburden material removed by truck and shovel operations one cut ahead of mining and battered back to within the natural angle of repose. The increasing difficulty in underground mining conditions and increasing production costs have resulted in investigations to open a new strip mine section (Sigma North-West) to supplement and to later replace the production from the underground section of the Sigma Colliery. The winding down of operations at Sigma Colliery is planned to begin in 2004 and to coincide with the build-up of natural gas supplies to SCI from Mozambique (*Mining Review Africa*[22]). As with all the coal produced by Sasol Mining, the coal from Sigma Colliery is supplied to SSF and SCI. New Vaal Colliery is a dedicated supplier of coal to Eskom's Lethabo Power Station.
South Rand	No operating mines
Highveld	The Highveld Coalfield is the next most productive coalfield with ten operating collieries. In 2001, it accounted for about 73.65 million tons (24.92 %) of the total ROM production (SACSMM[18]). Mining was largely initiated by the development of the coal-fired Kriel and Matla power stations with collieries established to feed these power stations. Since then, the five Sasol mines around the Secunda area were developed. All the Sasol mines are dedicated coal suppliers to the SSF and SCI where the coal is used as a feedstock in the production of liquid fuels and chemicals (SACSMM[18]). The coal produced at Forzando and Dorstfontein Collieries is exported, whereas New Denmark Colliery is a dedicated supplier of coal to Eskom's Tutuka power station.
Ermelo	In 2002 there were ten operating collieries in the Ermelo Coalfield, most of which are small to medium sized. Mining in this coalfield has been dormant for some time with most mines closed with reserves. Of the total saleable production of 222.551 Mt in 2001, the Ermelo Coalfield contributed about 7.2 million tons. Most of the high-grade steam coal produced by Xstrata Coal SA in the Ermelo Coalfield is destined for export. In the past, the now closed Ermelo Mines and Usutu Colliery supplied Eskom's Camden power station, with defunct Majuba Colliery supplying the Majuba power station. Camden is being brought back on-stream by the end of 2004 and will be supplied by a black empowerment consortium operating Golang Colliery, incorporating Golfview Colliery and the former Usutu Colliery.
Klip River Utrecht Vryheid Nongoma	There has been a substantial decline in coal-mining in KwaZulu-Natal over recent years, with the closing of major collieries within the coalfields. Ten collieries are currently operational—four each in the Klip River and Vryheid coalfields, and a single operation in each of the Utrecht and Nongoma coalfields (SACSMM[18]). The KwaZulu-Natal coalfields are the major producers of high quality anthracite in the country. The Welgedacht Colliery produces only bituminous coal with some collieries in the Vryheid Coalfield producing coking coal. The total saleable anthracite production for 2001 amounted to 2.56 Mt; around 80% of it came from the KwaZulu-Natal coalfields while 4% came from Nkomati Anthracite in the Kangwane Coalfield and 8% from small ad-hoc exporters (SACSMM[18]). Before the opening of Grootegeluk (GCM) and Tshikondeni Coal Mines, the KwaZulu-Natal coalfields were the only source of high-grade coking coal for Iscor. The coalfields are still set to remain the country's major source of anthracite, bituminous and high quality metallurgical coal for local industry (Barker[7]). Other major coal users in the area are the pulp, paper and textile industry. Gus Seam mined in all major collieries within the Vryheid Coalfield. The Alfred Seam has not been extensively mined but has been worked in opencast operation (Bell and Spurr[11]).
Somkhele	Main Seam economic, has been exploited in the past. Further development probable in near future.
Molteno-Indwe	No current exploitation; minor exploitation in the past; plans for future development.

* GCM: Grootegeluk Coal Mine

suffice to produce a steam coal feedstock. The coals are, however, amenable to significant upgrading through dense-medium beneficiation methods, although the yields are expected to be around 50% on ROM for a product floated at a relative density of ± 1.65 (de Jager[2]). This beneficiated product, with high vitrinite content, is suitable for a number of end uses including feedstock for direct liquefaction, blend-coking and coking coal. The middlings produced through beneficiation make a product suitable for steam raising, direct reduction furnace feedstock and indirect liquefaction feedstock.

Coal from the Limpopo (Tuli) Coalfield has never been utilized in any application except during bulk testing, carried out by Anglo American during 1970 when a prospecting shaft was sunk (Ortlepp[1]). The results from these tests indicate that the quality of the washed product is high and there is potential for this washed coal to be a good blend coking coal (Ortlepp[1]). Currently there are no mining operations in the South Rand Coalfield, although the now defunct Springfield Colliery was located in this coalfield. The coal is of poor quality and has high ash content. In most cases the coal seams are too thick to currently mine economically with underground methods but are too deep for opencast mining (Barker[7]). In the past, the Molteno Coalfield produced coal to supply the energy needs of the diamond mines around Kimberley. Coal production started around 1877 and peaked at 175 ktpa between 1900 and 1904. However, production declined, falling to 7.5 ktpa by 1917, once better quality coals were discovered in Mpumalanga and KwaZulu-Natal. The coalfield has been dormant since then and the last official recorded production was in 1948. Currently, there is no coal production within the Molteno Coalfield, although there is again interest in exploiting the coalfield. Poor coal quality and the long distance from industrial and commercial centres have hindered any recent formal exploitation of the coal in this coalfield (Prevost[14]).

Summary

In summary, South Africa has large, although not unlimited, amounts of coal. The Witbank and Highveld coalfields are approaching exhaustion (estimated 9 billion tons of recoverable coal remaining in each), while the coal quality or mining conditions in the Waterberg, Free State and Springbok Flats coalfields are significant barriers to immediate, conventional exploitation. New extraction technologies, technologies exploiting the energy content of the coal *in situ*, as well as suitable uses and markets for low-grade, high-ash coal are required before the country can utilize its admittedly vast coal resources. Major challenges for exploiting some Limpopo province coalfields are severe water shortages, insufficiently developed infrastructure, fragile environments and poor roof conditions due to the depth and complex geology. In the Central Basin (Witbank, Highveld and Ermelo coalfields) technical innovations for thin-seam extraction, economic mining of both pillar coal and intrusion-fragmented resource blocks and the utilization of lower grade coals are required. The success of the fluidized bed combustion technology is necessary to utilize the low-grade coals of the Free State and Molteno coalfields, while environmental exemption for past problems, together with strategies for mining small, disjointed thin-seam resource blocks, is required in KwaZulu-Natal.

Clean coal technologies, coal cost and quality, environmental considerations, sustainable development, the growth of the South African economy and Government's regulation of the electricity industry are the main challenges to the continued use of coal as South Africa's primary energy source.

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