



Presidential Address: The role of pyrometallurgy in the development of South Africa

by N.A. Barcza *

Synopsis

Pointing out that South Africa needs to utilize its wealth-creating activities, together with local and international investment, to further develop its industries, the address asserts that the mining and minerals industries, especially in the manufacture of beneficiated products, offer the greatest potential for South Africa to achieve its goal.

As many mineral-beneficiation processes are based on pyrometallurgical routes, the address goes on to describe some historical pyrometallurgical operations and to indicate probable developments in the future. These include growth in the fields of both precious and base metals.

After discussing environmental and recycling matters, together with manpower requirements, the address concludes that the major growth in the mining and minerals industries will occur in the manufacture of steel, stainless steel, ferro-alloys (particularly ferrochromium), aluminium, and titania slag.

Introduction

At his inauguration in May 1994, President Mandela declared, 'We have at last achieved our political emancipation. We pledge ourselves to liberate all our people from the continuing bondage of poverty, deprivation, suffering, gender and other discrimination'¹. In *Long Walk to Freedom* he wrote, 'I have taken a moment here to rest, to steal a view of the glorious vista that surrounds me, to look back on the distance I have come. But I can rest only for a moment, for with freedom come responsibilities, and I dare not linger, for my long walk is not yet ended'².

We now all look forward to moving along the road to growth and development for all our people. However, to achieve this objective, we must utilize our wealth-creating activities and some of the revenues thus generated, together with investment, both local and international, to further develop our industries. In this regard, there is little doubt that our mining and minerals industry, and the manufacture of beneficiated products, offer the greatest potential for us to achieve this goal.

Many mineral-beneficiation processes comprise pyrometallurgy as a major component of the conversion of ores and concentrates into

intermediate and final products. I would like you to join me on a journey through some of the historical applications of pyrometallurgy, and to share a vision of the areas in which future developments are most likely to occur. The role that The South African Institute of Mining and Metallurgy (SAIMM) has played, and continues to play, in providing a platform for technical exchanges in this field is also of great benefit to the advancement of the industry.

History of pyrometallurgy

Pyrometallurgical activities started in southern Africa well before the arrival of the white man. The indigenous people had mastered the art of making metal long before modern science and technology were available. Many interesting historical sites remain to bear testimony to this. Today's scientists and engineers have tried to reproduce in the laboratory what our African predecessors achieved in practice, but with only moderate success. Have we lost some of the valuable skills they had?

Furnaces and signs of copper, tin, and iron mining and smelting activities have assisted archaeologists in obtaining an understanding of how people previously lived in this area. For example, pieces of dark iron slag and furnace structures have been found in places such as the Melville koppies and Lonehill (the latter being one of the largest furnace and forge sites unearthed in Africa³).

Historical studies reveal a rich diversity of experimentation, local adaptation, and interaction between smelting technologies that in some ways are very similar to what takes place today. The iron technology generally used was a two-stage process. In the first stage, cold raw iron was produced in reduction furnaces, and was then ground into powder. Selected pellets were heated with charcoal in bellows-assisted forges, and the blacksmiths then forged the lumps of

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purified iron into artifacts. Such a process probably had a very low productivity, and obviously involved very hard work.

Introduction and definition of pyrometallurgy

Pyrometallurgy is the processing or extraction of metals and materials at high temperatures, using a suitable source of thermal energy. The customary stages of processing are as follows:

- ▶ pretreatment (e.g. calcining in a rotary kiln)
- ▶ melting: changing from the solid to the liquid state, with separation of the slag and metal (e.g. in an arc furnace)
- ▶ smelting: extraction and separation of sulphide or oxide materials to produce mattes, metals, alloys, and slags, some of which are products too (e.g. in a submerged-arc furnace)
- ▶ post-treatment: converting or refining a material to meet a desired specification (e.g. carbon, silicon, sulphur, and phosphorus levels).

Electro-metallurgical processes, which are based primarily on molten-salt electrolysis, have traditionally been grouped under pyrometallurgical operations because they are generally regarded as high-temperature operations (e.g. aluminium smelting).

Where does pyrometallurgy fit into the overall field of mineral beneficiation? The answer is just about everywhere. However, it complements and, in some instances, competes with other metallurgical processes, e.g. comminution, flotation, biotechnology, hydrometallurgy (leaching, precipitation, and ion exchange, or solvent extraction and electrowinning).

The diversity of minerals in southern Africa has created unique challenges to those charged with the research, development, and implementation of appropriate technologies to extract, process, and refine metals and alloys and, in many instances (especially more recently), to fabricate end products. These industries were almost entirely instrumental in the growth and development of our economy over the past century. It is becoming increasingly recognized that future growth and prosperity will also depend on further beneficiation of our mineral and metal products. However, ongoing, cost-effective production and growth of the intermediate beneficiated products currently being produced cannot be neglected in our programme towards adding value to these products.

Theoretical considerations

Thermodynamics determines the extent to which a pyrometallurgical process (i.e. from inputs to outputs) should proceed, and what the resulting equilibrium between the product phases such as slag and metal should be. Computer-based thermodynamic calculations to predict the results of metallurgical processes have made significant progress over the past ten years. These advanced tools have enabled potential improvements to existing processes to be evaluated prior to more costly experimentation. New mining and metallurgical projects can also be studied technically and economically based on predicted results, but testwork is still necessary to ensure that all of the plant's specifications are determined reliably.

The dynamic reactions in a process are more difficult to predict, but considerable progress has been made in the past five years. Kinetics determines the rate at which a pyrometallurgical reaction proceeds. Most pyrometallurgical processes

occur above 1000°C, where the reaction rates are very rapid compared with those in hydrometallurgical processes. Several techniques to improve the rate and extent of metallurgical reactions have resulted from a better theoretical understanding of pyrometallurgical processes. Electromagnetic stirring or gas bubbling and injection techniques have been used for refining, and to increase the reaction rates in a variety of processes.

Process modelling, simulation, and control

Pyrometallurgical processes occur rapidly compared with other processes, as a result of the fast reaction rates at elevated temperatures where good mixing and contacting of the different phases occur. The numerous species present, and the difficulty in measuring parameters at elevated temperatures, mean that process modelling and both steady-state and dynamic simulation can be of great value in understanding, developing, and controlling pyrometallurgical processes.

An example of the successful use of process control in a pyrometallurgical operation is the calculated resistance-based control of submerged-arc ferro-alloy furnaces to ensure optimum energy input and maximum production developed by Mintek (MINSTRAL), which is now used on over 25 ferro-alloy furnaces worldwide.

The use of expert systems and neural networks is growing as tools to aid the operator of pyrometallurgical processes and ensure consistent and effective process conditions. The approach developed at Mintek of using the interrelationship between metallurgical and electrical process parameters in ferrochromium, ferromanganese, and silicon smelting is an important aspect of a control and operator-guidance system that is bringing the technology of the submerged-arc furnace into the 21st century.

However, we need more specialized and highly trained manpower for such important developmental work to continue.

Process selection

The extraction of metals and alloys from ores normally involves a variety of process steps, such as size reduction to achieve liberation and facilitate transportation and handling, and concentration by various physical means, followed by either hydrometallurgical or pyrometallurgical processing, or both. The most economic and appropriate process route depends on the physical and chemical characteristics of the feed materials, and the ease with which the necessary chemical reactions can be achieved to produce the required materials. The thermal processing of materials is normally indicated when they are very stable chemically, and where reduction of a metal oxide by carbon, or the separation of a metal sulphide or alloy from gangue minerals, is feasible and necessary.

In most cases, the selection of a hydrometallurgical or pyrometallurgical route as the primary processing option is based on well-established criteria, and the prospects for alternatives are limited. For example, in iron- and steel-making and the manufacture of ferrochromium, only pyrometallurgical processes are feasible. There are several examples of the use of alternatives, such as the conversion of ilmenite into titania, where either smelting to produce pig or foundry iron and titania slag, or pre-reduction and subsequent leaching to produce synthetic rutile, is practised. Here, specific issues, such as the particle size and reducibility of the ilmenite, the availability of suitably sized low-ash reactive carbonaceous reducing agents, the level and

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form of radioactive components, the disposal of leach residue, the value of pig or foundry iron, and the cost of electricity, play a deciding role. Hence, the smelting route shown in Figure 1 is favoured in South Africa, and the pre-reduction process in Australia, which have the second-largest and largest world reserves, with 72 and 130 Mt (based on contained titanium) respectively⁴.

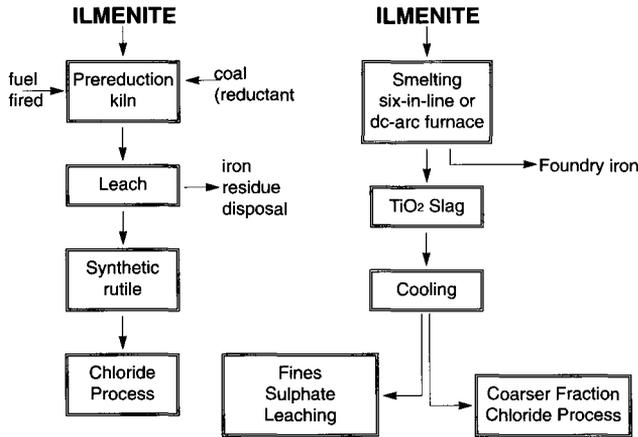


Figure 1—Process alternatives for the production of ilmenite

Energy considerations and sources of thermal energy

Pyrometallurgical processes require a suitable source of thermal energy, of which there are three different forms: electrical, combustion, and chemical. Electrical energy is fairly expensive but is efficient and clean, permits a strongly reducing environment, and is also used for high-temperature electrolysis. Combustion energy is usually less costly, but is limited to processes in which only moderately reducing conditions are required (e.g. lead and copper smelting). Chemical energy is

used for the metallothermic reduction of refractory oxides, such as chromium and vanadium, to produce pure metals.

The development of South Africa's pyrometallurgical industry has been based on an abundant supply of raw materials and concentrates, as well as the availability of coal, electrical energy, and carbonaceous reducing agents. South Africa annually consumes about 80 Mt of steam coal in power stations to generate about 150 TWh of electrical energy. Nuclear and hydropower add another 20 TWh to this figure, to give 170 TWh in total⁵. The energy consumed in the mining and metallurgical industries amounts to about 65 TWh, as shown in Figure 2, and about 35% of this (i.e. 25 TWh) is used for pyrometallurgical operations. Ferro-alloys consume 42%, and aluminium 29%, of the energy used in pyrometallurgical operations^{6,7}.

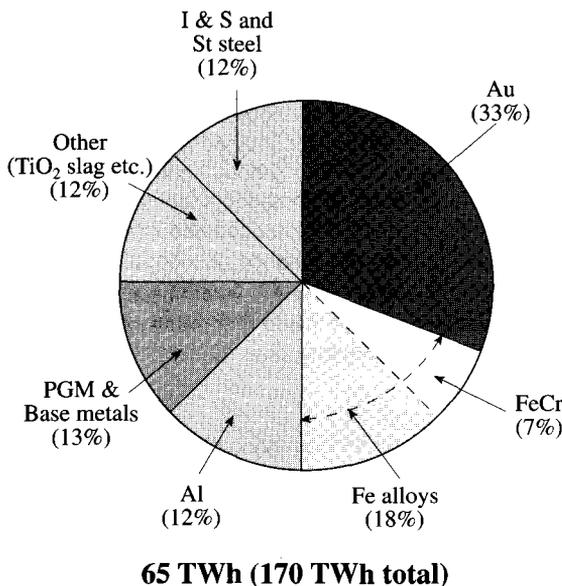
Metallurgical reductants, supply considerations, and energy potential

About 5% of the 210 Mt of coal produced annually (i.e. 10 Mt/a) is used in the local metallurgical industry—almost half as coking coal, and the rest as carbonaceous reducing agents (e.g. anthracite, coal, char, and coke) mostly for ferro-alloys. The iron and steel industry consumes over 3 Mt/a of coal (largely as coke) to produce about 8.7 Mt of iron and steel, and the ferro-alloy industry consumes about 2 Mt/a of coal to produce over 2 Mt of ferrochromium, ferromanganese, and ferrosilicon alloys.

Metallothermic reductants are used for the reduction of refractory metal oxides to produce pure metals or alloys that are free of carbon (e.g. ferrovanadium). Silicon and aluminium are used most frequently.

Although South Africa has extensively developed its abundant coal resources, there has been little development of prospective natural gas and coalbed methane fields. However, there is noteworthy potential for gas as both an energy source and (especially) as a gaseous reducing agent, particularly for iron production in the southern African region, as shown in Figure 3⁸.

MINING AND METALLURGY



PYROMETALLURGY

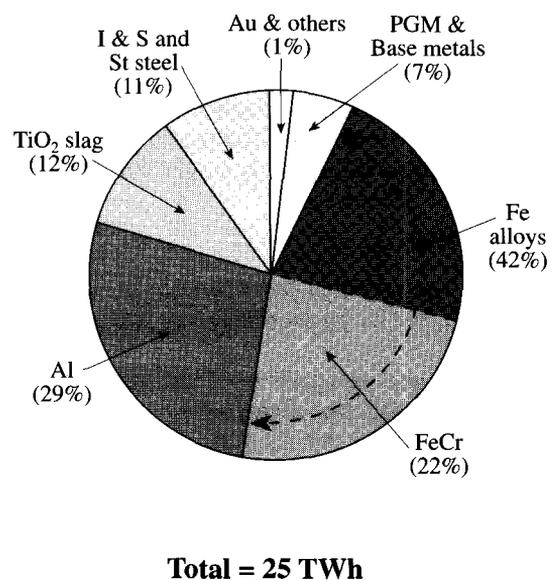


Figure 2—Usage of electrical energy in mining, metallurgy, and pyrometallurgy in South Africa—1996 estimate

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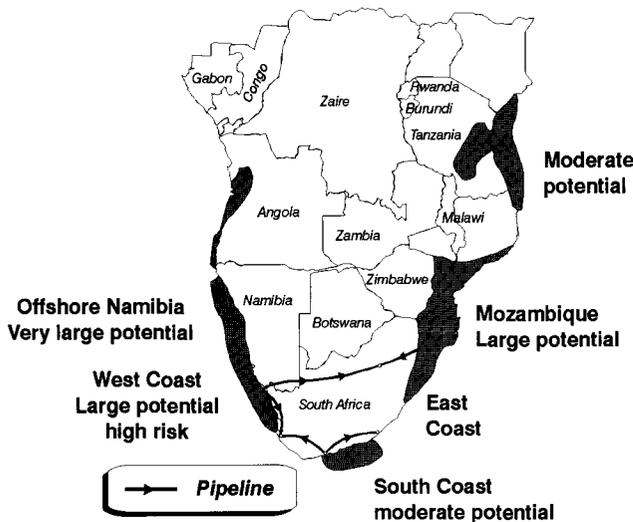


Figure 3—Gas potential of southern Africa

The proposed exploitation of gasfields and coalbed methane over the next ten years, locally and in the neighbouring states of Mocambique and Namibia, holds significant promise for the mining and metallurgical industries. A network of gas pipelines is being evaluated to bring gas to targeted development regions such as the Mpumalanga–Maputo corridor, Saldanha Bay, and the Eastern Cape.

Furthermore, the potential development of a regional electricity supply grid extending up to central Africa holds great prospects for the generation of a much larger quantity of electrical power, possibly as much as 380 GW in the southern African region, compared with the present 36 GW in South Africa, which alone has a potential of about 160 GW according to Eskom⁹.

The prospects, from an energy-supply perspective, for the increased production of iron and steel, ferro-alloys, stainless steel, zinc, titania slag, and aluminium are therefore excellent over the next two decades given the necessary investment, manpower resources, market-growth opportunities, and technology.

Developments in metallurgical sectors

Considerable development has taken place recently in the fields of precious metals, base metals, ferrous metals, industrial minerals, and light and refractory metals, and further growth is expected in the future.

Precious metals

As we all know, growth in gold production has moved away from South Africa during the past twenty years, as shown in Figure 4.

The smelting of gold bullion is almost as ancient as the metal itself, although the refining technology for gold has advanced significantly over the years at the Rand Refinery, which is still by far the largest facility for the treatment of gold metal in the world (over 500 t/a). Pyrometallurgy plays only a small (but important) role in the final stages of gold extraction and refining from non-refractory gold sources. However, pyrometallurgy is used extensively in the pre-treatment of refractory gold-bearing pyrite and arsenopyrite concentrates to

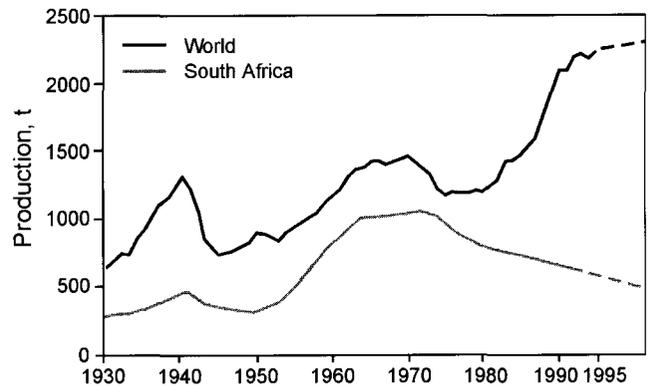


Figure 4—World production of gold

remove sulphur and arsenic, and to render the concentrate leachable.

Unlike the gold industry, where the role of pyrometallurgy is decreasing, the PGM industry is making growing use of pyrometallurgical processes, together with improved mineral-processing and refining technologies. The blastfurnace route for the smelting of PGM concentrates was replaced by six-in-line electric smelting during the late 1960s but, because of problems caused by the build-up of chromium oxide in the hearth, there are limits to the amount of UG-2 concentrate that the six-in-line furnace can accept. New smelting technology for UG-2 and LG-6 PGM concentrates containing high levels of chromium oxide has therefore been developed over the past 15 years. In the early 1980s, there was a technical breakthrough at Lonrho's Western Platinum Mine in the smelting of concentrate predominantly from the UG-2 reef, which contains about ten times more chromium oxide (about 3%) than Merensky concentrate. The process, which Lonrho developed together with Mintek, uses a circular submerged-arc furnace¹⁰.

Attempts to improve conventional Peirce-Smith PGM matte-converting technology have not met with much success to date. However, there is considerable scope for the introduction of flash-smelting and converting technology, as already applied overseas to copper and nickel sulphide concentrates, provided that the higher temperature necessary to give a liquid slag and good matte-slag separation during PGM smelting can be attained by either oxygen enrichment or supplementary heating.

A slag post-treatment step would probably be required to ensure complete recovery of the precious and base metals. The dc-arc furnace appears to have some advantages over the conventional three-phase submerged-arc furnace in the treatment of both converter slag and PGM concentrates with high chromium oxide contents (above 8%), as is the case for LG-6 tailings, which are a by-product of chromite beneficiation¹¹. A PGM and base-metal ferro-alloy is produced that can be processed further by hydrometallurgical means.

Base metals

Zinc metal is produced both by pyrometallurgical and hydrometallurgical processes. However, over 80% is produced electrolytically from the sulphate solution resulting from the leaching of roasted zinc sulphide concentrate. I discuss this process later under environmental matters, since the treatment of the residue has become an important issue in the process design for new zinc smelters.

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A conventional reverberatory copper smelter is used at PMC. Copper, nickel, and a small amount of cobalt are also produced locally as co-products of the PGM industry. However, the recently developed copper and nickel combined flash-smelting and converting process (e.g. as developed by Outokumpu) to improve the capture of sulphur dioxide has not yet been implemented in South Africa. The slags produced from this process contain higher levels of base metals than those produced in conventional smelters, and require further treatment. Bath-smelting processes based on in-bath combustion are practised in Zimbabwe for the smelting of nickel, and a plant was installed recently at Tsumeb in Namibia by Gold Fields to replace the lead blastfurnace¹².

The improved recovery of copper, nickel, and cobalt from both smelting-furnace and converter slags by processing in a dc-arc furnace has been demonstrated by Mintek, and is being evaluated for implementation at Bindura in Zimbabwe. This technology also holds significant potential for the recovery of additional cobalt in the local PGM and base-metal industries.

Copper

Copper production in central and southern Africa has fallen dramatically, from over 1 Mt/a to less than 0,5 Mt/a, over the past 25 years while growing rapidly in other producing countries, as shown in Figure 5¹³. Prospects for new investments and better technologies could turn this situation around to some extent, provided the political and infrastructural problems can be resolved. The scope for greater production in South Africa is limited, but is fairly good in the medium term in the region as a whole.

Cobalt

The production of cobalt has shown considerable sensitivity to political situations, especially in Zaire, and has fallen by more than half to less than 10 kt/a, as shown in Figure 6¹³. This and its high price have encouraged cobalt production in several other locations during the past few years. A resurgence of cobalt production in central Africa is possible once the political and infrastructural problems have been resolved. South Africa's production is small but could more than double to over 500 t/a by the introduction, as mentioned earlier, of improved pyrometallurgical technology that would lead to the recovery of greater quantities of cobalt from slags.

Nickel

South Africa annually produces about 30 kt of nickel as cathode and powder, and exports almost half of this quantity. This production is very small in relation to the world's production of about 900 kt/a (Figure 7)¹³. The local demand for nickel units is projected to increase to about 80 kt/a by the turn of the century as a result of the expansion of the stainless-steel industry to about 1 Mt/a. Unlike major first-world producers, South Africa has little stainless-steel scrap available locally, and thus most of the additional nickel units will have to be imported, mostly as primary nickel and ferronickel. Japan is a major importer of lateritic ore and producer of nickel (about 120 kt/a) in spite of its high costs, and the production of nickel in South Africa from imported ore or concentrates should not be discounted.

Iron and steel

The iron and steel industry in South Africa has had a tradition of innovation, and a number of new processes have been

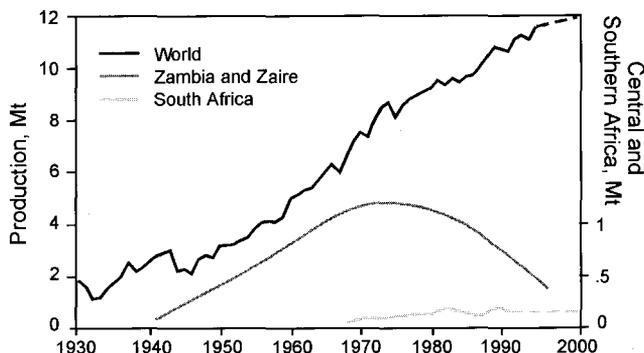


Figure 5—World production of copper¹³

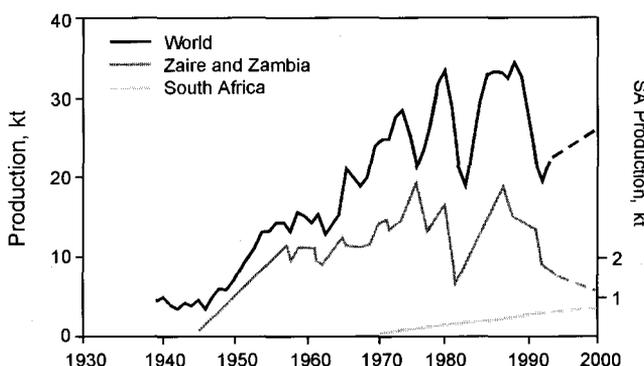


Figure 6—World production of cobalt¹³

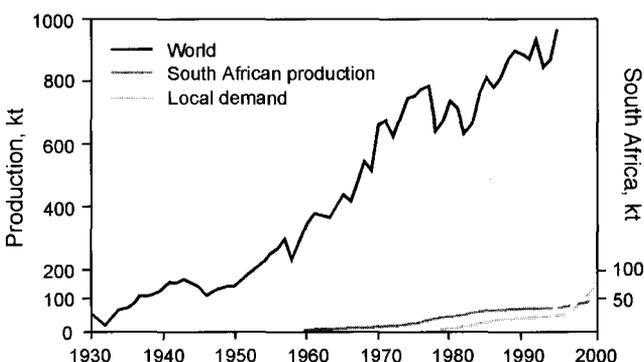


Figure 7—World production of nickel¹³

successfully implemented. The major developments are related to the need to overcome the shortage of coking coals, and include the following:

- ▶ the use of form coke in blastfurnaces
- ▶ the production of direct reduced iron (DRI) in rotary kilns using coal, which has also been applied at Highveld Steel and Vanadium, where titaniferous magnetites are processed to produce both steel and vanadium (as slag, oxide, and ferrovanadium)
- ▶ the development of Corex ironmaking technology, comprising a gas:solid-based vertical pre-reduction shaft and a subsequent smelter gasifier in which the iron units are smelted, using coal instead of coke

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- ▶ the charging of liquid iron units (hot metal) to the UHP electric-arc furnace, together with scrap, as pioneered by Iscor.

There is a strong incentive for the development of a pre-reduction process capable of treating 100% minus 6 mm fines, and further processing these fines to produce iron and steel units. Iscor is developing a new bath-smelting process (IFCON¹⁴), and Voest Alpine and Lurgi are developing the FINEX¹⁵ and CIRCORED¹⁶ processes respectively. Iron Carbide Holdings in the USA has developed the IRON CARBIDE¹⁷ process, which uses reformed natural gas as a reducing agent and source of energy.

Testwork at Mintek has shown a dc-arc furnace to be very suitable for melting pre-reduced DRI fines at very high throughputs and efficiencies in continuous operation. Iron carbide can be co-melted with DRI and scrap in this manner. The linking of a fines pre-reduction and/or iron carbide plant to a dc-arc furnace is a very real prospect in the next few years.

The world's first Corex plant (300 kt/a) has been operating at Iscor's Pretoria works since 1989 and, after the initial problems had been overcome, led to the installation by Voest Alpine of a larger (600 kt/a) unit in Korea. A similar 600 kt/a unit is planned for the recently announced Saldanha Steel project near Cape Town. Both liquid iron and the DRI from a second shaft furnace will be fed into two electric-arc furnaces to produce about 1,2 Mt of steel, as illustrated in Figure 8¹⁸.

South Africa has the potential to increase its iron and steel production, from about 9 Mt/a to at least 15 Mt/a, in the next 10 to 15 years, and one or more of the new pyrometallurgical processes mentioned will probably be used.

Ferro-alloys

The production of ferro-alloys started in earnest in South Africa only in the early 1960s, but the industry has grown very rapidly (at 14% per annum) over the past 35 years. W.M. Bleloch predicted this development in 1956¹⁹.

South Africa is now the world's leading overall producer of ferro-alloys, and dominates ferrochromium production, with just over 1,5 Mt/a from five producers in 1995 (Figure 9). Samancor is the world's largest producer of ferrochromium, with a capacity of over 1 Mt/a²⁰. Ferromanganese production

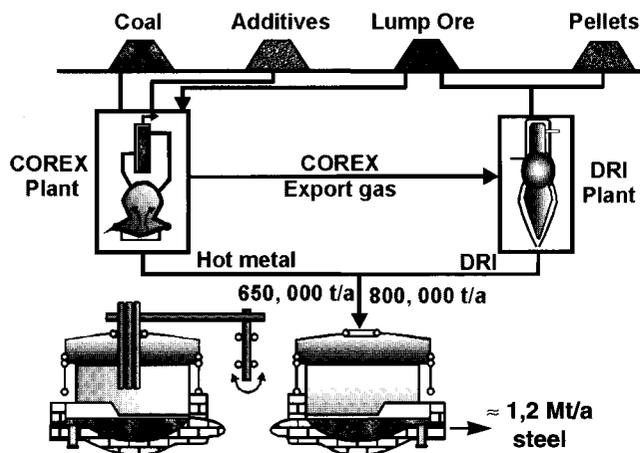


Figure 8—Process flowchart for the plant at Saldanha Steel

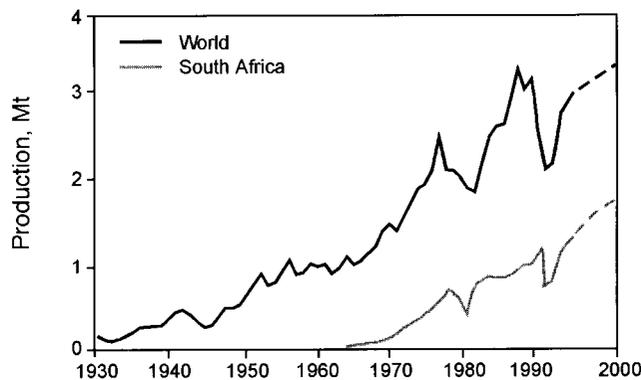


Figure 9—World and South African production of ferrochromium alloys¹³

locally accounts for just over 1 Mt/a out of a world production of about 6 Mt/a. The rapid development of the ferro-alloy industry can be attributed in part to the technology used, which was initially imported from overseas, but was further developed, adapted, and improved in South Africa through the innovative efforts of high-calibre R&D workers and producers.

One of the more noteworthy recent technical developments in ferro-alloys is the implementation at Palmiet Ferrochrome of dc-arc technology for the cost-effective smelting of ferrochromium direct from chromite fines without agglomeration.

The successful 40 MVA dc-arc project at Palmiet Ferrochrome for ferrochromium smelting, carried out by Mintek and Samancor, and submitted by The South African Institute of Mining and Metallurgy, received the AS&TS award for outstanding contributions to science, or the application of science, in South Africa in 1995.

Further developments are the use of fluidized-bed preheating of chromite fines, and a pre-reduction process using chromite fines in a high-temperature rotary kiln prior to smelting in a dc-arc furnace. These two options are illustrated in Figure 10. The latter process has been recently implemented at Middelburg Ferrochrome with the installation of a 62 MVA dc-arc furnace based on testwork carried out at Mintek and Palmiet Ferrochrome.

Stainless steel

The invention of the AOD converter process in the USA in the late 1960s led, not only to the expansion of the world's

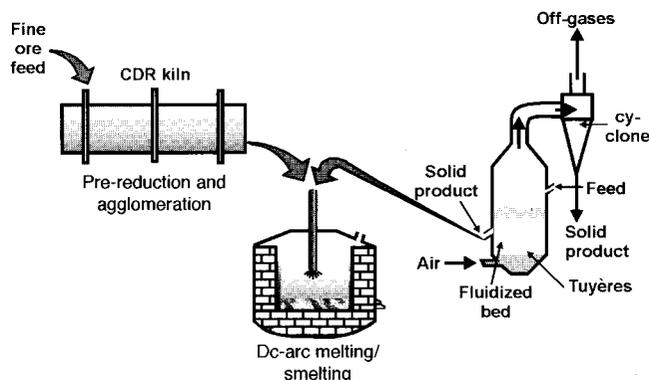


Figure 10—Fluidized preheating/Chrome Direct Reduction (CDR) and dc-arc smelting of ferrochromium

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stainless-steel industry (currently growing at almost 6% per annum), but also to the dramatic development of the ferrochromium industry in South Africa. Pyrometallurgy features very dominantly in the production of stainless steel, and one of the developments that have taken place includes the use of a liquid ferrochromium feed to the three-phase ac-arc furnace in the production of liquid crude stainless steel. Columbus Stainless have made provision to use liquid ferrochromium in their new plant, and Iscor, which recently started producing stainless steel, plan to use liquid ferrochromium at their Pretoria Works at a later stage.

Computer-controlled converting of liquid crude stainless steel in an AOD/CLU vessel to produce refined stainless steel has significantly improved the productivity of the process. The demand for better qualities of stainless steel is placing emphasis on the use of cleaner feed materials, and on the development of processes that limit the input and transfer of impurities. The selection of the sources of iron, chromium, and nickel units is a very important aspect of a stainless-steel operation. The possibility of Columbus Stainless obtaining iron units from sources such as magnetite fines by producing DRI is being evaluated. However, good dephosphorization is a very important issue, and can be readily achieved only prior to mixing the iron with chromium. Iscor produce their own liquid iron units in their Corex plant and, since iron consists of about 70 to 75% stainless steel by mass, this is an advantage at the Pretoria Works.

The direct production of stainless steel from chromite ore without ferrochromium as an intermediate product is a subject of interest both locally and internationally. Several approaches have been considered, but one of the major difficulties has been the occurrence of phosphorus in the presence of chromium, and the cost of its removal (which is high when compared with that from iron units). Phosphorus arises mostly from the iron ore and, to a lesser extent, from the ferrochromium and carbonaceous reducing agent. However, several technologies under investigation appear to offer good prospects for the direct production of stainless steel within a few years.

The advantages of stainless-steel production locally include the presence of low-cost energy, the potential direct use of liquid ferrochromium, and the availability of state-of-the-art technology. Columbus Stainless is expanding its capacity from 180 to 500 kt/a, and Iscor's production of stainless steel at the Pretoria Works and at Micro Steel in Durban could raise South Africa's production to about 1 Mt even before the year 2000.

Environmental and recycling considerations

Environmental awareness is playing an increasingly important role in process selection, and changes in technology necessitated by environmental considerations have the potential to actually reduce production costs. New projects in developing countries give engineers the opportunity to 'design in' the environmental aspects, unlike the often more costly add-on solutions for existing plants in first-world countries.

Although hydrometallurgical processes have been projected in many instances to take over from pyrometallurgical routes, environmental considerations have reversed this trend in a number of cases, particularly where the residues generated can leach toxic species into ground water. This trend towards pyrometallurgical processes in environmental management is also affecting South Africa quite significantly. Here, we are in the fortunate position of being able to learn from the lessons of

first-world countries, and to protect the environment by creating and maintaining environmental awareness through events such as symposia orchestrated by the SAIMM's committee for the environment.

One example of this sort of international environmental problem is that arising from the production of zinc metal by the conventional hydrometallurgical electrolytic route, which involves the roasting of zinc sulphide concentrate in a fluidized-bed reactor (FRB), followed by several leaching stages in the sulphuric acid recycled from the electrolytic plant. The final iron-rich residue contains leachable lead and cadmium, and no hydrometallurgical process developed to date can render this residue completely safe for disposal. The latest approach has therefore been to leach the roasted zinc oxide in a neutral or single leaching stage, followed by fuming of the zinc oxide.

Several producers, which are predominantly located in countries with former centrally planned economies, use the conventional rotary kiln or Waelz process to treat these residues. However, the clinker produced by the kiln does not normally meet the required standards for disposal, and alternative routes are being developed that produce disposable slags (e.g. that using the dc-arc furnace as shown in Figure 11). The advantage of this process is its ability in principle to produce either zinc metal direct or zinc oxide fume (which has to be recycled to the electrolytic zinc circuit and has therefore to be compared in quality and cost with roasted zinc concentrate). The proposed new zinc smelter based on imported zinc concentrates that is being evaluated for the Eastern Cape will no doubt have to face these issues.

Zinc production could grow from about 100 to 300 kt/a by the year 2000 if this project proceeds. The Gamsberg deposit requires very large-scale mining (200 kt/a of concentrate) to justify its development. Furthermore, the presence of high manganese levels also limits the selection of the process. Fortunately, the use of either a bath-smelting or the dc-smelting/fuming process can in principle overcome the manganese problem. A process route based on roasting concentrate followed by dc-arc smelting, zinc fuming, condensing, and distilling should be evaluated since this would eliminate the need for electrowinning. If Gamsberg proceeds, zinc production could increase to about 0.5 Mt/a.

Manpower considerations (education and training)

If the revenue lost by falling gold production is to be made up by income from other industries such as stainless steel and

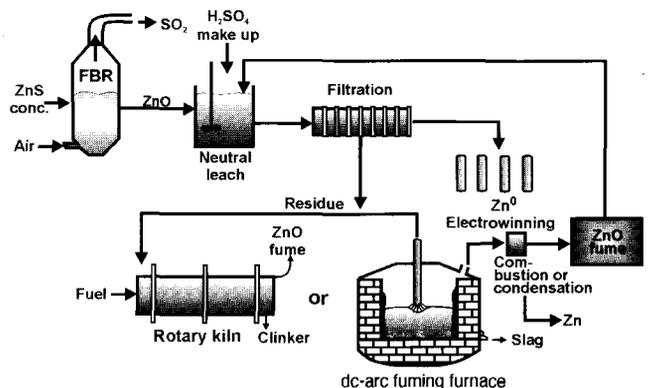


Figure 11—Flowsheet for the treatment of residue from a zinc smelter

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aluminium, the effect on manpower requirements will be significant. The gold-mining industry has been able to rely on chemical engineers, as well as on metallurgical engineers, for its extractive technology. However, the technology for the production of titania slag, stainless steel, and aluminium is very different from that for gold, and I forecast that this will inevitably place an increased demand for pyrometallurgists and physical metallurgists by the year 2000, and even more so by 2010.

This means that we have to start recruiting more prospective students now if we are to graduate the requisite numbers in time. To service and grow the anticipated 1 Mt/a of stainless steel in 2000 to, say, 2 Mt/a by 2010 will require at least 20 additional graduates per year in pyrometallurgy, and an equal number in physical metallurgy. This is a serious challenge to our universities and technikons. If the gold production is sustained at about 500 t/a, there will be little scope to save on high-level manpower requirements here; therefore, a real increase in metallurgical engineers at universities and technikons is needed. Unfortunately, the number of enrolments in metallurgy at technikons and universities has been declining in recent years. There is a great need to create an awareness of the expected developments in these industries, and of the variety of interesting and challenging jobs that will be forthcoming.

For example, the growth in the coal and ferrochromium industries to supply the world's stainless-steel needs will increase employment from about 30 000 jobs to double that number by 2020. A similar growth in jobs can be expected in the combined development of other local pyrometallurgical industries (i.e. 60 000 overall), which would be one of the major contributions to the national drive for the creation of employment opportunities. The importance of educating greater numbers of scholars in science and technology cannot be over-emphasized, and the SAIMM will continue to support initiatives such as RADMASTE via its regional branches. However, it is very important that the funding of scientific and technical work, and the remuneration of our technical staff, are addressed to limit the brain drain, and change the negative perception of careers in science and technology locally.

Future trends in further beneficiation

The projected growth of steel in the last quarter of this century, which was based on the rapid growth prior to the energy crisis (i.e. from the turn of the century to early in the 1970s), has not been realized. In fact, the world's production of carbon steel has stayed almost constant during the past two decades at about 750 Mt/a. It is dangerous to make forecasts based on mere extrapolation from past trends, unless serious consideration is given to all the market forces and equally (if not more important) to recognition of the enormous impact of technological development.

Steel consumption has, in fact, continued to grow, according to the number and extent of its applications, virtually to the extent of the mass growth forecasts. This has been primarily due to the development of higher-strength steels, which require far less mass to achieve similar (if not greater) benefit to the application. For example, the average mass of a motor car has decreased by almost 50%.

Environmental pressures and economic realities have resulted in an increased need to recycle metals and to make the use of energy and materials more effective and efficient.

The challenge to the pyrometallurgical industry is not only to improve the efficiency of processes and reduce the environmental impact, but also to decrease the production costs of light alloys based on aluminium and magnesium. The use of advanced alloys that have longer life-cycles is an additional way of decreasing costs and environmental impact in the longer term. This has been a major factor in the growth of stainless and alloy steels. The electrically powered car is already placing a greater demand on such metals and alloys, and this tendency can be expected to accelerate in the first five to ten years of the next century.

Is South Africa ready for this new wave of metallurgical technology? What does the future hold? What is the future for pyrometallurgy? It is my prerogative as President of the SAIMM to do a bit of crystal-ball gazing.

The areas in which major developments in the pyrometallurgical industries are likely to take place include the production of titania slag, where South Africa could double its slag output from just over 1 Mt/a over the next 10 years if market demand for titania pigment grows as expected, at about 3% per annum²¹. The value of titania slag could well approach 0,75 to 1 billion US dollars in the next 10 years, as shown in Figure 12.

Aluminium also offers significant potential in terms of additional wealth creation. The prospects for another smelter that would double the capacity from just under 0,5 to 1 Mt/a before the year 2010 seem good, and this could double up again to 2 Mt by the year 2020. This expansion could add over 2 billion US dollars to the revenue earned, as shown in Figure 13.

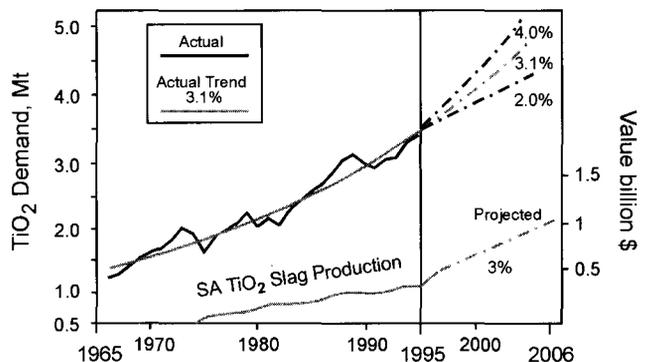


Figure 12—Demand for TiO₂ pigment²¹ and South Africa's production of TiO₂ slag

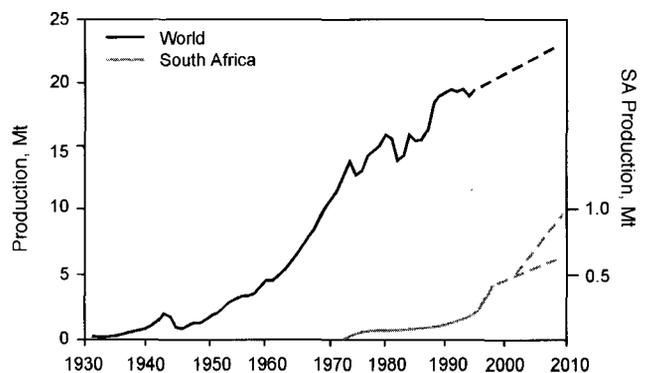


Figure 13—World and South African aluminium production¹³

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There is little doubt that South Africa's development has been largely built on the almost 50 kt of gold produced over the past 110 years. However, it is unlikely that gold will continue to play the same dominant role in the next 25 years. The metal most likely to fulfil this role is chromium as an alloying element for stainless and alloy steels, followed very closely by aluminium, as already mentioned.

However, chromium on its own will not be able to achieve this. Nickel, and potentially manganese and possibly vanadium, also have important roles to play. If the world's stainless-steel production reaches 30 Mt by 2020, based on a realistic average growth of about 6%, the demand for nickel units will almost double from 0,8 to 1,6 Mt/a. The nickel price could rise significantly, which would encourage substitution. Manganese has been shown to be a viable replacement for most of the nickel in certain grades of stainless steel, and vanadium-based nickel-free stainless steel has significant potential in specific applications²².

Vanadium stainless steels require further development in both the technical and the marketing sense. Fortunately, the production of vanadium in South Africa could be doubled from about 28 kt/a to meet the anticipated potential demand for such alloys over the next 20 years. This could increase the steel output by about 1Mt/a.

Given the necessary investment and market development, there are excellent prospects for stainless steel to overtake gold as the major foreign-exchange earner in the mining and metallurgical industry, possibly before 2010 and almost certainly before 2020. I hope that this will result from a substantial increase in the output of stainless steel rather than from a dramatic fall in gold revenue. If South Africa could increase its projected stainless-steel production of about 1 Mt/a in 2000 to 3 Mt/a by 2020, it would increase its share of world production from about 7 to 10%, and the revenue would reach about 6 billion US dollars per annum, as shown in Figure 14.

However, as shown in Figure 15, the local demand for nickel would increase to about 240 kt/a, most of which would have to be imported at considerable cost. It is therefore not surprising that several South African organizations have taken such a keen interest in exploring new nickel projects.

The total revenue from all South Africa's pyrometallurgical products could well grow from 10 billion US dollars in 1996 to double that figure in about 2020, as shown in Figure 16. The main contributions will still continue to be from iron and steel,

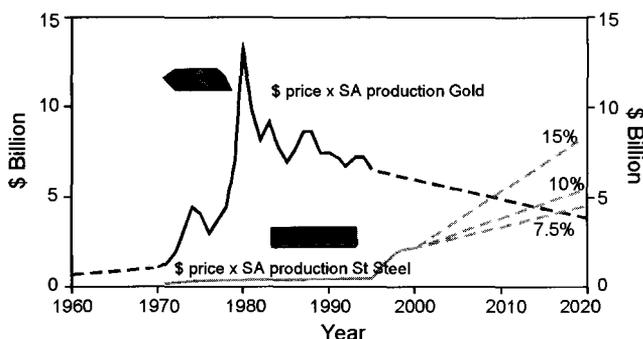


Figure 14—The potential for stainless steel to replace gold as a major earner of foreign exchange

ferro-alloys, and PGMs. However, the roles of titania slag and pigment, aluminium, and (especially) stainless steels will undoubtedly increase very significantly.

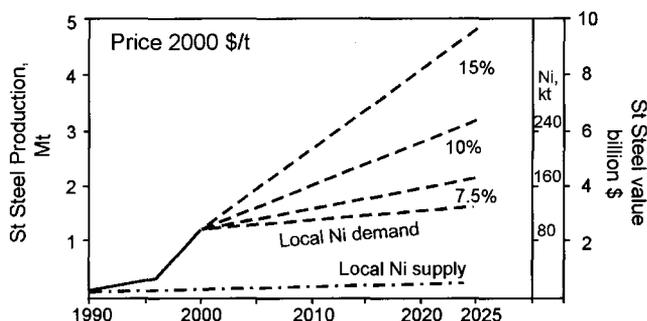
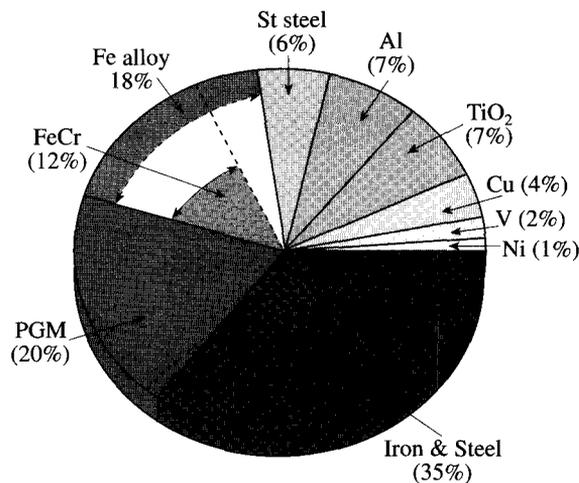
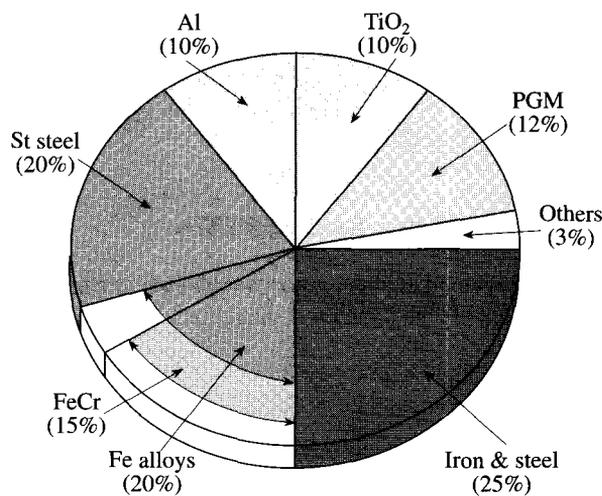


Figure 15—Projected scenarios for South Africa's share of stainless steel growth and nickel demand



1996 - Total \$10 billion

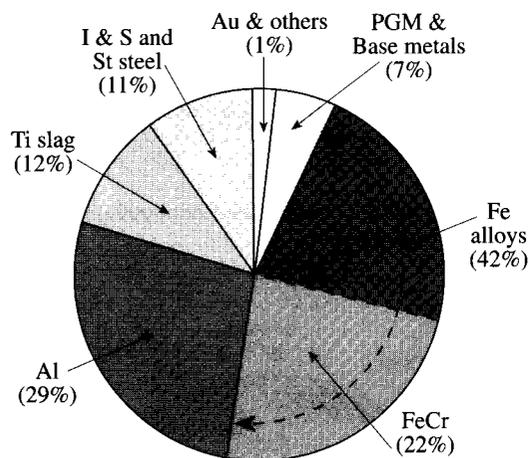


2020 - Total \$20 billion

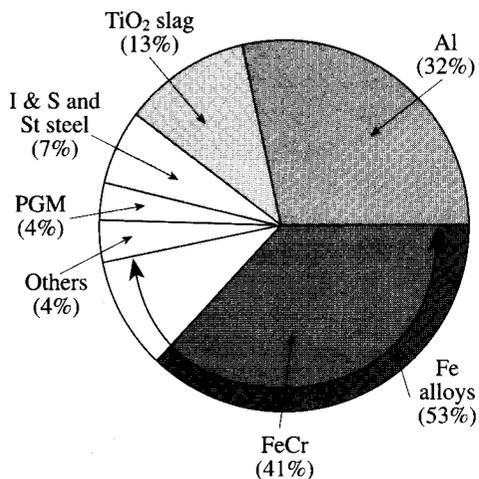
Figure 16—Current and projected value of South African pyrometallurgy products

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The projected usage of electrical energy in pyrometallurgical operations would increase from 25 TWh to about 68 TWh (i.e. about 10 GW of power) by 2020, based on the growth envisaged (Figure 17). This capacity would easily be provided out of the 160 GW of potentially available power in South Africa alone. Ferro-alloys (particularly ferrochromium) would be the major user of electrical energy, followed by aluminium and titania slag.



1996 - Total = 25 TWh



2020 - Total = 68 TWh

Figure 17—Current and projected usage of electrical energy in pyrometallurgy in southern Africa by 2020

Conclusions

- Pyrometallurgical technology has been applied successfully to most of South Africa's abundant mineral resources using the competitive energy sources of coal and electricity.
- The growth of the South African economy, while initially based on diamonds and gold, has resulted from an ability to produce many other metals and alloys such as steel, ferro-alloys, PGMs, copper, and aluminium.

- Local technologists have had to adapt and develop processes to suit local raw materials and processing requirements. R&D has played a very important role.
- A good scientific and technical understanding of pyrometallurgical and related processes has supported the implementation, control, and optimization of plants in various local mineral and metal industries.
- In spite of limited numbers of pyrometallurgically trained personnel, good progress has been made in the world-wide competitiveness of most local producers. However, future growth will become rate-determined if sufficient qualified artisans, and technician and university graduates, are not produced.
- The major areas in which growth is anticipated are those of steel, stainless steel, ferro-alloys (particularly ferrochromium), aluminium, and titania slag.
- The value of the products manufactured by predominantly pyrometallurgical processes could grow from about 10 billion US dollars in 1996 to almost 20 billion by 2020 (i.e. in about 25 years). Stainless steel and ferrochromium could well pass gold as South Africa's major foreign earner even before 2010. However, prospects to increase earnings from gold by producing far greater quantities of jewellery and by reducing the costs on deep-level mines should still maintain it as a significant contributor to the economy for the next 25 years and beyond.
- Further beneficiation of pyrometallurgical products still offers the best opportunities to generate wealth and create employment. However, the production of intermediate beneficiated products can be achieved more rapidly in the medium term in most instances since we are often better placed to pursue such activities.

The generation of wealth is what South Africa most needs right now to support its social and educational projects. As I have discussed, we have witnessed the growth and development of the major pyrometallurgical industries over the past 70 years, and I believe that the era of stainless steel has now arrived. Further beneficiation of these intermediate materials to produce added-value products offers significant additional opportunities for the generation of wealth and the creation of employment. However, the production of intermediate products can be achieved more rapidly in the medium term in most instances. It is encouraging for us to have initiatives, such as the cluster studies of the Department of Trade and Industry, aimed at added value in the metals industries covering gold, copper, aluminium and, especially, stainless steel. The multiplier effect of stainless steel in terms of job creation cannot be over-emphasized.

I would like during my Presidential year to encourage leaders of the government and industry to interact more closely with the organizations concerned with technology advancement, to ensure that the optimum use is made of our limited highly trained resources by concentrating on the objectives in our own industry that are most likely to contribute to our nation-building objectives over the next few decades. I believe that this interaction will play an important role, and should make a significant contribution to the future growth and prosperity of all our people.

Acknowledgements

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New MAP College*

Randgold & Exploration's Durban Roodepoort Deep Mine is the fourth mine in the Randgold group to have established an in-house college to assist matric pupils to better their symbols in science and mathematics. The other mines are Blyvooruitzicht (Carletonville), ERPM (Boksburg), and Harmony (Virginia).

The MAP initiative, launched in-house by Mintek in 1992, has now been replicated at 21 different locations in five different provinces. There are now some 360 students participating in MAP, with an estimated 200 former

students studying technologically related courses at technikons or universities, mostly on bursaries. It is envisioned that MAP will play an important role in expanding the pipeline of technologically qualified youngsters needed for the expansion of South Africa's mining and industry-related activities.

Other companies running in-house MAP colleges include Iscor Mining, Kentron, Mossgas, Reunert, Silverton Engineering, and Sentrachem. ♦

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