The electric smelting revolution

PRESIDENTIAL ADDRESS
given by Prof. D. D. Howat
B.Sc. (Glasgow) Ph.D

In the field of high temperature smelting processes there have been two dramatic changes in the past twenty years. These are, first, the application of tonnage oxygen for direct injection for the refining of molten iron and other metals and to provide the means of enriching air used for the combustion of fuel. Second, the application of electric power for the generation of high temperatures in place of the combustion of fossil fuels. Of these two developments the application of tonnage oxygen for the refining of molten iron has virtually revolutionised the steel industry throughout the world. The magnitude of this development is exemplified by the fact that less than 5 per cent of the world's steel production in 1960 was made by this process or 16 million tons out of a total of 350 million tons of steel produced, while in 1970 over 40 per cent of the world steel production was made by this process, ie, 251 million tons out of 628 million tons total. In the same period the proportion of steel produced by the old-established open-hearth process has shrunk from 75 per cent to 38 per cent. In the whole history of the development of high temperature metallurgical smelting processes there has never been anything remotely approaching this.

The other development, the application of electric power for the generation of high temperatures has not had the impact of the oxygen injection process but I believe that what we should call the electric smelting revolution in metallurgical processes has very far-reaching ramifications for steel production and other pyrometallurgical processes. This may seem a bold and brash statement but it must be remembered that the oxygen injection process constitutes a link in the chain critically dependent upon the production of vast tonnages of molten iron from very large modern blast furnaces. The Achilles heel of this chain of processes, upon which such a large percentage of the world's supply of steel depends, is the availability of metallurgical coke in turn dependent on natural resources of coking coal. Without any exception each industrial country in the world faces a shortage of resources of coking coal and in some cases a critical shortage. Certainly within the present century the major iron and steel producing countries of the world will face this critical shortage of coking coal and major modifications to steel making processes will become inevitable.

W. F. Cartwright (Deputy Chairman of B.S.C) said recently that there are considerable doubts as to whether the world will be able to provide enough coking coal to meet world steel demands from the late 1970's onwards if the B.F.remains the main means for making iron from ore.

This is one of the supreme ironies of the world metallurgical situation to-day when the technology of iron and steel production has reached an extremely high peak of technical efficiency. The newest modern iron blast furnace capable of producing 6 000 to 8 000 tons per day of molten iron represents probably the most efficient piece of high temperature metallurgical plant and operation known to man. The conversion of this molten iron into steel by the oxygen injection process has made available to the engineering industry steel of a quality and at a price which is quite remarkable. Yet this vast metallurgical pyramid rests on the completely insecure and uncertain foundation of inadequate world resources of coking coal.

The shortage of reserves of coking coal in this country is acute and it is possible that these resources will be exhausted within the next twenty years. Yet unless some completely unexpected catastrophe occurs the demand for steel in this country will probably rise at a faster rate than in the Western world due to the expansion of the Bantu population and the increased standard of living.

To offset the inevitable shortage of coking coal are our much greater resources of bituminous coal which although of low grade provide a suitable fuel for electric power generation. The geographical disposition of the coal fields in relation to the great industrial areas of the Transvaal makes it inevitable that the development of the pyrometallurgical industries must depend heavily on electric power.

The position in this country with regard to electrical power generation and consumption is rather anomalous. Per capita consumption of electric power is high — in 1964 almost twice the world average of 870 KWH and twenty-five times the average of 34 KWH for the Continent of Africa. In 1964 fifty-four per cent of the total world electric power was used in industry — the ratio being approximately 1/9 mining to manufacturing uses. As shown in Table I in 1969 67.2 per cent of the total output of electric power from ESCOM was used for mining and other industrial uses but almost in the ratio 6/4 mining to industrial uses. These figures emphasise the enormous importance of the mining industry to the economy of this country and underline the major contribution made by the gold mining industry. What is of very significant importance is that although the mining industry remains by far the largest single consumer of electrical power the consumption of power for industrial uses is rising rapidly as shown in Table II.

TABLE I

TOTAL CONSUMPTION OF ELECTRICITY BY THE MAIN CONSUMER CATEGORIES IN SOUTH AFRICA

Main consumer category	Units sold by ESCOM (millions)		Percent of total in 1969	Percent increase 1968-1969	Percent average annual increase in 10 years
	1968	1969			
Bulk supplies to Municipalities	6 628	7 264	23.0	9.6	9.0
Direct supplies to:					
Mining	11 995	12 642	40.1	5.4	5.0
Industrial	7 439	8 574	27.1	15.3	12.1
Traction	2 181	2 307	7.30	5.8	10.0
Domestic	632	708	2.16	12.2	12.3
Street lighting	10	11	0.34	6.7	7.2
Total	28 885	31 506	100.0	9.1	7.9

TABLE II

PERCENTAGE OF TOTAL SALES OF ESCOM POWER TO THE MINING AND INDUSTRIAL SECTORS

Year	Percentage of total sales	
	Mining	Industrial
1964	46.5	23.0
1965	44.5	24.6
1966	43.9	24.8
1967	42.9	25.2
1968	41.5	25.8
1969	40.0	27.1

The breakdown of the use of industrial power as given in Table III shows that the major consumption in this sector occurs in the iron, steel and base metal industries which account for almost 43 per cent of the industrial power consumption and almost 12 per cent of the total power supplied by ESCOM and has shown a 57.8 per cent increase over the five years 1965-1969.

While inflation in the South African economy has not been unduly serious except in the past two to three years the same pattern of price changes in the electrical supply industry has been seen here as elsewhere. The surprising fact is that the price of electric power has not risen in anything like the same ratio as other basic costs. Fig 1 showing the number of units of power sold in this country over the past decade brings out the striking fact that during that period the price per unit sold has risen from 0.50 cents to 0.5565 cents, an increase of 11.3 per cent or just over 1.1 per cent per annum.

Several factors have combined to keep the rise in cost of electric power at such a relatively low level. First of these is greater efficiency of coal utilisation. Coal represents 27.1 per cent of the working costs of the ESCOM undertakings and the cost of coal per unit sold in 1965 was 0.1426 cents and in 1969, 0.1412 cents.

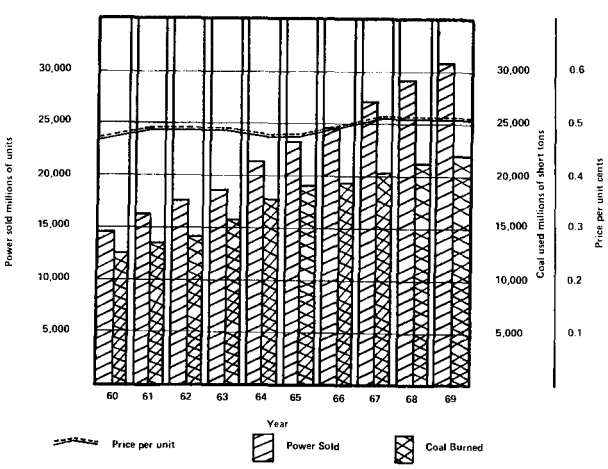

Fig 1

TABLE III

CONSUMPTION OF ELECTRICITY IN THE MAIN CATEGORIES OF INDUSTRY IN SOUTH AFRICA

	Units sold by ESCOM (millions)					Percent increase over the 5 year period	Percent of total in 1969	Percent of all units sold in 1969
	1965	1966	1967	1968	1969			
Iron, steel & base metals	2 326	2 435	2 680	2 967	3 672	57.8	42.9	11.7
Chemical (including pharmaceutical)	1 023	1 098	1 214	1 241	1 272	24.3	15.0	4.05
Foodstuffs consumer goods & commercial	751	935	1 022	1 111	1 088	44.8	12.5	3.45
Building & cement (including quarrying	508	530	562	646	716	41.0	8.5	2.25
Paper & paper products	267	416	469	493	542	103.0	6.44	1.70
Engineering (including motor industry)	393	415	544	562	535	36.2	6.34	1.65
Other	395	240	238	419	749	89.7	8.32	2.30
Total	5 663	6 069	6 729	7 439	8 574		100.0	27.1

There was a reduction of 12.8 per cent from 1.5026 lb of coal per unit in 1956 to 1.3112 lb of coal per unit in 1969. A further advantage was the increase from 66 per cent to 75 per cent in the proportion of coal burned at pithead stations with the resulting savings in transport costs.

Associated with this development has been the policy of designing equipment to burn on the power stations coal which would not be acceptable for most industrial or metallurgical purposes. This is shown by the fact that the average calorific value of the coal burned in the ESCOM power stations is 9,500 B.T.U.s per lb, compared with a calorific value of 11,500 B.T.U. per lb for coal sold for general industrial purposes.

Even in the United Kingdom where there has been an almost astronomical rise in the price of coal during the post-war period, there has been only a relatively slow rise in the price of electric power as shown in Fig 2.

Second and probably as important are the reductions in capital investment by the installation of the very large generating sets in the new power stations resulting in a marked saving in capital cost per KW of generating capacity.

This use of larger generating units is reflected in the power stations presently coming into use or under construction. Camden, Grootvlei and Hendrina are all equipped with 200 MW units. The Arnot station presently under construction will house six 350 MW units while the planned station at Kriel will consist of six 500 MW units.

As shown in Table I expansion in the sale of electric power has been at a rate of 7.9 per cent over the ten years 1960 to 1969 but the annual expansion in 1968 was 8.4 per cent and for 1969 9.1 per cent.

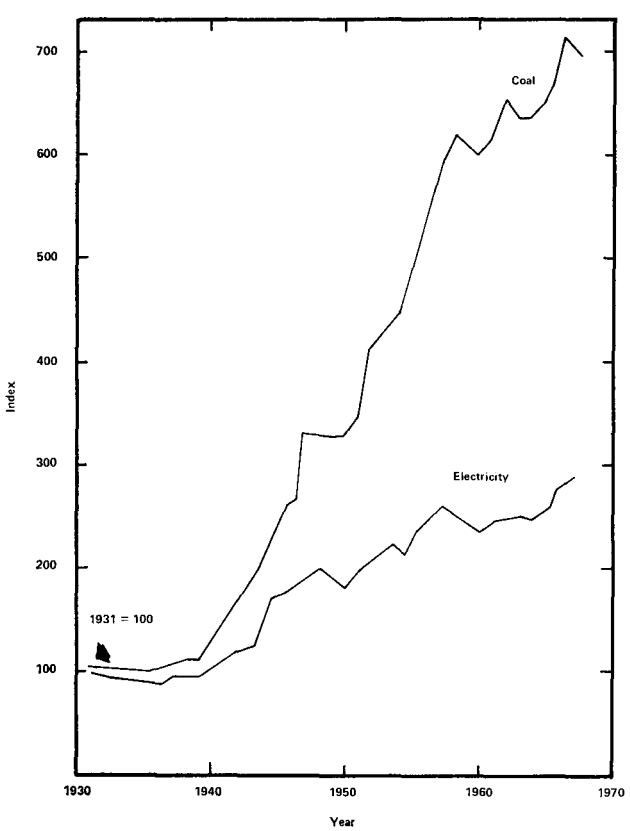

Fig 2

The installed capacity of ESCOM power stations was 4 625 MW in 1965 increasing to 6 985 in 1969 — an expansion of 51 per cent while the planned expansion to 10 880 MW in 1974 represents a further 43.5 per cent.

In the Rand and Orange Free State undertaking area of supply the average price per KWH sold was 0.4568 cents in 1969 while for mining the figure was 0.4302 and for industrial purposes the price eased slightly from 0.4414 cents in 1968 to 0.4391 cents in 1969.

While criticisms, many of them fully justified, may be levelled at certain aspects of ESCOM's policy and progress it appears to be reasonably true to say that the Commission has in general served the industry of this country well and is selling power for use in the iron, steel and base metal industries at about 0.4 cents per KWH. This must be compared with the price of electric power 0.635 cents (SA) per KWH as used by British Steel Corporation in the planning and assessment of new iron and steel making developments. This United Kingdom price of 0.635 cents per KWH is obviously based mainly on the use of oil fuel in the power stations as the general use of coal at R8 to R10 per ton would result in a much higher power cost.

The crucial question in relation to the future development in this country of pyrometallurgical operations based on electric power is the trend of power costs. If the present highly inflationary climate persists then this must be reflected in a rise in power costs and the relative stability of power prices over the past decade may be adversely affected. For this reason a tribute must be paid to those firms in this country who have under construction or on order an additional 300 000 MW of furnace capacity. These firms are presumably holding tenaciously to the belief that the price of power supplied to these plants will remain within the 0.40 to 0.50 cents range. In this connection it must be borne in mind that in the production of, for example, ferrosilicon, each 0.01 cent per unit rise in the price of power may add about R1 per ton to production power costs.

One factor which emerges very clearly is that the cost of electric power is sufficiently high that its application in pyrometallurgical processes calls for the greatest skill, ingenuity and research and development work in devising processes giving the maximum economy in the use of electric power.

Mankind has used pyrometallurgical processes for the production of metals and alloys from very primitive times. In those eras of history when slave labour was cheap and easily available, the heat, discomfort and hard physical effort of producing metals were minor factors which could be ignored by the entrepreneurs of those days and in some cases these are not so far distant. In modern times conditions are vastly different and particularly in the affluent societies of the present world.

The sociological phenomenon of to-day is that plant operators and labourers are not prepared to engage in a life-time of hot and highly disagreeable work. It is almost a truism to-day that in a society characterised by

full or overfull employment the first types of operations which suffer from labour shortages are the 'black trades' — the workers in the forge, in the foundry and in the mines. The average working man can now say to himself if not out loud — 'Why should I sweat and toil in these circumstances when I can easily get a job under much more attractive conditions?' The remarkable feature of the welfare society of to-day in the Western World is that the 'fringe benefits' are such that a man is often prepared and able to forego the limited financial advantages of working in the black trades. This implies that the incentive bonus for working in such conditions has to be considerably greater than might be considered necessary in the absence of the fringe benefits provided by the welfare state of to-day. Admittedly in this country our particular labour situation does not conform quite to this pattern. We have a large and to a considerable degree, willing if unskilled labour force, a large proportion of which works for wages lower than obtains in any of the other industrialised nations. Again there is a distorting factor because the politico-social conditions require the presence of skilled Whites as supervisors and controllers. Even where, as in mining, the ratio of white supervisors to Bantu labourers is very low the reluctance of skilled white staff to work in these conditions may nullify the potential benefits accruing from the large Bantu labour force. So long therefore, as the present industrial laws and codes of practice remain much effort has to be directed to improving the working conditions and amenities in the 'black trades' in the endeavour to retain the services of the skilled white labourers who frequently constitute only a small proportion of the total work force. A fringe benefit here is that the Bantu will have a share in the improved working conditions.

Looking back on many aspects of the pyrometallurgical industry as it was forty to fifty years ago and to-day the improvements which have been effected in the working conditions are quite remarkable. The open-hearth steel furnace, which produced about 80 per cent of the steel only twenty years ago, called for men with great physical stamina to stand the heat, the heavy labour demands for fettling and charging the ore and fluxes and the hazards of molten metal. To-day nowhere in the world would a new open-hearth shop be built, the many new plants required to provide the great tonnages of steel are equipped with LD oxygen converters and electric arc furnaces. With this equipment exposure to heat, which was probably the greatest and most trying of the conditions, has been greatly reduced.

There seems little doubt, however, that further efforts will have to be made to improve working conditions and to provide increasing amenities to attract or even to retain men in the 'black trades'. It is no flight of fancy to see the same sort of forces operating in the difficulty of recruiting students into the branches on mining and metallurgy in the Universities of the world. The marked decline in the numbers of students attending courses in foundry work in the Colleges of Advanced Education in this country is another pointer to the same state of affairs.

Much of the great improvement in working conditions in the pyrometallurgical process operations has resulted from the introduction of electric smelting. This has occurred most noticeably in those countries with the highest standard of living where presumably the difficulties of recruiting this type of labour are greatest and where in some cases, eg the United Kingdom the cost of electric power is high. This point may be illustrated by the rapid growth in the production of steel by the electric arc furnace as shown in Table IV. Within the period 1950 to 1970 world production of steel by the electric arc furnace has increased almost eight times and now accounts for almost 13 per cent of world steel production. As will be obvious from Table IV there

TABLE IV

PRODUCTION OF STEEL BY THE ELECTRIC ARC FURNACE: 1950-1970
(Thousands of metric tons)

Year	USA	Western Germany	United Kingdom	Italy	France	South Africa	World total
1950	5 392	288	736	941	528		10 423
1951	6 377	406	819	1 299	753		12 566
1952	6 069	501	930	1 510	789		12 943
1953	6 500	513	929	1 484	675		13 285
1954	4 853	666	929	1 654	821	112.3	12 080
1955	7 641	909	1 098	1 956	912		19 482
1956	8 167	1 134	1 197	2 167	994	132.1	22 031
1957	7 116	1 326	1 211	2 472	1 098	182.0	24 731
1958	5 943	1 508	1 125	2 286	1 246	211.5	24 238
1959	7 618	1 846	1 348	2 569	1 270	221.0	29 252
1960	7 481	2 139	1 685	3 128	1 470	282.1	34 290
1961	7 735	2 327	1 648	3 450	1 541	282.9	37 526
1962	8 047	2 526	1 480	3 897	1 502	309.0	38 472
1963	9 907	2 646	2 110	4 234	1 525	381.6	45 544
1964	11 501	2 998	2 985	4 226	1 675	413.0	51 181
1965	12 522	3 136	3 492	4 745	1 774	479.2	54 429
1966	13 489	3 091	3 397	4 970	1 862	503.0	57 685
1967	13 688	3 108	3 473	5 997	1 904	570.0	61 958
1968	15 253	3 683	4 217	6 427	2 067	625.0	66 766
1969	18 075	4 146	4 939	6 554	2 373	591.0	74 000
1970						732.0	77 000

has been a massive rise in electric arc steel manufacture in this country; the tonnage last year amounted to over 16 per cent of the total steel production.

Historically the first application of electric smelting in pyrometallurgical processes in this country was in the ferro-alloy industry. These ferro-alloys are essential raw material for the production of steel. Every ton of plain carbon steel produced requires 10 to 20 lb of manganese which is invariably added in the form of ferro-manganese. Thus with annual world steel production over 600 million tons between 4 and 5 million tons per year of manganese is required in the form of 5 to 8 million tons of ferro-manganese. Similarly, very large tonnages of ferro-silicon are needed. In the field of the alloy steels, eg, ball bearing steels, stainless steels, very large quantities of chromium are required, this chromium being produced as ferro-chromium.

The early development of the ferro-alloy industry was centred around ferro-silicon. So far as the production of this alloy is concerned it is probably true that this consists basically of a form of exporting cheap electric power, the other important raw material, silica, being available in large quantities widely distributed over the world.

The high consumption of power involved in the production of ferro-silicon (8 000-9 000 KWH per ton) and the relatively low cost of silica rock make this process rather different from that of the other ferro-alloys. At the normal price in this country power costs represent R35 to R40 per ton and it has been calculated that this may amount to almost 25 per cent of the price of the alloy delivered in Europe. In producing such alloys therefore even small fluctuations in the cost of electric power may play a very significant part in determining whether the alloys can be profitably disposed of overseas. Where hydroelectric power is available at say 3 US mills per KWH producers in these locations have a major advantage. At present the installed furnace capacity used in the manufacture of ferro-silicon is 38.7 MW but two new furnaces will be installed shortly, one of 48 MW and the other 45 MW expanding present capacity for ferro-silicon production by 3.5 times.

Production of ferro-manganese began about 1930 in this country using the No 1 blast furnace at Newcastle, Natal, and although modernised this furnace is still being used to produce ferro-manganese. Until fairly recently the bulk of world production of ferro-manganese was in blast furnaces but the application of this method is declining rapidly for two main reasons. Firstly, the consumption of coke at about 2 tons per ton of alloy is excessive and secondly, largely because of the high coke consumption, the rate of production of alloy is usually less than half that achieved when treating iron ores. Blast furnace production of the alloy may remain feasible if the capital investment has been virtually written off and if metallurgical coke is reasonably easily available.

Many operating problems exist in blast furnace production of ferro-manganese in addition to those mentioned. Manganese is relatively volatile at the temperatures prevailing in the furnace bosh and a relatively high proportion of metal vapour is formed. This consists of extremely fine particles, which are not easily precipitated on the charge in the upper colder regions and a significant proportion escapes with the gases. The high coke consumption results in a high gas production in a ferro-manganese blast furnace thus aggravating the loss of volatile metal. Attempts to reduce the volatilisation losses by running with lower hearth temperatures are not successful as they are almost invariably accompanied by increased losses of manganese to the slag. In consequence the recovery of manganese in the form of ferro-alloy is rarely much better than 70 per cent.

Submerged arc smelting offers extremely important advantages in ferro-manganese production, possibly the most important being the elimination of the need to use hard metallurgical coke. Carbon is required only as a reductant and this may be supplied as low temperature coke or coal char together with a greater or lesser proportion of anthracite and/or coal. In practice it has proved feasible to operate with coal alone as the reductant. Partially offsetting these advantages is the high consumption of electric power at 2 700 to 3 000 KWH per ton of alloy produced. Nevertheless at the normal price of 0.4 cents per KWH the cost of electric power barely equals that of 1 ton of metallurgical coke and normally the coke consumption in the conventional blast furnace practice is 1.75 to 2 tons.

The submerged arc furnace suffers from one of the same problems as the blast furnace, viz, high losses by volatilisation and to the slag. In open top furnaces of which there are quite a number in operation in this country, the volatilisation loss may be up to 18 per cent of manganese charged while 10 to 15 per cent is lost in the slag. Increasingly, closed top furnaces are being installed. While involving a much heavier capital investment, the outlets from these furnaces can be fitted with gas cleaning plants so reducing air pollution and making possible the recovery of high grade gaseous fuel.

The most recent development is the introduction of a submerged arc furnace, the body of which is made to rotate while the electrodes remain fixed. The hazard of electrode breakage under these conditions appears to be low as the furnaces make only one revolution in two or more days. Nevertheless the ploughing effect of the fixed electrodes appears to promote more uniform descent of the charge, greater porosity of the charge and freedom from accretions on the walls. These factors all contribute materially to improved working conditions for furnace operators and a reduction in labour requirements.

In ferro-manganese production a further development has been the introduction by the Japanese of a system of pre-heating the charge by feeding it through six vertical shaft furnaces located above the furnace roof, the exit gases from the furnace and the solid charge passing counter-current. Provision is made to burn the CO in the exit gases in the vertical shaft furnaces so increasing the pre-heat and possibly ensuring some pre-reduction.

TABLE V

FREE WORLD PRODUCTION OF STAINLESS STEEL INGOTS AND CASTINGS
(x 1 000 metric tons)

	1955	1960	1964	1965	1966	1967	1968	1969
USA	1 105	908	1 307	1 353	1 496	1 315	1 297	1 420
Japan	50	297	691	660	755	1 081	1 198	1 547
Western Germany	151	288	301	326	347	393	462	533
France	70	191	235	246	279	328	367	423
Sweden	86	180	255	280	295	308	355	371
United Kingdom	161	251	258	281	260	252	258	266
Italy	20	63	103	131	187	210	233	221
Others	57	97	150	158	171	188	200	219
Total	1 700	2 275	3 300	3 435	3 790	4 075	4 370	5 000

The furnace capacity presently in use for the production of ferro-manganese is relatively small at about 55 000 MW but AMCOR have two large furnaces of 48 000 MW each on order.

Of all the ferro-alloys produced in the world ferro-chrome has probably shown the most startling growth and at the same time changes in production pattern. By far the largest proportion of ferro-chromium alloys is used in the production of stainless steel. Table V shows that the production of stainless steel tripled from 1 700 000 tons in 1955 to just on 5 000 000 tons in 1969. Not all of this is austenitic stainless steel but it is a reasonable assumption that the average chromium content would be about 15 per cent so that a total of 800 000 tons of chromium is involved in the manufacture of these steels or 1 150 000 tons of ferro-chromium of the average grade of about 70 per cent.

Possibly up to two-thirds of this tonnage of stainless steels is composed of the typical 18/8 or austenitic stainless steels with low carbon content. Within reason the lower the carbon content of an austenitic stainless steel the better is the corrosion resisting property so that carbon contents of 0.05 per cent and much lower are commonly specified. Using the techniques for austenitic steel production common from 1947 to the late nineteen sixties much of the chromium had to be added in the form of a ferro-chromium alloy with a very low carbon content — as low as 0.02 per cent.

The escalation in world demand for this low carbon ferro-chromium alloy stimulated the development of production in this country with its vast resources of chromium ores. Production of such an alloy is a difficult metallurgical operation and the infant industry in this country was under the additional handicap that the Transvaal chromites, although existing in such vast quantities all have a low chromium to iron ratio as compared with Rhodesia and Turkish chromites.

The plants of RMB Alloys at Middelburg and Transalloys (Pty) Limited at Witbank were built and commissioned primarily for the production of low carbon ferro-chrome, both starting operations at about the same time. Meantime Palmiet Chrome Corporation had started production rather earlier but on a smaller scale. These processes, with many aspects in common, but differing substantially in many details started operations within a short period of one another. This activity in this country must have caused considerable thought in the other countries of the world in the same field. It is notable that coinciding with the expansion of production capacity in this country during 1961-1965 there was an unparalleled drop in the price of low-carbon ferro-chrome. In the United States one grade of low-carbon ferro-chrome fell from 33 cents to 22.5 cents in a period of 14 months, thereafter prices tended to stabilise at the low levels. It is a great tribute to the industry in this country that it was able to solve the technical problems including the use of ores with a low Cr/Fe ratio and to withstand the immense financial problem of the drop in low-carbon ferro-chrome prices and the so-called 'price war' which developed between South Africa and the other world producers.

Table VI gives the figures for the production of ferro-chromium alloys and the total production of all ferro-alloys in this country from 1939 to 1970 showing that the production of these alloys has increased by forty times from 1954 to 1968.

The irony of the situation is that the technique of producing austenitic stainless steel is undergoing a radical change at the present time with clear indications that the world demand for low-carbon ferro-chromium will ge drastically reduced. The new technique involves blowing a mixture of oxygen and argon through the molten charge of steel and scrap, using a converter type vessel rather similar to the Bessemer converter of 115 years ago. The latest installation of this type at Panteg in South Wales incorporates a 16 MW open arc furnace to melt the charge of scrap steel and ferro-chromium giving a molten metal which may contain up to 19 per cent chromium and 1.5 per cent carbon. This is transferred to the converter of 40 to 50 tons capacity and blown with oxygen-argon mixture which allows the carbon to be brought down to very low

TABLE VI

PRODUCTION OF FERRO ALLOYS IN SOUTH AFRICA

Year	Total production of ferro alloys (all types)	Production of ferro chromium alloys
	Short Tons	Short Tons
1939	4,300	
1944	9,000	811
1949	14,500	320
1954	28,500	3,041
1955		11,370
1956	69,900	20,876
1957	71,200	13,923
1958	76,100	4,858
1959	115,100	14,152
1960	190,000	26,134
1961	216,700	30,061
1962	201,000	24,040
1963	231,200	11,583
1964	253,900	85,913
1965	365,600	104,475
1966	370,400	108,833
1967	395,000	131,536
1968	385,300	113,256
1969	467,400	107,498
1970	462,000	103,762

levels. While the demand for low-carbon ferro-chrome will continue for some years it is almost certain to dwindle some estimates suggesting that it may decline to about 10 per cent of the total carbon ferro-chrome used in the industry. In consequence one of the plants in this country originally designed to manufacture low-carbon ferro-chrome is now producing quite different types of ferro-alloys.

Total installed furnace capacity at present used for the production of high-carbon ferro-chrome is probably about 30 MW and for the production of low-carbon ferro-chrome about 75 MW. The striking fact is that two new furnaces are presently being installed for the production of high-carbon ferro-chrome — one of 49 MW and the other 33 MW, no increase in the production capacity for low-carbon ferro-chrome being planned.

Production of high-carbon ferro-chrome and of the so-called 'charge chrome' is increasing rapidly. At the present time some 20 per cent of the world demand for ferro-chrome is exported from this country.

Although the drop in price and the expected drop in demand for low-carbon ferro-chrome represented a major set-back to the industry in this country there have been certain advantages. First, the submerged arc electric arc furnace equipment is sufficiently flexible to be used for the production of other types of ferro-alloys. The open arc furnaces used for the slag melting are rather less flexible and need much more extensive modification. Shop lay-out designed to facilitate the operation of the Perrin process for low-carbon ferro-alloy production represents a relatively high capital investment, and is of little value in the conventional manufacture of other types of alloys. Offsetting these to a considerable degree are the much simpler metallurgical processes involved in the manufacture of say charge chrome, which will probably largely replace the low-carbon ferro-alloys for stainless steel production in the new argon-oxygen blowing process.

The ferro-alloy industry, although relatively recent in its major developments, is still a field which in common with any other chemical metallurgy process is based largely on accumulated practical experience and know-how, the scientific and research background being very sketchy. Yet the industry operates under highly competitive and cut-throat price conditions where any benefit resulting from the application of valid technical data may mean a substantial price advantage. It is no secret that except for ferro-silicon the two major cost items are raw materials (mainly ore and coke) and electric power, raw materials amounting to 34 to 38 per cent of production cost and electric power 20 to 25 per cent. There can therefore be little doubt as to the directions which research and development work should take. First, a study should be made of those factors which determine the percentage recovery of the relevant element in the finished ferro-alloy. There are indications that recovery figures are in many cases disappointingly low. Some preliminary test work has shown that recovery of the chromium in the ferro-alloy may be less than 80 per cent with losses of oxidised metal in the slag up to 17 per cent, and entrained particles of ferro-alloy in the slag up to 3 per cent. So far as losses of metal oxides in the slag are concerned research should be directed to the determination of the activity of the oxides of chromium in the type of slags commonly used and also to the kinetics of the reduction reactions. In this regard we have already found that the presence of chromium oxides in the slags raises the liquidus temperatures very markedly. In some respects this may be an advantage as it facilitates attaining the necessary superheat in the alloy prior to tapping. Equally this creates problems in that the slag becomes increasingly viscous and the liquidus temperature is probably so high that the slags tapped are not completely molten. The viscosity of the slag and the necessity to tap below liquidus temperature are bound to aggravate the loss of chromium, both in the form of entrained alloy particles and probably as unreacted chromite ore. Apart from purely temperature consideration any assessment of possible improvements in recovery of chromium oxide from the slag will depend upon a knowledge of the activity of the oxides and of the kinetics of the reduction reactions.

Electrical power consumption in any ferro alloy process is to a degree a reflection of the free energy of formation (or stability) of the oxides concerned, and when producing 75 per cent ferro-silicon the power consumption is about 9 000 KWH per ton, while roughly the same grade of ferro-manganese involves the consumption of about 3 000 KWH per ton. Energy balances in submerged arc smelting are very difficult to determine, one of the few publications available suggesting that in the electric smelting of haematite iron ores the efficiency is only 65 per cent. It is a fairly safe deduction that the efficiency will decrease when treating oxides of much greater chemical stability than haematite.

Even at the relatively moderate price of electric power in this country there is obviously great incentive to investigate possible methods of reducing power consumption in the production of ferro-alloys.

While many of the details of submerged arc heating are very uncertain it is reasonably clear that the highest temperature zones are just at the tips of the electrodes and normally a pool of molten alloy with a superincumbent layer of molten slag is underneath each electrode. Ideally there would only be one uniform pool of molten alloy and slag in the base of the furnace, the pool being circular in cross-section. The hard facts of experience however, show that the ideal is frequently not achieved, two or more separate pools being formed in a cloverleaf type of pattern. Above the molten pool and constituting a zone around the end of the electrode is the bed of incandescent coke with molten material percolating down through the interstices of the coke bed. Hot gases produced in the zone at the tip of the electrodes flow upwards through the coke bed and then through the unmelted charge transferring heat to the downward descending material and possibly effecting reduction of some of the oxides. To ensure that the hottest zone is at the tip of the electrode it is essential that the zone of highest electrical resistance should be right at the top, the resistance decreasing progressively down to the zone at the tip of the electrodes. If these conditions are not fulfilled then — to use the colloquial expression — the electrode starts to climb out of the charge so upsetting the smooth operation of the furnace. The carbonaceous reductant is probably the biggest single factor which may be employed to control the resistance of the solid charge. In this respect reductants other than metallurgical coke (char, semi-char, anthracites, etc) perform better in the furnace, their higher resistivity ensuring deeper penetration of the electrodes with a reasonable power consumption, while changes in size of the reductant also bring about significant changes in the resistance.

The metallic oxide ores in the charge also contribute to the total resistance. The available data are scanty but it would appear that some of the oxide ores and particularly the chromites show a very marked reduction in resistance when heated up to 1 200 °C. In some test work in my Department we found that the resistance of chromite ore fines dropped by values of 10^4 as the temperature was raised from 400 °C to 1 200 °C.

Variations in the chemical compositions of the chromites also exerted a marked effect on the resistance and it would appear that Transvaal chromites have a significantly lower resistance than the Rhodesian chromites.

Nevertheless the total resistance of the submerged arc electric furnace is so low — usually about 1 milliohm — that although the reduction in resistance of the charge does undoubtedly occur the net effect of charging preheated material to the furnace results always in a reduction in power consumption.

One new development which may force changes in the whole technique of smelting is the proposed use of pre-reduced pelletised material. The friable nature of many of our chromite ores results inevitably in producing a high proportion of fines in the product from the mine. It is highly uneconomic and wasteful to dump these fines yet the proportion which may be safely accepted in the furnace charge is usually small, although some recent developments suggest that much higher proportions may be safely accepted.

The alternative is to grind and pelletise the fines incorporating the reductant in the pellets. Firing in a rotary kiln or by other means may then be used to produce mechanical strength together with virtually complete reduction of the iron oxide and a conversion of a substantial proportion of the chromium oxide to chromium carbide. Feeding these reduced pellets to the normal submerged arc furnace may result in profound changes in the pattern of electrical resistance of the charge, particularly as the carbon reductant is dispersed uniformly and in finely divided form and the inherent resistance of the reduced pellets is significantly lowered.

If it proved necessary under these conditions to operate the smelting furnaces as open arcs charging the reduced pellets around the periphery of the furnace body would the potential savings in power consumption due to the pre-reduction of the iron and the chromium oxides be offset by increased power consumption in open arc operation? Alternatively would it be possible to operate the smelting furnaces in a way similar to that employed in the matte smelting furnaces? In these furnaces the electrodes are submerged to a substantial depth in the slag layer. The much greater differences in resistance between ferro-alloy and slag as compared with molten matte and slag might preclude this type of operation.

Obviously there are many exciting new lines of research and development even in the one field of ferrochrome production which urgently need to be followed up.

While there is no consensus of opinion on the matter there are several indications that the resistivity of the slag produced in submerged arc furnace operation may have very important effects, slags with higher resistivities tending to keep the electrodes down in the charge and making possible increased power input to the furnace. Several research projects are in progress dealing with the resistivity of slags, particularly those used in the production of ferro-chromium. Salient points of interest in the practical application of this work are (a) that the resistance of the slag increases with the silica content, (b) that the lower the value of the ratio MgO/CaO the higher is the resistivity of the slags, (c) an increase in the Al_2O_3 content causes a decided decrease in resistance of the slag. These findings are already revealing practical problems in slag control in submerged arc smelting. To ensure reasonably good superheat in the molten alloy before tapping a high melting point slag must be formed. This normally implies a high basicity ratio but a relatively low electrical resistance, slags with high resistivity values contain higher SiO_2 contents but having lower liquidus temperatures.

The application of electric smelting of iron ores constitutes another extremely important new development in this country. Reference was made earlier to the generally accepted fact of the limited resources of coking coal in this country and to the efforts being made by Iscor to develop a suitable formcoke reductant for

use in the conventional blast furnace. For a short term future Iscor have to accept the undoubted technical and economic superiority of the blast furnace/basic oxygen route to steel production, and their plans for the new plant at Newcastle are presumably made on this basis. In the face of the great reserves of high grade iron ore in the country the comparatively large resources of bituminous coal which could be used as a reductant, and the assumption of the maintenance of reasonably priced electric power, there is a strong incentive to make a really sustained effort on adequately sized plant of the possibilities of direct reduction of iron ore followed by smelting sponge iron in electric arc furnaces.

The process in use at Highveld Steel and Vanadium Corporation Limited differs significantly from any currently accepted version of the direct reduction processes in that a partially reduced ore is smelted in submerged arc furnaces to produce pig iron. The necessity to recover the vanadium contained in the ore has largely dictated the adoption of this unusual procedure. The very intriguing feature of the Highveld process is the partial reduction of the crushed magnetite ore in a kiln at about 1 100 °C. The use of partially reduced and preheated ore can reduce the power consumption per ton of molten iron produced in the submerged arc furnace to 50 to 60 per cent of the figure of 2 600 KWH which is typical of that obtained in smelting a cold unreduced charge. When the recovery of vanadium is an integral part of the whole process — as is the case at Highveld — then this somewhat unusual process can be accepted even with the high power consumption involved.

When using high grade haematite iron ores as the starting material it would almost certainly be necessary to adopt some form of the SL/RN kiln processes in which the reduction in the rotary kiln is carried to a much higher degree than at Highveld and a true sponge iron is produced. For efficient operation reduction of the iron oxide must exceed 95 per cent and the proportion of gangue in the ore must be low — probably in the region of 5 per cent. In the case of the high grade haematite ores of this country this would not be an impossible requirement and could probably be achieved by a well controlled sink/float treatment in the manner presently practised by Iscor.

The degree of reduction achieved in the kiln has a significant bearing on the power consumption in the open arc electric melting furnace. This could probably be held within the range 600 to 800 KWH per ton melted. This however is significantly higher than in the best practice for melting scrap where values down to 480 KWH/ton have been reported.

At the recent International Congress on electric arc steel production several papers dealt with the direct reduction of iron ores and melting of sponge iron in the electric arc furnace. The Steel Company of Canada have developed the SL/RN contimelt steelmaking process which has been tested in furnaces up to 200 ton capacity. A very careful economic assessment has been made of the capital and operating costs of a steel plant to be built from a green field site starting with a capacity of 1.3 million tons of steel and going up in three further

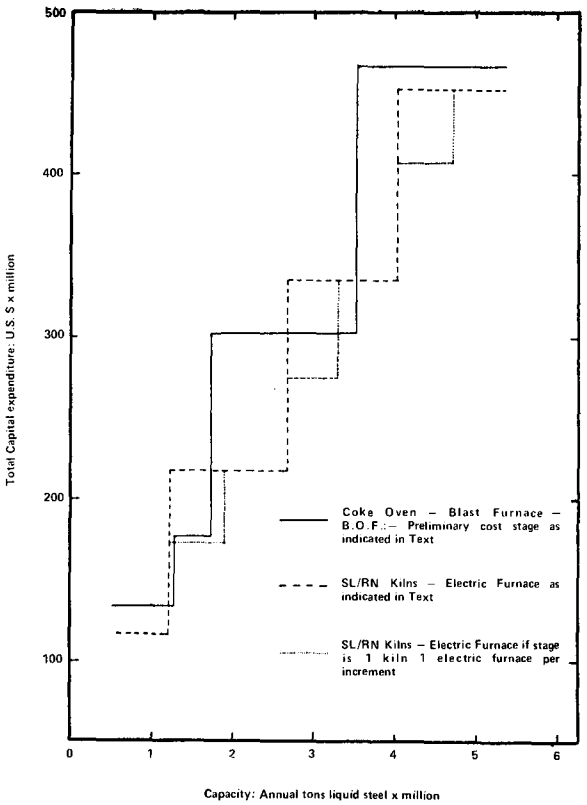

Fig 3

stages to a maximum capacity of 5.4 million tons of steel. The comparison is made between an integrated plant with coke ovens, 32 ft, blast furnaces and basic oxygen steel making and the SL/RN process involving kilns 6.6 m × 155 m and 250 ton 26 foot diameter open arc melting furnaces.

Fig 3 shows total capital expenditure versus annual capacity over the four stages of production and Fig 4 shows operating costs for the two processes against annual capacity. The claim is made that the capital charges for the kiln/electric arc process can be kept lower than those for the blast furnace BOF plant up to the 5.4 million ton level, although at this point the costs for the two different processes became almost equal. As shown in Fig 4 operating costs are significantly lower for the kiln/electric arc combination but the difference becomes progressively smaller with increase in the size of the plant.

Big changes in any of the components of capital cost of the two different plants is not anticipated but one of the main components of the working costs of the conventional blast furnace/basic oxygen steel making, viz, the price of coke, may change markedly in the relatively near future. The price of coke may be expected to increase both on account of increasing scarcity of supplies of coking coal and because of the higher wages that will be commanded by men prepared to engage in the unpopular and unpleasant task of mining the coal. This can only operate favourably towards enhancing the working costs advantage of the SL/RN versus the conventional process.

When the capacity of plants is small and the supplies of scrap limited or erratic then the SL/RN process appears to offer very definite advantages. For this reason the Dunswart Iron and Steel Works, Benoni, have very recently placed with Fried Krupp GMBH an order for the installation of a SL/RN process with a capacity of 150 000 tons of steel per year. The reduction kiln, 4.6 m diameter and 74 m in length, will be supplied with high grade iron ore with not less than 65 per cent iron crushed to the size range 5 to 25 mm.

These are some aspects of the electric smelting revolution in pyrometallurgical processes. By its very nature this revolution has not hit the headlines nor influenced astronomical tonnages of material in the manner characteristic of the oxygen injection processes. Nevertheless from the general industrial angle it has had a great impact on working conditions in plants which formerly were characterised by conditions so unpleasant that difficulties of recruiting labour were becoming serious. While it does present certain new problems I think it may be said that this revolution is making a substantial contribution to minimising pollution of the atmosphere, a theme to which the younger generation attaches great importance, probably with considerable justification.

Power stations fired with low-grade pulverised coal still present problems in relation to smoke and sulphur dioxide. There are however two mitigating factors, one being that in this country the stations are usually remote from the populated urban centres. Secondly, in the really large modern power stations it becomes economically feasible to install efficient gas cleaning plant.

Installation of really large hydroelectric generating plants demands favourable geophysical and climatic conditions but increasingly the capital investment is reaching extremely high levels. The contribution which such sources are capable of making to the total electrical demand is not very great so that the major expansion of power supply must still be provided by fossil fuel fired and nuclear stations. So far as fossil fuel is concerned conditions in this country are favourable and the exploitation of the bituminous coal resources for the generation of power is proceeding rapidly. While capital investment per KW of installed power in a fossil fuel station has been reduced during the past decade or more the major item — running cost — is critically affected by the inflationary climate of the economy. Over the past decade the purchase price of power in this country has shown only a small increase and the still larger capacity stations now coming into operation should help to stabilise capital investment costs together with effecting savings in fuel and labour in relation to running costs.

There appears therefore to be a reasonable hope that the large metallurgical groups may go ahead planning expansion in production with the confidence that increase in power costs will not be of such a magnitude as to affect adversely their ability to compete in world markets.

The extent of the resources of any mineral is always a subject for heated debate and frequent revision of

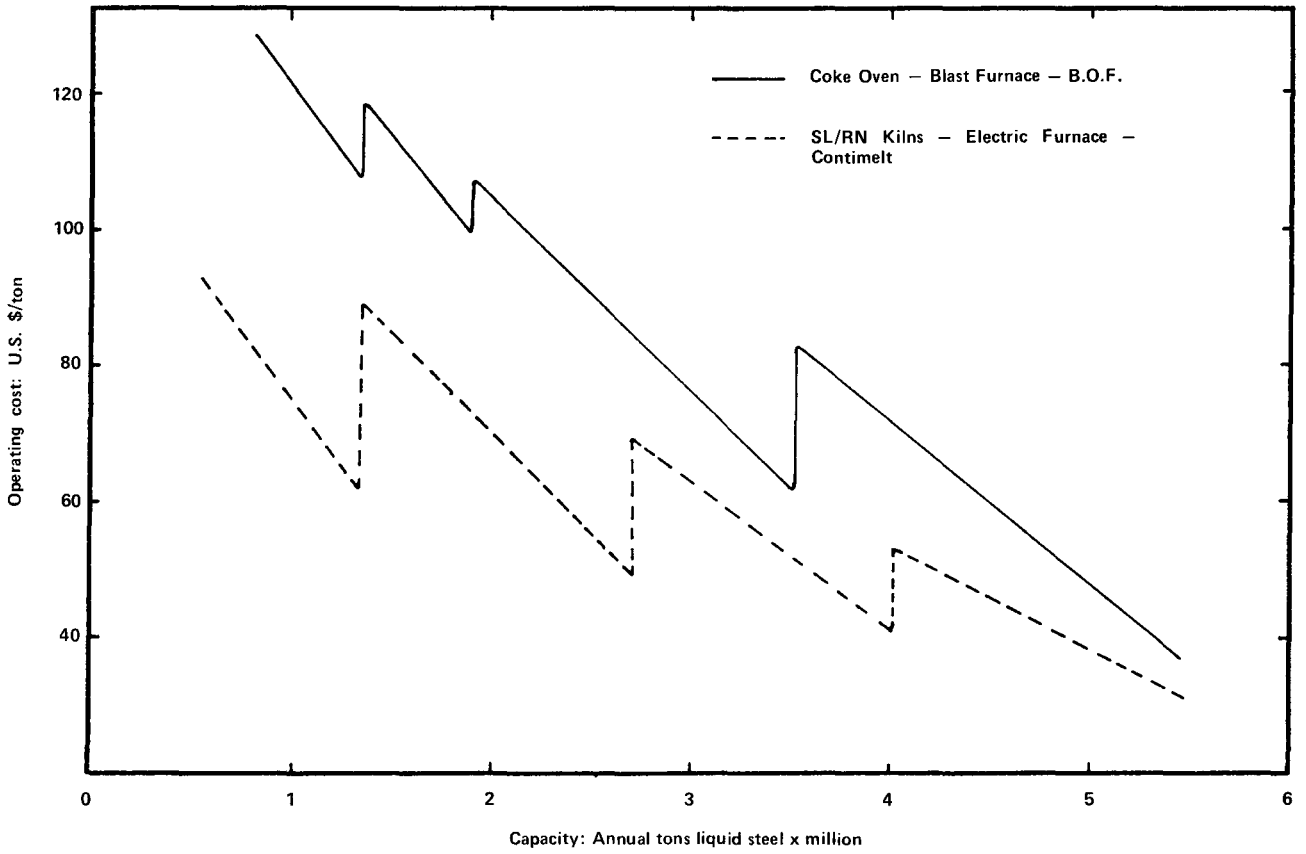

Fig 4

judgment but of the magnitude of the resources of chromite ores in this country there appears to be little doubt. Assuming that chromium remains an alloying element of major significance in steel production and particularly in stainless steel, it would appear that by the end of this century this country may be by far the largest producer of ferro-alloys in the world.

In relation to developments in the iron and steel industry this country may be forced, by reason of the paucity of resources of coking coal, to develop extensively in the direct reduction field in which Dunswart are now the pioneers.