The energy requirements of the mining and metallurgical industry in South Africa

Presidential Address

by P. R. JOCHENS*, Pr. Eng., B.Sc. (Eng.) (Wits.), M.Sc. (Eng.) (Wits.), Ph.D. (Wits.)

SYNOPSIS

South Africa depends to a considerable measure on the exploitation of mineral reserves and the processing of these minerals. One of the prime requirements for the mining and metallurgical industry to continue in this vital role is access to sufficient energy in a suitable form. Hence, four important questions are discussed:

Does South Africa have sufficient energy for the processing of its minerals and metals?

Will the cost of energy allow South Africa's minerals and metals to compete on world markets?

Can mining and metallurgical processes become more energy-efficient?

Can mining and metallurgical processes be adapted to the various forms of energy that may have to be utilized in the future?

It is concluded that about 26 per cent of the extractable reserves of coal would be required in the mining and processing of 50 per cent of South Africa's reserves of gold, platinum-group metals, copper, iron, ferrochromium, and ferromanganese. However, the reducing agents required exceed the extractable reserves but not the total estimates of mineable in situ resources of metallurgical coal and anthracitic coal. Even under the severe constraint that coal could become virtually the sole source of energy, only about three-quarters of the extractable reserves of coal would have been consumed by the year 2025.

The reasonably assured resources of uranium metal that can be recovered at less than $80 per kilogram are considerable and, at current conversion efficiencies to electricity, are equivalent to one-fifth of the extractable reserves of coal. The rate of exportation of energy in the form of U3O8 was about five times that of coal in 1978.

It is pointed out that the price of energy has a direct effect on the competitiveness of metals, and, although constituting only a small proportion of the selling price of precious metals, it represents a significant proportion of the selling price of copper and metals recovered from oxide ores.

The scope for the conservation of energy appears to be greater in the extraction and conversion of primary energy-carriers to electrical energy than in other mining or metallurgical fields.

Provided that alternative sources of energy can be converted to electrical energy, they can be applied to the mining and metallurgical industries. The decision as to which type of energy should be used in specific mining and metallurgical situations is complicated, and is likely to be subjected to closer scrutiny than in the past.

The hope is expressed that the tentative conclusions reached will give rise to more-quantitative analyses from those qualified to undertake such an exercise. Inevitably, the questions asked at the outset give rise to more questions, and the more interesting ones are posed in the context of each conclusion.

SAMEVATTING

Suid-Afrika is in 'n groot mate afhanklik van die ontginning van sy mineralreserwes en die verwerking van hierdie minerale. Een van die primêre vereistes vir die mynbou- en metallurgiese bedryf om hierdie belangrike rol te kan vervul, is die bekommernis van voldoende energie in 'n geskikte vorm. In die lig hiervan is daar vier belangrike sake wat bespreek word:

Het Suid-Afrika genoeg energie vir die verwerking van sy minerale en metale?
S al Suid-Afrika se minerale en metale in die lig van die energiekoste op die wereldmarkte kan meeding?
Kan mynbou- en metallurgiese prosesse energie meer doeltreffend gebruik?
Kan mynbou- en metallurgiese prosesse aangepas word by die verskillende vorms van energie wat moontlik in die toekoms gebruik sal moet word?

Die slotsom is dat ongeveer 26 percent van die ekstraheerbare steenkoolreserwes nodig sal wees vir die ontginning en verwerking van 50 percent van Suid-Afrika se reserwes van goud, platimumgroepmetale, koper, yster, ferrochrom en ferromangaan. Die redelosemiddels wat nodig is oorskry egter die ekstraheerbare reserwes, maar nie die totale ramings van ter plaatse ongjinbare bronne van metallurgiese steenkool en antrasietkool nie. Selfs met die ernstige belemmering dat steenkool feitlik die enigste bron van energie kan word sal daar net ongeveer drie-kwart van die ekstraheerbare steenkoolreserwes teen die jaar 2025 verbruik wees.

Die redelik versiereerde bronne van uraanmetal wat teen koste van minder as $80 per kilogram herwin kan word is aansienlik, en is met die huidige rendement van die omsetting in elektrisiteit gelyk aan een-veelde van die ekstraheerbare steenkoolreserwes. Die uitvoertempoa van energie in die vorm van U3O8 was in 1978 ongeveer vyf maal die van steenkool.

Daar word op gewys dat die prys van energie 'n direkte uitwerking op die mededingingsvermoe van metale het en hoewel dit slegs 'n klein gedeelte van die verkoopprys van edelmetale uitmaak, verteenwoordig dit 'n beduidende deel van die verkoopprys van koper en metale wat uit osikiederse herwin word.

Die geleentheid vir die behoefte van energie is blykbaar groter in die ekstraksie en omsetting van primêre energiedraeis in elektriese energie as op ander mynbou- of metallurgiese terreine.

Mits alternatiewe energiebronne in elektriese energie omgeset kan word kan hulle in die mynbou- en metallurgiese bedryf gebruik word. Die besluit oor die tipe energie om in 'n bepaalde mynbou- en metallurgiese situasie te gebruik is ingewikkeld en sal waarskynlik noukeuriger aandag as in die verlede geniet.

Die vertroue word uitgespreek dat die tentatiewe gevolgtrekkin kiks gemekaar word, sal lei tot meer kwantitatiewe ontledings beheer deur die neue wat bevoeg om sulke ontledings te doen. Die vrae wat aan die begin gestel is, lei onvermydelik tot nog vroeë en die interessante daarvan word in samehang met elke gevolgtrekking gestel.

*SDeputy President, National Institute for Metallurgy, Private Bag X3015, Randburg, 2125 Transvaal. © 1980.
Introduction

As stated repeatedly, the standard of living of all the inhabitants of South Africa depends to a considerable measure on the exploitation of mineral reserves and the processing of these minerals. The mining and metallurgical industry provides employment for about one million people, makes the country independent of almost all mineral and metal imports, provides a secure basis for future industrial development by ensuring the supply of raw materials, confers a considerable degree of strategic importance on the subcontinent, encourages growth points in underdeveloped areas, and, in constantly demanding industrial and technical equipment, assists in creating sophisticated secondary industries. As an example, revenue from mineral and metal sales currently represents about 65 per cent of all foreign exchange earned by South African exports abroad, and the contribution to the Gross Domestic Product in 1979 was about R10 000 million.¹

One of the prime requirements (apart from adequate capital and trained manpower) for the mining and metallurgical industries to continue in this vital role is access to sufficient energy in a suitable form. Hence, the following rather naive, but nevertheless important, questions should be asked:

1. Does South Africa have sufficient energy for the processing of its minerals and metals?
2. Will the cost of energy allow South Africa’s minerals and metal to compete on world markets?
3. Can mining and metallurgical processes become more energy-efficient?
4. Can mining and metallurgical processes be adapted to the various forms of energy that may have to be utilized in the future?

One could doubtless adopt several sophisticated approaches in attempting to answer any one of these questions in detail. In fact, each question deserves an intensive investigation by persons with the necessary expertise, and several organizations and committees are known to be considering various facets of the local energy situation. I do not pretend to supply quantitative answers, but merely attempt, from the non-confidential information that is available, to arrive at qualitative trends that may be found sufficiently interesting to initiate discussion and to motivate an in-depth study of the questions posed. The energy-supply industry and the mining and metallurgical industry are extremely large, technically complex, and capital-intensive, and changes cannot therefore be made rapidly. Long-term planning is indicated, which in turn directs attention to the questions posed above.

1. Does South Africa have sufficient energy for the processing of its minerals and metals?

Energy for Production of Metals

The most simplistic approach to this question would probably involve the identification of known reserves of ores, the arbitrary assumption that 50 per cent will be mined and processed locally, and a determination of the total amount of energy consumed in the production of metal commodities from 50 per cent of the reserves. The value for the total consumption of energy per unit of metal produced would have to include the sum of the energy consumed during mining, beneficiation, hydrometallurgical or pyrometallurgical processing, refining, shaping, and transportation on site, together with energy consumed in the commodities and services used during any of these activities. In Table I, I have attempted to do this for some of the metals produced in South Africa. The energy consumed per ton of metal produced can be regarded as low because only the operations associated with known consumptions of energy on site were considered. In addition, the reducing agents required for oxide ores are included in the total coal required for the processing of 50 per cent of the metal in the ore reserves.

It is appreciated that the list of minerals and metals in Table I is by no means complete. However, as the next most important consumer of electrical energy in 1978 used only half that of copper, which was the lowest consumer on the list, the list is sufficient for the purposes of this discussion. It is interesting to note that coal mining itself consumed 1 078 000 MW.h in 1978, which places it slightly ahead of the copper-mining industry in terms of annual energy consumption.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Estimated contained metal or alloy in reserves of ore</th>
<th>Estimated average consumption per ton of metal</th>
<th>Estimated coal required Mt</th>
<th>Energy* MW.h</th>
<th>Coal* t</th>
<th>As electricity†</th>
<th>As coal‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>20 000¹</td>
<td>20 000</td>
<td>112</td>
<td>0,56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platinum-group metals</td>
<td>30 646¹</td>
<td>20 000</td>
<td>171</td>
<td>0,6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>6 400 000²</td>
<td>10,6¹</td>
<td>19</td>
<td>0,8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>5 700 000 000³</td>
<td>3,7</td>
<td>1284</td>
<td>0,9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferrochromium</td>
<td>1 240 000 000⁴</td>
<td>2,7</td>
<td>907</td>
<td>0,8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferromanganese</td>
<td>1 200 000 000⁴</td>
<td>2,7</td>
<td>480</td>
<td>0,8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sub-totals</strong></td>
<td><strong>2493</strong></td>
<td></td>
<td><strong>3888</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6381</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Estimates based on available information (see text)
† 0,56 t of coal = 1 MW.h
‡ Total energy consumption is expressed in electrical units for the purpose of this calculation.

Note: The superscript numbers refer to the list of references on p. 342.
From Table I it can be seen that, in the mining and considered, the major consumers of electricity and coal would be the oxide ores of iron, chromium, and manganese. Gold and the platinum-group metals obviously have the highest consumption per unit mass. The sum of the energy and reducing agents required is equivalent to about 6381 Mt of coal. (Note that, for this calculation, it was assumed that pig iron is produced by the blast-furnace route although it is recognized that a considerable proportion of iron units are obtained by pre-reduction and electric smelting or melting routes).

This value represents about 26 per cent of the extractable reserves of coal, which were given as 24 915 Mt in the Report of the Petrick Commission6. During the decade 1970 to 1979, the proportion of coal consumed by the mining and metallurgical industry in the form of electricity and reducing agents is likely to have been close to this value of 26 per cent. Therefore, it could be reasoned that there are more than sufficient reserves of coal at present to supply the energy and the reducing agents required in the processing of 50 per cent of the metal in the ore reserves under consideration. (This reasoning does not allow for the fact that a particular quality of coal is required for reducing agents.) This simple analysis may have been regarded as adequate until the 'energy crisis' of 1973-74, but since then two new factors on the local energy scene have to be taken into consideration: the export of coal, and the proportionally greater use of coal to supply all forms of energy, particularly liquid products.

Therefore, the above qualitative analysis should be modified to include the possible effects of relatively large-scale exports and the utilization of coal as virtually the only source of energy (including liquid products) in South Africa.

**Consumption of Coal**

Recent forecasts of coal consumption in the year 2000, based on the assumptions that electricity will play an ever-increasing role and that coal will be used to obtain an ever-increasing degree of self-sufficiency in terms of liquid products, vary widely5, 6. Somewhat arbitrarily, I have abstracted from several forecasts a relatively high figure of 300 Mt for the annual consumption of coal (excluding exports). If 40 Mt of coal are exported in the year 2000 (4 a figure already predicted for the mid-1980s), the annual consumption of coal could be 340 Mt by 2000. Such a rapid expansion in the local consumption of coal (from 71 Mt in 19783 to 300 Mt in 2000) – a growth rate of 6.8 per cent per annum) and in exports may not be matched by an expansion in the consumption of energy and reducing agents by the mining and metallurgical industry. Therefore, it is possible that, within the next few decades, the proportion of the coal reserves utilized annually by the mining and metallurgical industries may be lower than that required (26 per cent) to ensure that ultimately 50 per cent of the ore reserves can be mined and processed locally if the energy supply is based solely on coal.

It has been stated repeatedly that the figure of 24 915 Mt for the extractable reserves of coal and the figure of 81 274 Mt for the in situ reserves of mineable coal have been increasing rapidly since they were published by the Petrick Commission6, and that these increases are likely to continue. This is a natural outcome of the increasing price that coal has been able to command since 1973, which leads to increased exploration, the reclassification of what were non-economic deposits, the increased recovery during mining and processing, and the use of lower-grade coals in certain applications. However, it is common knowledge that somewhat similar reasoning can be applied to the reserves of the metals under discussion; for example, the reserves of manganese ores have recently3 been revised upwards by a factor of 4.

**Coal Reserves versus Metal Reserves**

If the above approach indicates that the extractable reserves of coal may become depleted before half the reserves of metal ores can be mined and processed, one should ask whether this is likely to occur sufficiently far into the future to permit the development and large-scale introduction of alternative sources of electrical energy.

Let us undertake an exercise of this nature, focusing our attention on the years 2000 and 2025. The year 2000 (only 20 years from now) will mark the beginning of a new century and usher in the technology of the twenty-first century, whereas the year 2025 is sufficiently far in the future for extensive changes to have taken place in the supply of energy. The following assumptions are made for this exercise.

(a) The production of each metal will increase by 4 per cent per annum. (One has to assume that there will be an increase on average but not necessarily for every metal; otherwise, the contribution expected from the mining and metallurgical sectors will not be what is required with regard to foreign-exchange earnings and Gross Domestic Product.)

(b) During this period, virtually all the energy used in this country will be provided by coal.

(c) The local consumption of coal will increase annually at a constant rate from 71 Mt in 1978 to the forecast consumption of 300 Mt in 2000.

(d) There will be a growth in the consumption of energy, both to ensure an adequate long-term growth rate

---

**TABLE II**

<table>
<thead>
<tr>
<th>Metal</th>
<th>% of Metal Extracted from Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1978 to 2000</strong></td>
<td><strong>1978 to 2025</strong></td>
</tr>
<tr>
<td>Gold</td>
<td>*</td>
</tr>
<tr>
<td>Platinum-group metals</td>
<td>10</td>
</tr>
<tr>
<td>Copper</td>
<td>**</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Ferrochromium</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Ferromanganese</td>
<td>&lt;5</td>
</tr>
</tbody>
</table>

* To preserve confidentiality, the figures, rounded off to 5 units, were based on the reserves quoted in Table I, and the production rates for the base year 1973 were estimated from the installed production capacities for each metal times an assumed value for the plant utilization for each metal.

** The rate of extraction of these metals can be expected to decrease at some date prior to the dates under consideration.

---

JOURNAL OF THE SOUTH AFRICAN INSTITUTE OF MINING AND METALLURGY

SEPTEMBER 1980
in the economy, and to meet the increased energy demand as a result of the phenomenal increase in population and in per capita consumption that has been forecast.

(c) Coal exports will average 40 Mt per annum throughout the period under consideration. (All indications are that export quotas and railage facilities will enable such an amount to be exported within the next few years.)

Table II gives the proportions of the present reserves that would have been extracted at annual growth rates of 4 per cent to the year 2000 and 2025.

Because of the trend that is established between the reserve of a commodity and the rate of its exploitation at any given time, the growth rate of 4 per cent per annum for gold and copper is completely unrealistic. For example, the most recent predictions for gold are that, until 1987, the production of gold will remain relatively close to the present levels of around 700 t per annum and then fall off gradually to about 350 t at the turn of the century. In fact, at a real gold price close to that at present, the existing mines are expected to produce over 15 000 t of gold in the next 50 years. New mines can be expected to add another 5000 t.

By the year 2000 the reserves of the ores from which iron, ferrochromium, and ferromanganese are produced would have been little affected, in that less than 5 per cent of each would have been mined and processed locally. The platinum-bearing reserves would also have been relatively unaffected, in that about 10 per cent would have been mined and processed. By the year 2025, the situation would have undergone relatively little further change; that is, over three-quarters of each of the oxide ores will not have been processed locally (significant proportions may have been exported) and over half the ores containing platinum-group metals will still be in the ground.

On the previous assumptions of a growth rate in local coal consumption of 6.8 per cent from 1978 to 2000 and 4 per cent thereafter, and of an annual average coal export figure of 40 Mt, it can be calculated that the proportions of the extractable reserves (24.891 Mt) that will have been consumed will be 18 per cent by 2000 and 76 per cent by 2025. Therefore, in the context of the assumptions that were made, there should be no shortage of coal by the year 2025, and there should be adequate time to permit the development and introduction of alternative sources of energy.

Uranium Resources

At this stage, you will be justified in wondering whether I am going to consider nuclear power. Of course, I am. South Africa's reasonably assured resources of uranium metal can be recovered at less than $80 per kilogram are estimated to be 247 kt. The current conventional nuclear-power stations would be capable of generating at least about 8744 x 10^6 MW.h from such a quantity of uranium. (Depending on the load factor and on fuel cycle parameters, a conventional reactor can generate at least 30 MW.h from 1 kg of UO_2.) Therefore, if all these reasonably assured resources of uranium were utilized in conventional reactors, the electrical-energy content in the extractable reserves of coal.
far the greatest consumer of electricity. So far, all the uranium has been produced as a byproduct or co-product of gold, the production ratio in 1978 having been 6,5 kg of U₂O₅ for every kilogram of gold produced. The ratio of U₂O₅ to gold is expected to increase rapidly to 8,5 as present expansion programmes are implemented and new mines are opened. However, even at the present ratio, it can be calculated that the U₂O₅ recovered by the gold-mining industry would be capable of generating 196 MW·h for each kilogram of gold mined. Therefore, although 20 MW·h were consumed for each kilogram of gold produced, the byproduct contained the equivalent useful electrical energy of 196 MW·h. In fact, although the gold-mining industry is the largest single consumer of electrical power, it produced as a byproduct or co-product a primary energy-carrier with an energy content almost twice the energy that was required by Escom in 1978.

2. Will the cost of energy allow South Africa's minerals and metals to compete on world markets?

An attempt to provide some qualitative answers to this question requires consideration of at least two aspects: the proportion of a commodity's selling price that is attributable to the cost of the energy component, and the situation of competing countries with respect to raw materials and energy.

Table III gives estimates for 1978 of the cost of electrical energy as a proportion of the selling price of metals. It can be seen that, for gold and the platinum-group metals, the cost of electrical energy contributes about 5 per cent to the selling price. All other things being equal, a country producing gold and platinum-group metals that has electrical energy at half the South African price would have an advantage of only about 2,5 per cent. Perhaps it could be argued that even such a major advantage in electrical energy by one competitor should not significantly affect the competitiveness of the other, because the difference should be within the profit margin of either. However, the absolute price of local electrical energy does have an effect on the mining of marginal ores and on the ultimate recovery during processing. Hence, if consideration is given only to the cost of energy and the extent of reserves, South Africa should be able to retain its competitiveness on overseas markets in respect of gold and platinum-group metals. (South Africa's gold reserves are 51 per cent of the world's reserves, and its platinum reserves are 75 per cent.) At the risk of making a self-evident statement, I can say that the ore will always be processed locally, irrespective of whether the prices of foreign energy are significantly less than those pertaining locally, because the transportation costs of the ore would exceed any cost advantage provided by the energy used in the processing of the mined ore.

Energy Cost for Copper

The total energy consumption per ton of copper is high, as noted in Table I, and therefore the cost of energy as a proportion of the selling price of copper will be high. If all the energy requirements were met by electrical energy, the estimated cost of this electrical energy as a proportion of the selling price would be about 15 per cent. However, it is common practice for pulverized coal to be used to fire the reverberatory furnaces (a cost saving), but a very considerable additional cost in energy is incurred by the use of liquid fuels to power the large vehicles used in open-pit mines. The local reserves of copper are relatively small (about 2 per cent of the world's reserves) and the cost of energy is a significant proportion of the selling price. Several types of energy can be used, and careful evaluation of the lowest overall cost is essential to ensure future competitiveness.

Energy Cost for Ferro-alloys

The costs of electrical energy represent about 17 per cent of the selling price of ferrochromium and ferromanganese, and a competitor could have a very definite advantage if his energy costs were significantly lower. Even a relatively small advantage in the price of energy could affect market penetration in the over-supply situation that exists from time to time. Also, it will remain economically feasible for competitors to import ores and process them, provided that the cost of their energy is not significantly higher than that of the country from which the ore is imported. The vast reserves of ores and large reserves of energy should ensure that these important alloys continue to be exported to an increasing extent. Indeed, increased further processing of ferrochromium to stainless-steel ingots and hot-rolled bands can be visualized, which would take advantage of energy-conservation measures within a large integrated plant for the production of ferrochromium and stainless steel. If the cost of electrical energy in South Africa were to show an increase disproportionate to that of other countries, not only would the ability of the local ferro-alloy producers to compete be seriously affected, but it is not inconceivable that, when wishing to expand and to remain competitive, they would contemplate exporting the ore to countries in which they could take advantage of lower energy costs.

Energy Cost for Steel

Although by far the greatest proportion of virgin steel in South Africa is produced in blast furnaces, an increasing amount of steel is being produced in electric-smelting furnaces, and this latter steel is even more susceptible to the price of electricity than are the ferro-alloys.

This significant dependence on the price of electricity is demonstrated by the existence of rotary kilns for prereduction or metallization, which prepare the raw...
material for electric smelting or melting and so decrease the consumption of electrical energy by using coal for a portion of the energy requirements.

Cost of Electrical Energy

Therefore, the cost of electrical energy can affect to a relatively small degree the life of a precious-metal mine and the recovery of the metal mined, or can affect to a very considerable degree a producer's ability to compete in the electric-smelting industry. The record of electrical energy costs in South Africa shows that the average tariff increase from 1950 to 1975 was 4.4 per cent per annum, which compares favourably with the inflation rate. This increase was followed by increases of 30 per cent in 1976, 48 per cent in 1977, and 16.5 per cent in 1978. The quite extraordinary tariff adjustments in 1976, 1977, and 1978 reflected the necessity for this income to be used for the financing of expansion by means of the Capital Development Fund. The 1979 and 1980 tariff adjustments appear to indicate a return to Escom's traditional price stability as shown in the period before 1976. If such a trend can be maintained, it is difficult to visualize that the price of electrical energy would place South African mining and metallurgical industries in a disadvantaged position.

Those metals for which certain unit operations utilize coal directly as a primary source of energy are likely to continue to benefit from the comparatively low prices of coal; competitiveness should therefore be assured in this respect.

The effect of the rapid price increases in liquid fuels is likely to affect most producers in Western countries to a similar degree. However, their change to alternative types of primary energy-carriers may not be as flexible as in South Africa.

The sudden dramatic increase in the price of oil has had a tremendous world-wide effect on the price of the alternative primary energy-carriers, coal and uranium. It is interesting to note that the increased demand for these sources of energy has had a very beneficial effect on South Africa's foreign-exchange earnings by increasing both the quantities and the prices of coal and uranium exports. On the negative side, it can be expected that, in the long term, this new supply-and-demand situation will also affect the local prices of these sources of energy. However, the price of electrical energy is not so much a function of the cost of the primary energy-carrier (coal or uranium), but rather of the cost and amortization of the electricity-generating plant and its associated equipment. It will be interesting to see how long primary energy-carriers will be controlled by free-enterprise and supply-and-demand forces before various States initiate some form of control to ensure sufficient local supplies at favourable prices to promote other sectors of their economies.

3. Can mining and metallurgical processes become more energy-efficient?

The energy-efficiency of a mine and an extractive-metallurgical recovery plant depends on a number of factors, and a distinction has to be made between the metals that occur in very small concentrations (for example, the precious metals) and those which, although present in high concentrations, occur as compounds having high free energies of formation (for example, chromite).

Production of Gold

In 1978, the gold-and-uranium mines of the Chamber of Mines milled 78.2 Mt of rock to produce 691,4 tons of gold\textsuperscript{10}, and purchased about 15.8 million MW.h of electrical energy. This represents a consumption of about 200 kW.h per ton milled, or about 20 MW.h per kilogram of gold. It was forecast\textsuperscript{11} in 1975 that the continuing programme on the improvement of the underground-mining environment through better ventilation practices and the use of refrigeration would increase the consumption of electrical energy. The implementation of the planned long-term mechanization of underground-mining operations will further increase the consumption, as will the cooling of this machinery, which will represent an additional increase of 40 per cent. The power for pumping is not expected to increase measurably as the depth of mining increases, because the water to be pumped is fissure water originating in the upper levels, but the power required for hoisting increases at a rate faster than the increase in depth of mining.

The necessity for improved strata control as the depth of mining is increased may result in the hoisting of lower tonnages of rock (less by up to 30 per cent) if the waste rock is used to refill worked-out areas. In addition, more selective mining could decrease the tonnages of rock to be hoisted (by up to 25 per cent), and would also decrease the tonnages to be treated in the reduction works (which account for almost 20 per cent of the total energy consumed in the mining and extraction of gold\textsuperscript{12}). Little change is expected in the consumption of energy per ton treated in the reduction works, and this includes the introduction of gold-recovery processes based on the adsorption of gold on activated carbon.

It is expected that the proposed process for the concentration of gold and other valuable minerals underground, which would permit about 60 per cent of the tonnage mined to be replaced in the excavation, could effect savings in energy, although this is not the prime motivation for this novel concept\textsuperscript{13}.

Production of Platinum-group Metals

The consumption of electrical energy for the platinum-group metals and gold is similar - about 20 MW.h per kilogram. Because the ore reserves are adequate and the geothermal gradients are relatively high, the platinum mines are shallow. If the Merensky Reef has to be followed to much greater depths or the lower UG-2 Reef is mined, hoisting and pumping are likely to increase proportionately, and the cooling requirements could be even more significant. When the UG-2 Reef is mined, the consumption of electricity during matte smelting could be very much lower than for Merensky ore, in that the grade of the flotation concentrate is often much higher - three to five times higher than that of concentrate from the Merensky Reef. The effect on energy saving could be considerable; at present, matte smelting is estimated to account for as much as 25 per cent of the energy consumed in the production of the platinum-group metals. In terms of specific power consumption.
during the smelting of matte, detailed heat balances for the smelting of Merensky Reef concentrates in electric-smelting furnaces clearly indicate the potential benefit (perhaps a saving of up to 25 per cent14) to be derived from the feeding of dry concentrate, the reduction of the slag volume by the minimum of flux additions, and the improvement of thermal insulation as a result of the correct cover of raw material over the slag.

Production of Copper

Copper produced from open-pit mines via conventional milling circuits, reverberatory furnaces, and electrorefining requires energy equivalent to between 10 and 11 MW.h per ton of copper15. Modern developments in smelting can considerably decrease the energy consumed during that process step, but the effect on the overall consumption of energy is unlikely to exceed 15 per cent.

Much has been said about the possibility that the energy required in the hydrometallurgical recovery of copper may be less than that consumed in pyrometallurgical processing. However, the majority of the proposed hydrometallurgical processes incorporate electrowinning for the final recovery, and this consumes about 2.2 MW.h per ton, compared with about 0.3 MW.h per ton for electro-refining by the conventional pyrometallurgical routes16. This leads one to suggest that, for high-purity copper, hydrometallurgical processing is unlikely to be less energy consuming than pyrometallurgical processing. It is recognized that cement copper from dump leaching can be obtained at a saving in energy of more than 20 per cent15 of the energy required in the conventional pyrometallurgical process. However, the product requires further refining.

Production of Steel

The production of steel slabs by the smelting of ore in a pig-iron blast furnace and refining of the hot metal to steel in a basic oxygen furnace consumes energy equivalent to slightly more than that in 1 t of coal17; most of it in the form of coke. This is the process that is used most for the processing of iron ore, and has the lowest energy consumption. In fact, the energy consumption is low compared with that used in other metallurgical processes, indicating that steelmaking is a relatively efficient process that benefits from the availability of high-grade ores.

The advantages to be gained from the recycling of scrap are also clearly shown in the case of steel (although nowhere nearly as spectacularly as for the precious metals) in that the energy consumed (in the form of electricity) for the melting of scrap in the electric-arc furnace is only half that required for the production of steel from ore15.

In the production of steel, there is a slow but steady increase in the use of the direct-reduction process, in which ore is reduced with a gas or solid reducing agent followed by electric melting. Several advantages can be claimed for such a process, but lower consumption of energy does not appear to be one of them.

Production of Ferro-alloys

Detailed heat and mass balances have shown that the theoretical minimum energy consumption17 in the production of ferrochromium from standard raw materials and by a standard process in large units is about 3.2 MW.h/t, and it was recently shown that, with modern furnace technology, process optimization, and computer control, a consumption of 3.6 MW.h/t can be attained. Little further reduction in the consumption of electrical energy can be predicted. The heat lost during the tapping of molten alloy and slag is unlikely to be recovered, except in integrated plants in which the hot alloy can be transferred to the process for the making of stainless steel. Particularly in the ferrochromium process (but also relevant to other electric-smelting processes), the off-gases are rich in carbon monoxide because they are produced by the reduction reaction and very little of the carbon monoxide participates in pre-reduction. Heat balances for a 48 MVA furnace operating at 38 MW for one hour show that the carbon monoxide in the off-gas stream at 1000°C is equivalent to about 15 MW.h at a conversion efficiency of 100 per cent17. There appears to be little doubt that the rapidly increasing cost of energy will warrant capital expenditure on the utilization of this source of energy in large plants, either for the generation of electric power or the preheating and pre-reduction of the ore (and other raw materials). Better utilization of off-peak power should be attempted, either by sophisticated control strategy or by the installation of an additional process that can operate with a supply of interrupted electrical energy.

An interesting aspect is that the partial prereduction of chromite ore with carbon fines prior to smelting can lower the electrical energy required for smelting from about 4 MW.h/t to about 2.4 MW.h/t. However, the overall consumption of energy per ton of alloy is unlikely to be altered significantly, since, although the generation of electricity is an inefficient process, it burns the coal to carbon dioxide, whereas the rotary-kiln process converts the coal predominantly to carbon monoxide.

In respect of the carbonaceous reducing agent, the efficiency of chemical utilization is about 90 per cent, and little improvement can be expected beyond the further utilization of the carbon monoxide off-gasses.

It is perhaps interesting to note that research and development on the applicability of plasma-arc technology to the large-tonnage production of ferro-alloys is making slow but steady progress. Although it has several advantages, particularly the ability to smelt fines direct, there has been no evidence that its specific energy consumption is likely to be significantly less than in the conventional process. Some attention has also been focused on the use of modified blast-furnace technology. Short shafts, which would permit the use of non-coking coals, and high degrees of oxygen enrichment may make such a process economically attractive, but the overall consumption of energy is likely to be similar.

Similar reasoning can be applied to the production of ferromanganese, provided it is recognized that the higher oxides of manganese can be reduced by carbon monoxide.

Very interesting economic calculations could be undertaken to show whether the production process should use less-expensive coal involving increased capital expenditure (for example, rotary kilns for preheating and prereduction), or whether the process should be
based on a lower capital investment, all the energy being supplied by electricity, which is relatively more expensive. Such calculations would be particularly valuable in the local ferro-alloy industry, which has access to coal and to coal-based electrical energy at reasonable prices.

**Effect of Energy Cost on Recovery**

In most mining and metallurgical operations, the percentage recovery is affected by the costs incurred in the recovery of additional values. Hence, the cost of energy can also, and often does, have some small but quantifiable effect on the recovery: for example, finer grinding can increase the recovery slightly by improving the liberation. On the other hand, the overall consumption of energy per unit mass of metal can be reduced if the incremental energy per unit mass of metal required to effect the additional recovery is less than the present consumption of energy; for example, if the recovery of the platinum-group metals by flotation can be improved from the present 85 per cent to over 90 per cent at a similar grade.

The rapidly increasing cost of energy will focus increasing attention on the need to improve the efficiency of mining and metallurgical processes as regards energy consumption. However, rapid changes are not possible because of the capital-intensive nature of the industry. Also, although energy savings can be accomplished in certain processes, such savings are not likely to total more than 10 to 15 per cent. A mitigating factor in several instances is the decreasing grade of raw materials, which implies an increasing consumption of energy per ton of final metal product.

**Efficiency of Energy Production from Coal**

In this context, perhaps it would be useful to consider the efficiency of energy production in the same way as the production of metals was considered above; the recovery and efficiency of conversion of the primary energy-carriers assumes a greater role because there is an 'energy crisis' but not yet a 'metal crisis'. Until the beginning of the 'energy crisis', a 30 per cent recovery of extractable coal deposits in South Africa was a commonly accepted ratio18. The increasing use of open-pit mining methods for relatively shallow and thick coal seams, and of panel and longwall mining methods for deeper coal seams, together with improvements in bord-and-pillar mining methods, is contributing to an overall increase in coal extraction during mining. However, it has been suggested that bord-and-pillar mining is likely to remain the most important method of coal extraction for many years, and it has been calculated that about 60 per cent of the country's coal reserves could fall within the scope of bord-and-pillar mining with a coal loss of 40 per cent19.

Overall, the extraction ratio is determined by economic, legislative, technical, and geological considerations, of which the first is still the most important.

The average conversion efficiency of coal to electricity by Escom's modern single-reheat stations is about 37 per cent20. From this must be subtracted, firstly, the electricity used for auxiliaries, which is about 5 per cent of the power generated, and, secondly, the loss during transmission, which amounts to about 7 per cent of the power sent out to the point of sale of the units21. Therefore, on the assumption that these figures are reasonably representative, and that the efficiency of mining extraction is 40 per cent, the average overall efficiency in the provision of electrical energy from coal in the ground to the point of consumption is about 13 per cent.

As already mentioned, the efficiency of mining extraction is improving and will continue to improve, but relatively little improvement is taking place in the efficiency of conversion to electricity. This is not a local problem; indeed, Escom's new large power stations are comparable with the best in the world. Efficiencies significantly higher than those of the conventional power station do not appear to be practical because these would require an increase in the pressure and temperature of the steam entering the turbines. The metallurgical constraints on operation at higher temperatures and the economic constraints on operation at higher pressures are such that alternative concepts for electricity-generating stations may be sought.

One of the most promising developments is that of the combined gas-turbine/steam-turbine cycle, which achieves a higher efficiency than that of the steam or gas turbine on its own. With the present technology for combined cycles, thermal efficiencies as high as 44 per cent can be attained. As the technology advances to permit an increase in turbine inlet temperatures to 1200°C and higher, thermal efficiencies of 50 per cent may be possible22. The fuel requirement of such combined-cycle power stations will be clean fuel (gas or oil) and, in the South African context, the gasification of coal will be a prerequisite. (It has been demonstrated that a combined-cycle installation could be supplied direct from a pressurized fluidized-bed combustor. However, it appears unlikely that full advantage could be taken of higher gas-turbine operating temperatures; the combustion temperature would be limited to about 900°C because of problems with ash fusion and deposition on the turbine blades.) Gasification is the topic of research-and-development projects throughout the world, and continuous advancement can be expected. A gasification plant feeding a combined-cycle electricity-generating plant would permit the production of a wide range of hydrocarbon byproducts, and could form the basis of an integrated power station and chemical complex producing liquid fuels and chemical products, as well as electricity from coal. An additional advantage in the gasification of coal as fuel for a combined-cycle generating plant is that the quality of the coal in terms of ash content and size need not be as good as in other power-station applications. This would make possible a better recovery and utilization of coal.

Therefore, it can be seen that both mining and conversion efficiencies are capable of improvement, depending on the usual technological and financial limitations.

**Efficiency of Energy Production from Uranium**

The other primary source of energy that is to be utilized in the immediate future for the generation of electricity is uranium (the first of two nuclear-powered electricity-generating plants under construction is to be commissioned in 1982), and should be considered along the same lines as was coal. Mining at gold-and-uranium mines has been governed predominantly by a desire for the recovery of the maximum amount of gold, and
extraction efficiencies of 85 per cent and higher are believed to be generally achieved. The attitude is presumably different for the deposits outside the greater Witwatersrand Basin, namely, the southern Karoo, the northern Cape Province, and the uraniumiferous coal deposits of the northern Transvaal. There, the recovery during mining will be determined predominantly by the prevailing price of uranium, which will also determine the grade below which mining and processing are uneconomic.

However, attention could be focused on the efficient extraction of uranium from ore that has been mined predominantly for the recovery of gold. (Virtually all current uranium production falls into this category, and it should be borne in mind that less than 10 per cent of the known reserves that can be recovered at a cost of less than $80 per kilogram of uranium do not occur in the greater Witwatersrand Basin.) The efficiencies in the extraction of uranium by leaching with sulphuric acid can be as low as 75 per cent, but several plants achieve 85 per cent. However, it can be predicted that there will be a considerable increase in leaching efficiency when use is made of higher temperatures, increased concentrations of ferric ions and acid, and pressure leaching.

Continuing research and development are being undertaken in South Africa to decrease the cost and increase the recovery of the uranium-extraction process, and to permit the economic exploitation of ores with lower head values. A good example is the recent industry-wide introduction of continuous countercurrent ion-exchange processes for the treatment of unclarified solutions. High-density resins will permit feeds with higher solids concentrations or increased flow-rates to such plants, and it is predicted that resin-in-pulp plants may be successful in certain applications.

Although uranium recoveries during mining and processing are comparatively high, the present commercial reactors are poor converters and burn less than 1 per cent of the natural uranium required to run them. This is therefore the area on which attention is being focused. The first step is likely to be the recycling of plutonium, which is not yet carried out in general; when it is, the proportion of uranium burnt will increase to 2 per cent, and the efficiency of providing electrical energy from uranium in the ground to the point of consumption will then approach 1 per cent.

The nuclear variant of the gas-turbine/steam-turbine cycle, namely the high-temperature gas-cooled reactor (HTR) using an all-ceramic core and helium as the cooling agent, is under development. It may become commercially available towards the end of this century, and could be used for the generation of electricity (either via the combined cycle or the direct helium gas-turbine cycle), or possibly for direct thermal applications.

Fast-breeder reactors hold the greatest promise for the good utilization of nuclear fuel. Such reactors produce more fresh fissile fuel than the primary fuel destroyed, and it should be possible for fast-breeder reactors to be designed so that, over a lifetime of thirty years, they will fuel two similar additional units (i.e., a doubling time of fifteen years). Several prototypes exist, and commercial demonstration units are under construc-


4. Can mining and metallurgical processes be adapted to the various forms of energy that may have to be utilized in the future?

As is apparent from what I said earlier, electrical energy constitutes the major proportion of the energy utilized by the local mining and metallurgical industries. Furthermore, there appear to be no technical reasons why mining activities and metallurgical processes should not be adapted so that their total energy requirements can be supplied by electricity. It can therefore be argued that, provided alternative sources of energy can be converted to electrical energy, they can be applied to the mining and metallurgical industries. However, the likelihood that alternative sources of energy can be applied direct should be examined.

Alternative Sources of Energy

Alternative sources of energy, such as those provided by the action of wind, tides, and waves, could be applied direct to mechanical devices in the mining and metallurgical industries, but remote geographical locations and non-assured continuity of supply would probably militate against this, and the conversion to electrical energy may be the obvious solution. Some alternative sources of energy, such as those provided by thermal gradients in the earth and oceans, geysers, and hot springs, do not provide a sufficiently intense direct source of heat for pyrometallurgical operations, but could be used to provide a continuous supply of heat at the temperatures required by hydrometallurgical operations. In general, these sources of energy are also likely to be converted to electrical energy. It has been demonstrated that solar energy can be utilized direct to provide temperatures sufficiently high for all types of pyrometallurgical applications. However, large-scale pyrometallurgical operations are essentially continuous, the object being the conservation of energy (apart from the optimum utilization of capital-intensive equipment), and it is therefore suggested that even solar energy will
generally be converted to electrical energy. (Solar evaporation is an obvious exception.)

Although these alternative sources of energy are likely to be converted to electrical energy for use in the mining and metallurgical industries, it is expected that their contribution will be relatively small for the foreseeable future.

Electricity the Best Vehicle

Perhaps a more important consideration is whether electricity is always the best vehicle for the energy content of coal and uranium when this energy is to be used in the mining and metallurgical industries.

The mining industry generally requires energy in the form of electrical energy, except possibly for nuclear explosive devices for underground rock shattering as a preliminary to solution mining. It should also be noted that, traditionally, liquid fuels (mainly diesel) are used to power the large vehicles in open-pit mines. Dependence on this source of energy has given rise to rapidly escalating mining costs. For example, a local copper producer stated that the cost of diesel fuel per ton of copper produced was about R58 in 1978, and that this figure would reach R215 per ton of copper produced in 1979. Because no decrease can be expected in the cost of liquid fuels, even when they are produced locally from coal in large quantities, serious consideration will be given to the electrification of mine transportation systems if the additional capital expense can be recouped over a reasonable period.

In the majority of metallurgical operations, electricity is either essential or already established as the optimum form of energy. However, the blast furnace for the production of molten iron, using coke as the source of fuel and as the reducing agent, is an example of a process that not only uses less energy than alternative processes, but is also associated with lower production costs. The motivation to explore the application of blast furnaces (so modified as to permit the use of reducing agents other than coke) for the production of ferro-alloys is based predominantly on the economics of iron production. Similarly, consideration is being given to the partial prereduction of oxide ores by the use of pulverized-coal firing in rotary kilns to decrease the consumption of electrical energy during smelting or melting by the use of cheaper coal at additional capital expense.

Thermal Energy

It can be reasoned that thermal energy from nuclear fission could be utilized direct instead of being converted to electrical energy first. The thermal energy could be transferred direct from the nuclear pile to, for instance, a molten metal from which the heat could be transferred by heat exchange to a pyrometallurgical operation. Attention is also being focused on utilization of the reactor cooling load to produce reducing gases at high temperature and pressure.

Fusion Energy

It has been stated that the supplies of fuel for fusion energy (as opposed to fission energy) are so large as to be considered inexhaustible. However, a vast range of technical problems, including the high ignition temperature (the lowest is $50 \times 10^6$ K for the deuterium–tritium reaction), containment of the high temperatures, and a sufficiently high product of particle density and confinement time, must be solved before electricity-generating stations based on fusion become viable. There is little optimism that industrial units can be considered in this century, and it may not be until the middle of the twenty-first century that a significant proportion of electrical energy can be provided by this means.

Carbonaceous Reducing Agents

Obviously, coal (or electricity derived from it), apart from constituting a major source of energy to the mining and metallurgical industries, has an even more important role as a carbonaceous reducing agent for local oxide ores; that is, here the emphasis is on the reactive chemical properties of coal rather than on its energy potential. Table IV shows the estimated amounts of reducing agents required to process 50 per cent of South Africa’s reserves of oxide ores. The calculations were based on the assumption that 50 per cent of the reserves of iron, chromium, and manganese ore will be processed locally, that the minimum quantity of carbon required is governed by the stoichiometric requirements of the chemical reactions, and that the average fixed-carbon content of the reducing agent is 55 per cent. From these figures, it can be seen that about 1981 Mt of coal suitable for use as a reducing agent would be required. The Report of the Petrick Commission classified 705 Mt of metallurgical coal and 375 Mt of anthracite coal as extractable reserves. Certainly, the sum of these two is only half of the requirement predicted above. The Commission’s figures for total metallurgical coal (washed) and anthracite coal (washed) are 3451 Mt and 744 Mt respectively, but these totals include proven, indicated, and inferred categories on the basis that the in situ reserves of mineable coal are 8 Mt.

Although these requirements for reducing agents constitute a relatively small proportion of the coal reserves, pyrometallurgical processes require coal with more closely defined specific characteristics than those required for coal that is to be converted to electricity or liquid fuels; that is, not only are the properties of the coal specific with reference to its coking and charring properties, but the ash content and its composition are also very important, and the contents of sulphur and phosphorus have to be below certain levels. It has not yet been possible to identify which of the known deposits of coal are suitable for use as reducing agents, nor what fractions of other coal deposits could be rendered suitable by coal-processing operations. It should be noted that the minimum required properties of coal for use as reducing agents could be decreased as a result of modified

<table>
<thead>
<tr>
<th>Oxide ore</th>
<th>Coal required for reduction Mt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>943</td>
</tr>
<tr>
<td>Chromium</td>
<td>558</td>
</tr>
<tr>
<td>Manganese</td>
<td>480</td>
</tr>
<tr>
<td>Total</td>
<td>1981</td>
</tr>
</tbody>
</table>

TABLE IV REDUCING AGENTS REQUIRED FOR THE PROCESSING OF HALF SOUTH AFRICA’S RESERVES OF OXIDE ORE
pyrometallurgical processes and processed reducing agents like form coke. Iron oxides can be completely reduced, and manganese and chrome ore partially reduced, by carbon monoxide, and therefore the issue of coal quality can be circumvented to a degree by coal gasification. In the long-term future, a hydrogen-based energy cycle could perhaps lead to an alternative reducing agent.

**Choice of Energy**

It might be argued that, because there is no legislation requiring that mining and metallurgical operations (in fact any operation) should be efficient in terms of energy utilization, the type of energy used and the efficiency of its utilization will be determined by the price to the consumer of a particular form of energy. Several metallurgical operations can be identified where either coal or electricity (derived from coal or uranium), or both, can be utilized. Also, there are certain operations on mines and metallurgical plants, particularly transport systems, in which electrical energy or liquid fuels (both are produced locally from coal) can be utilized. The comparison between the use, on the one hand, of cheaper energy involving an increase in capital costs, and the use, on the other hand, of more-expensive energy involving lower capital costs will continue to be an interesting one. A number of complicated factors must be considered in such an analysis:

(a) the long-term availability of a particular type of energy (particularly metallurgical-quality coal),

(b) the future efficiency with which coal and uranium are converted to electricity, and coal to liquid fuels,

(c) the future capital cost per annual unit of capacity of the various conversion installations (electricity and liquid fuels from coal, and electricity from uranium),

(d) the efficiency with which the mining and metallurgical industries utilize various types of energy on site,

(e) the on-site capital costs associated with each type of energy in relation to the cost of purchased energy, and

(f) the effect of incremental expansion of mining and metallurgical operations on the cost of the additional energy required.

**Conclusions**

From my qualitative discussion of four important energy-related questions affecting the mining and metallurgical industries, I can draw the following tentative conclusions. If they are wrong, my excuse is that I avoided the use of confidential information, that, in several instances, the required information was not available, and, especially, that my interpretation is subjective. Also, the conclusions may encourage more-quantitative analyses from those qualified to undertake them. Inevitably, the questions asked at the outset have given rise to more questions, and the more interesting ones are posed in the context of each conclusion.

(1) The mining and processing in South Africa of 50 per cent of the reserves of gold, platinum-group metals, copper, iron, ferrochromium, and ferromanganese would require about 26 per cent of the extractable reserves of coal. On the assumption that coal could become virtually the sole source of energy for a prolonged period, the proportion of coal reserves utilized annually in the mining and metallurgical industries within the next few decades may be lower than that required to ensure that 50 per cent of the reserves of ores are ultimately mined and processed locally. However, even under these severe constraints, about three-quarters of the extractable reserves of coal would have been consumed by the year 2025, i.e., sufficient time is available to make major changes in the energy-supply industry and the mining and metallurgical industries. At that stage, the reserves of gold and copper as estimated in the past would be close to exhaustion, while over half the platinum-group metals would still be in the ground, and over three-quarters of the oxide ores would not have been processed locally. Hence,

(a) although South Africa has an enviable record in the planning and utilization of energy (namely, the supply of adequate electrical energy, the recovery and beneficiation of uranium, and the conversion of coal to liquid products) is sufficient effort being devoted to ensure that alternative sources of energy will be available locally on a sufficient scale during the 21st century?

(b) is there any reason to change the established policy of exporting both oxide ores and metals while encouraging increased local processing?

(2) The reserves of uranium are considerable and, at present conversion efficiencies to electricity, are equivalent to one-fifth of the coal reserves. Both coal and uranium have shown such rapid increases in demand, and hence price, that they contribute significantly to foreign-exchange earnings; that is, R325 million and R335 million respectively in 1978. On the basis of the contained energy at present conversion efficiencies and on the assumption that the major proportion of the $U_3O_8$ is exported, the rate of exportation of energy in the form of $U_3O_8$ was about five times that of coal in 1978. In relation to their respected reserves, the rate of exportation of energy via $U_3O_8$ was about twenty-five times greater than that of coal.

Hence:

(a) although the predicted annual exportation of coal will soon reach 40 Mt, should the figure be encouraged to increase or decrease with time?

(b) is the local and international nuclear-energy programme sufficiently defined for an assessment to be made of the period for which the major proportion of the annual production of $U_3O_8$ can be exported?

(3) The price of energy will always affect the overall recovery of metals. For precious metals, the cost of electrical energy constitutes a sufficiently small proportion of the final price of the metals for their competitiveness not to be affected. However, as the cost of energy represents a significant proportion of the production costs of copper and of metals and
alloys from oxide ores, the local price of energy has a direct effect on their competitiveness. There are indications that the local costs of energy should not hinder expansion in the exportation of minerals and metals. Hence,

(a) for what period of time is the relatively low cost of electrical energy assured to the mining and metallurgical industry?

(b) as several major processors of raw materials depend on the importation both of raw materials and of primary energy-carriers, can such producers continue to compete with producers in countries that have reserves of both these commodities?

(4) Considerable attention is being focused on increased efficiency in the utilization of energy in the mining and metallurgical industries. Although there are several process steps in which the efficiency can be increased by 10 to 15 per cent, the specific consumption of energy per unit of metal can be expected to increase in several instances because of a decrease in ore grade and an increase in depths of mining. However, scope for the conservation of energy appears to be greater in the extraction and conversion of primary energy-carriers to electrical energy than in other mining or metallurgical fields. Hence,

(a) is sufficient co-ordinated planning, research, development, and on-site improvement being undertaken to decrease the consumption of energy per unit of metal and to increase the efficiency of extraction and conversion of coal and uranium to electrical energy?

(b) as, theoretically, only the conversion of coal to electrical energy is associated with a permanent loss, is this the area that should receive most attention, or are there other areas of loss in which subsequent recovery is unlikely or the application of effort would have more chance of success?

(5) If other sources of energy can be converted to electrical energy, they can be used in the mining and metallurgical industry, but their direct application is unlikely to be common. The decision as to which type of energy should be used in specific mining and metallurgical situations is complicated. Hence,

(a) can a meaningful study be undertaken of the optimum types of energy for the various mining and metallurgical operations so that not only the minimum energy is consumed, but the minimum capital requirements (on a plant and a national basis) are also assured?

(b) can it be deduced that the cost of liquid fuels derived locally from coal will follow the example of local electrical energy and be relatively low in the future since their reserves are not subject to the same short-term horizons as are the liquid fuels derived from crude oil

(6) The reducing agents required for the local processing of 50 per cent of the oxide ores exceed the extractable reserves but not the total estimates of mineable in situ resources of metallurgical coal and anthracitic coal. Hence,

(a) are sufficient attempts being made to ensure that the comparatively limited reserves of coal suitable as reducing agents are identified and reserved for this application and, further, that the maximum amount of suitable fractions are recovered from other coal deposits before the coal is used for other purposes?

(b) are sufficient research and development programmes being undertaken to ensure that lower-grade and alternative reducing agents can be utilized by the pyrometallurgical industries?

Finally, although South Africa has been endowed with an absolute treasure-chest of minerals and primary energy-carriers (except, apparently, oil), a tentative mass and energy balance of raw materials shows that man will have to use his ingenuity, both technical and economic, to ensure that these resources are exploited in the best possible way and for as long as possible, to the benefit of all the inhabitants. In particular, the foresight and detailed planning that have characterized past developments in this context in South Africa are even more important for the future.

References

Graduate studies programme at Wits

The University of the Witwatersrand offers a Graduate Diploma in Engineering (GDE) and the following higher degrees:

- Master of Science in Engineering (M.Sc. (Eng.))
- Doctor of Philosophy (Ph.D.)
- Doctor of Science in Engineering (D.Sc. (Eng.))
- Doctor of Engineering (D.Eng.)

The Faculty of Engineering is introducing a specialized programme of coursework and research leading to the M.Sc. (Eng.) in the field of physical metallurgy, which is open to candidates who have a three-year Bachelor or Science degree with suitable physics of chemistry major subjects.

Graduate Diploma in Engineering

A candidate for the diploma must hold the degree of B.Sc. (Eng.) (or the degree of B.Sc. (Hons.) with an appropriate grouping of subjects) of the University or an equivalent qualification from another institution.

The curriculum extends over one year of full-time study, or up to three years part-time, and comprises a programme of A-level (graduate level) and B-level (undergraduate level) engineering courses or undergraduate courses offered in other faculties. (Such courses may each be rated as equivalent to more than one B-level course.) The credit point-rating system for courses is explained below. The University will take into account a candidate’s previous training and experience when approving a student’s proposed curriculum. Exemption will not be granted on the grounds of attendance at previous courses of a similar nature, nor will a student be permitted to register for a course substantially the same as one previously completed. No dissertation is required, except when converting to an M.Sc. (Eng.). It should be noted that, for this conversion to take place, all GDE courses must have been passed at the first attempt.

Occasional courses

Courses may also be attended by graduates on an occasional basis, i.e. not for degree purposes.

Credit point ratings for coursework for GDE

Candidates admitted to study for the Graduate Diploma in Engineering shall complete courses with credit points totalling not less than 24, of which not less than 18 shall be derived from A-level courses.

Credit point ratings for coursework for M.Sc. (Eng.)

Candidates admitted to study for the degree of Master of Science in Engineering by a programme of coursework and research or development shall complete either

(i) a set of courses with credit points totalling not less than 18, together with a report on a project equivalent to not less than six months of full-time work (counting an additional 18 points),

or

(ii) a set of courses with credit points totalling not less than 24, together with a report on a project equivalent to not less than four months of full-time work (counting an additional 12 points).

At least 18 credit points shall be derived from A-level courses. A candidate shall be required to complete every course at the first attempt.

The credit point ratings of each course offered are listed below after the A or B designation of the course.

A-level (3 points each):
37510 Geostatistical methods in mineral evaluation
37560 Mining finance
37568 Economics of energy resources
37536 Mechanics and design of major rock slopes
37569 Mechanized earthmoving
37543 Mine design – open-pit workings
37556 Thermal environments underground
B-level (2 points each):
37612 Introduction to mineral economics
37614 Exploitation systems (Part 2)

Any enquiries should be directed to Mr M. J. Martinson, Department of Mining Engineering, Mining & Geology Building, University of the Witwatersrand, Jan Smuts Avenue, Johannesburg. (Tel. 39-4011, ext. 559.)