HANDBOOK H1/2013

SOUTH AFRICANFERROALLOYS HANDBOOK

2013

DIRECTORATE: MINERAL ECONOMICS

mineral resources

Department:
Mineral Resources
REPUBLIC OF SOUTH AFRICA

SOUTH AFRICAN FERROALLOYS HANDBOOK

2013

DIRECTORATE: MINERAL ECONOMICS

Compiled by: Ms K Ratshomo

Email: (keneilwe.ratshomo@dmr.gov.za)

Picture on front cover

Source: The BoshoekSmelter, North West Province

www.meraferesources.co.za

Issued by and obtainable from

The Director: Mineral Economics, Trevenna Campus,

70 Meintjies Street, Arcadia, Pretoria 0001, Private Bag X59, Arcadia 0001

Telephone (012)444-3531, Telefax (012) 444-3134

Website: http://www.dmr.gov.za

DEPARTMENT OF MINERAL RESOURCES

Director-General	Dr. T Ramontja

MINERAL POLICY AND PROMOTION BRANCH

Deputy Director-General	Mr. M Mabuza

MINERAL PROMOTION CHIEF DIRECTORATE

Chief Director	Ms. S Mohale

DIRECTORATE MINERAL ECONOMICS

Director: Mineral Economics	Mr. TR Masetlana
Deputy Director: Precious Metals and Minerals and Ferrous Minerals	Ms. L Malebo

THIS, THE FIRST EDITION, PUBLISHED IN 2013

ISBN: 978-0-621-42052-4

DISCLAIMER

TABLE OF CONTENTS

Contents Page

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

South Africa is amongst the largest producer of ferrous minerals and amongst the leading suppliers of its ferroalloys, globally. With more than 85 percent of global consumption of ferrous minerals, steel manufacturing is by far the leading demand driver of ferrous minerals and their alloys. The country's ferrous mineral production increased on average by 6.6 percent over the last decade (2003 – 2012), with increasing proportions of these ores being processed to value-added alloys, growing at an average rate of 1.8 percent annually. Over the past decade, ferroalloys contribution to the country's Gross Domestic Product (GDP) grew at an average rate of 7 percent, contributing on average 1.5 percent to GDP. The growth in production and revenue of ferroalloys over the last decade highlights the growing importance of these minerals in the local mining industry as well as globally.

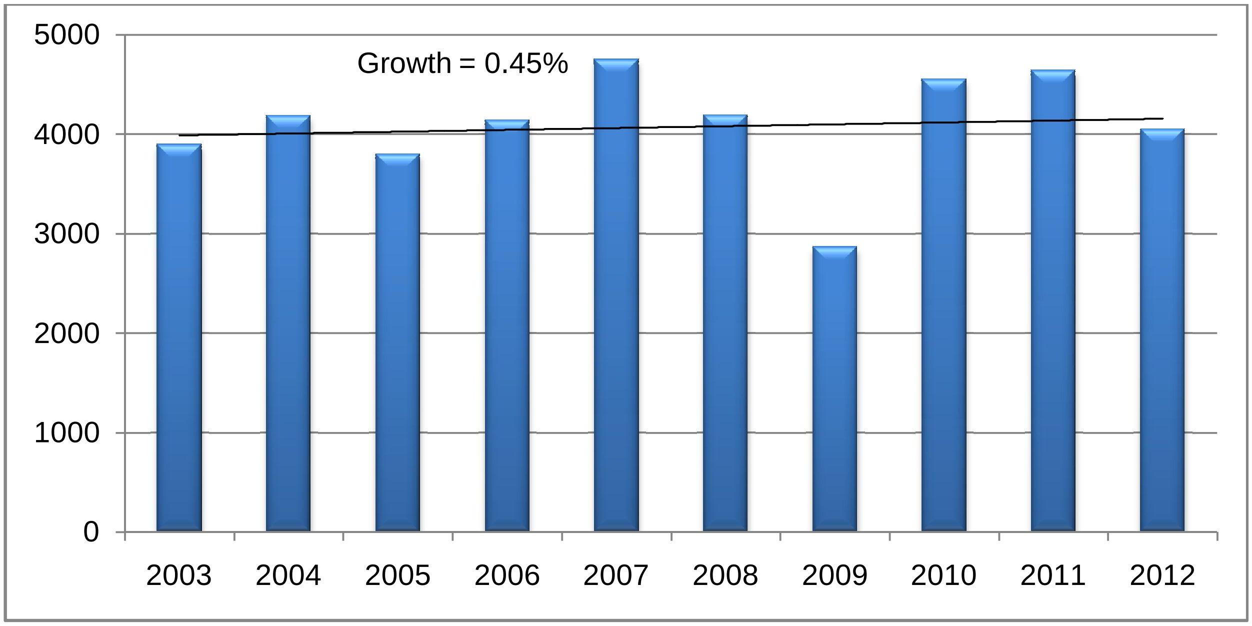
Since the promulgation of the Mineral and Petroleum Resources Development Act 2002 (MPRDA), South Africa has been striving to achieve optimum exploitation and utilization of the country's resources. Despite more than a century of mining, South Africa has low levels of mineral beneficiation in that most minerals are exported as ores, alloys or metals, rather than high value intermediate to finished products. The Beneficiation Strategy for the mineral industry of South Africa was adopted in 2011, aiming at promoting and encouraging local beneficiation of raw materials. The strategy is intended to support national programmes such as the National Industrial Policy Framework, among others.

The Beneficiation Strategy provides a framework that seeks to translate the country's sheer comparative advantage, inherited from the mineral resources endowment, to a national competitive advantage. Included in the strategy, is the iron and steel value chain amongst others.Ferrous alloys are used in the production of steel and stainless steel to instill different qualities and characteristics to the metals produced. The aim of this document is to report on the ferrous alloys specifications, value chains, production processes and their effect on steel products.

2. SOUTH AFRICA'S FERROUS ALLOYS OVERVIEW

South Africa's total ferroalloys production grew at an average rate of 0.45 percent annually, from3 896kt in 2003 to 4 049kt in 2012 (Fig. 1).Major production growth was experienced during the first half of the 10 year period, driven by the emerging global demand. The second half of the period grew at a lower average rate of production,despite the commodity boom in 2007. The global economic crisis had the worst effect on the industry, which saw South Africa's total ferroalloys production declining by 11.7 percent and 31.3 percent in 2008 and 2009, respectively. However, the recovery in the global steel market during 2010 drove the recovery of South Africa's ferroalloys market.

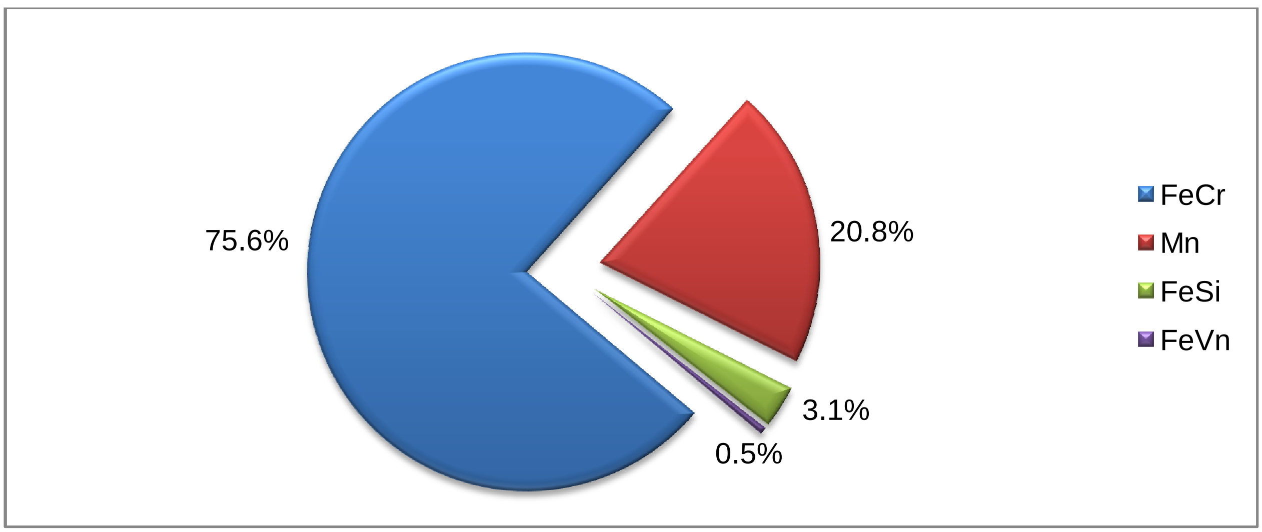
FIGURE 1: SOUTH AFRICA'S PRODUCTION OF FERROALLOYS, 2003 - 2012



Source: DMR, Directorate Mineral Economics

Ferrous alloys production was dominated by ferrochromeproduction(Fig. 2), whichgrew at an annual rate of 1.2 percent from 2003 to 2012. However, manganese and vanadium alloys production declined at average rates of 1.9 percent and 3 percent, respectively, while silicon alloys declined at an average rate of 3.7 percent annually during the same period.

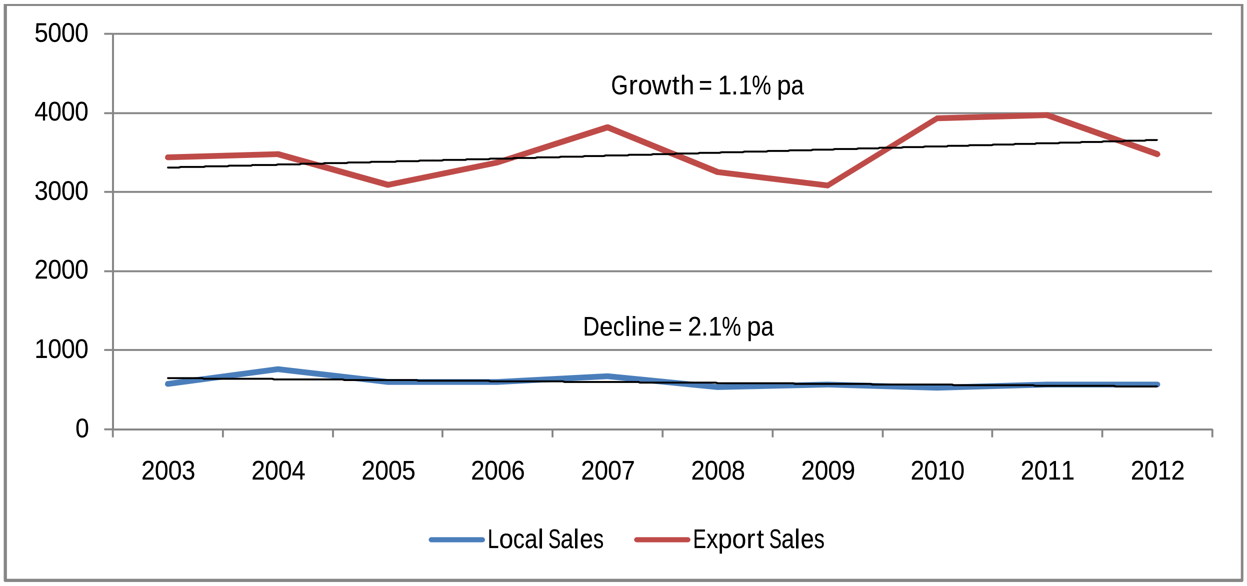
FIGURE 2: PERCENTAGE CONTRIBUTION TO TOTAL FERROALLOYS PRODUCTION



Source: DMR, Directorate Mineral Economics

Local sales volumes of ferrous alloys declined annually at an average rate of 2.1 percent during the period understudy while export sales volumes grew by 1.1 percent (Fig. 3). The ratio of export sales volumes to total sales volumes rosefrom 85.7 percent in 2003 to 86.1 percent in 2012.

FIGURE 3: SOUTH AFRICA'S LOCAL AND EXPORT SALES VOLUMES OF FERROALLOYS, 2003 - 2012



Source: DMR, Directorate Mineral Economics

3. FERROCHROME

Ferrochrome (FeCr) is an alloy of chromium and iron containing between 50 percent and 70 percent chromium. It is produced by electric arc melting of chromite, which isan iron magnesium chromium oxide and the most important chromium ore. South Africa's Bushveld Igneous Complex is a large layered mafic to ultramafic igneous body, with some layers consisting of 90 percent chromite making the rare rock type, chromitite.This complex has the largest chrome reserve base in the world amounting to about 72.4 percent,whilereserves amount to about 84.6 percent.

3.1. FERROCHROME VALUE SYSTEM

3.1.1. Chrome ore

The ferrochrome value system commences at the chrome ore production level, which is segmented by ore characteristics. The ore is produced for different applications into metallurgical, chemical, foundry and refractory grades, with each application requiring a specific grade of ore (Table 1).

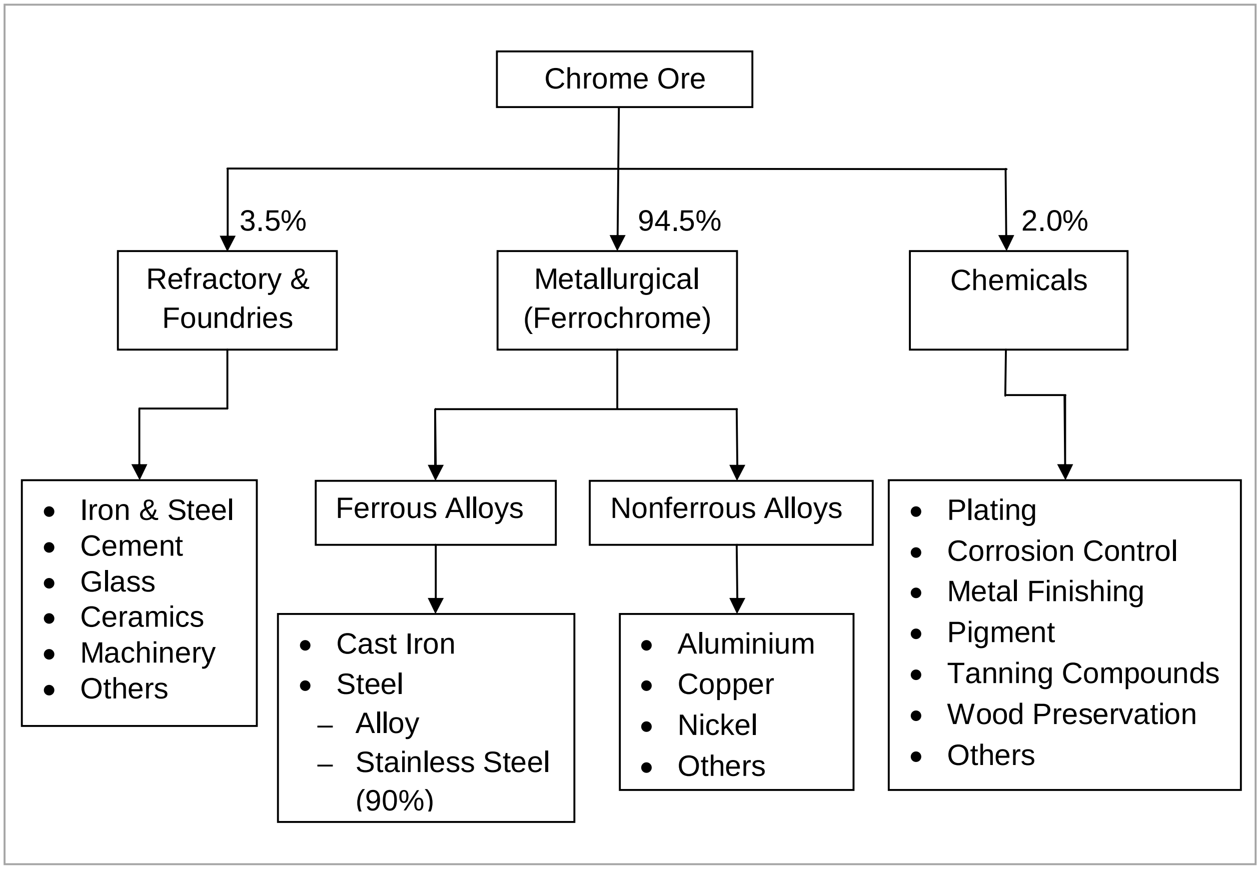
TABLE 1: CHROME ORE SPECIFICATIONS

APPLICATION	GRADE (Crcontent)
Metallurgical	>46%
Chemical	40% - 46%
Foundry Sands	40% - 46%
Refractory	>60%

Source: DMR, Directorate Mineral Economics, South African Ferroalloys Handbook, 2006

The metallurgical ore accounts for 94.5 percent of the chrome ore produced, while refractory and foundry grade ore as well as chemical grade ore account for 3.5 percent and 2 percent, respectively (Fig. 4). The ore is processed by crushing and screening, milling, screening and pelletizing.

FIGURE 4: FERROCHROME VALUE SYSTEM



Source: Ideasfirst Research, Ferrochrome, 2010

3.1.2. Ferrochrome Production

The metallurgical grade oreis used to produce ferrochrome, and it is classified by the ratio of chrome to carbon (Cr:C) it contains, into high carbon (HC FeCr), medium carbon (MC FeCr) and low carbon (LC FeCr) grades (Table 2).

TABLE 2: CHEMICAL COMPOSITION OF FERROCHROME

Grade	Chrome	Carbon	Phosphorus	Sulphur	Silicon
HC FeCr	48 - 65%	4 - 8%	0.04% max	0.05% max	1% max
MC FeCr	55 - 65%	2% max	0.04% max	0.01% max	1.5% max
LC FeCr	60 - 65%	0.03 - 0.2%	0.04% max	0.01% max	1.5% max

- **High Carbon Ferrochrome**

The vast majority of ferrochrome produced in South Africa is charge chrome, which has a lowCr:C ratio,followed byHC FeCr. Charge chrome has chrome content of 48-55 percent with carbon contents ranging from 6-8 percent.

Charge chrome is produced by reducing chrome ore with coke in a submerged arc furnace with the charge being introduced from an open top. The latest trend in charge chrome production entails the adoption of plasma furnace technology, which involves the injection of pulverized chrome ore into a shaft furnace containing generators that produce high temperature ionized gases. Plasma furnaces allow friable chrome ore fines to be used as the raw material, which results in lower material loss thereby increasing the ferroalloy recovery rate.

- **Medium Carbon Ferrochrome**

Medium carbon ferrochrome is producedby further refining of charge chrome. The silicon in the product is reduced to below 0.3 percent, and carbon is reduced to less than 1.5 percent for the lowest intermediate grade.

The process takes place in a convertor where the liquid charge chrome is bottom blown by oxygen and steam to a specific carbon content. The final product, an intermediate carbon ferrochrome, is produced in granulated form.

- **Low Carbon Ferrochrome**

In the low-carbon process, charge chrome, quartzite and reductants are combined in a submerged arc furnace to produce ferro-silicon-chromium (FeSiCr) in a ‘dry’ or slag-free process. The ferro-silicon-chrome has a low carbon content.

Ferrochrome Production Process

A generalized process flow diagram, which indicates the most common process steps utilized by the South AfricanFeCr producers, is shown in Figure 5. The country utilizes four process combinations to produce FeCr, namely:

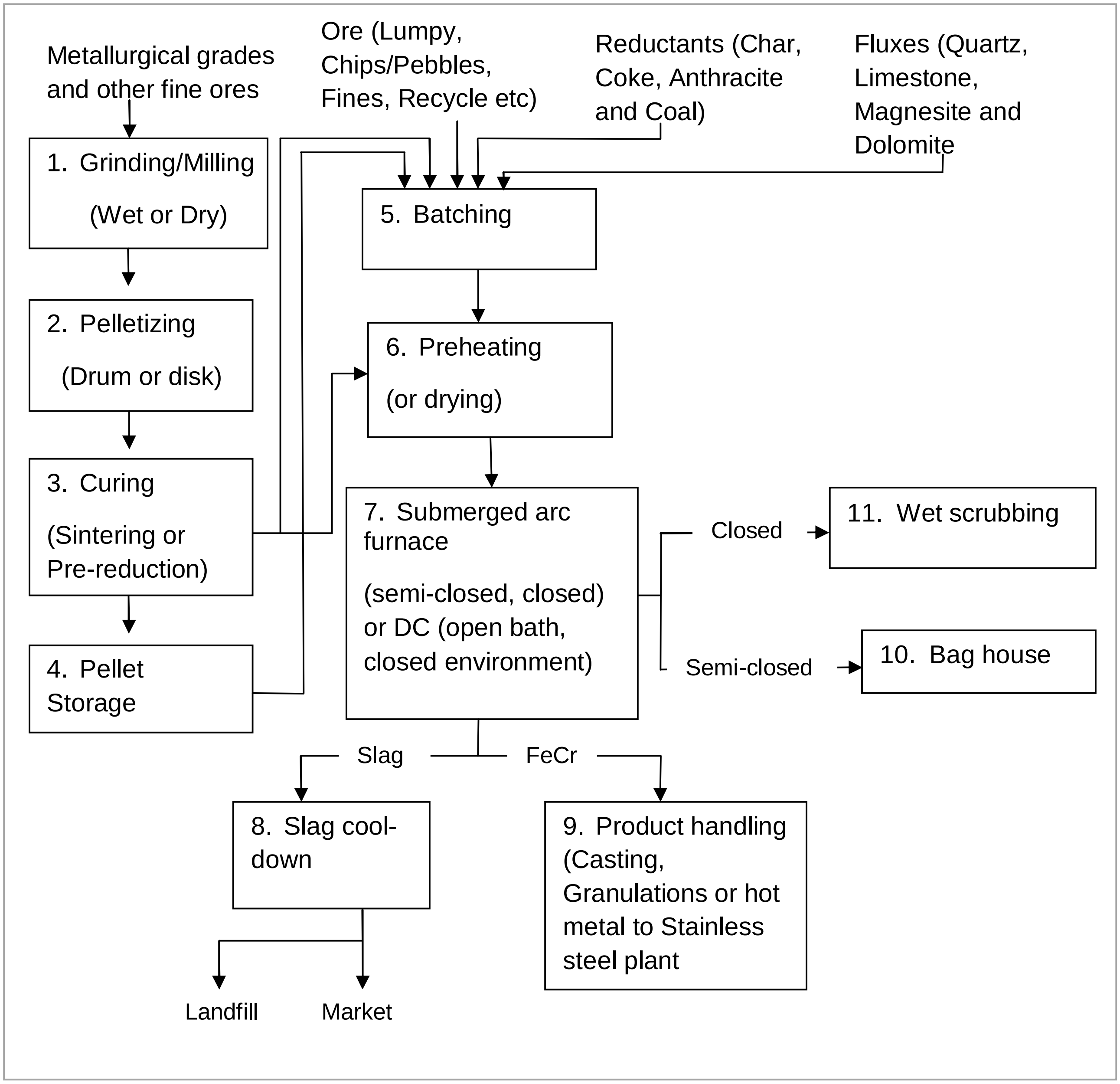
- Conventional semi-closed furnace operation with bag filter off-gas treatment. This is the oldest technology applied in the country, but still accounts for a substantial fraction of overall production. In this type of operation, coarse (lumpy and chips/pebble ores) and fine ores can be smelted without an agglomeration process undertaken to increase the size of fine ores.

- Closed furnace operation usually utilizes oxidative sintered pelletized feed. This has been the technology most commonly employed, with the majority of green and brown field expansions during the last decade utilizing it.

- Closed furnace operation with pre-reduced pelletized feed. The pelletized feed differs substantially from the oxidative sintered type due to the fact that the pellets are pre-reduced and mostly fed hot, directly after pre-reduction, into the furnaces

- DC arc furnace operation is a type of operation where the feed can consist exclusively of fine material.

FIGURE 5: FERROCHROME PRODUCTION PROCESS FLOW DIAGRAM

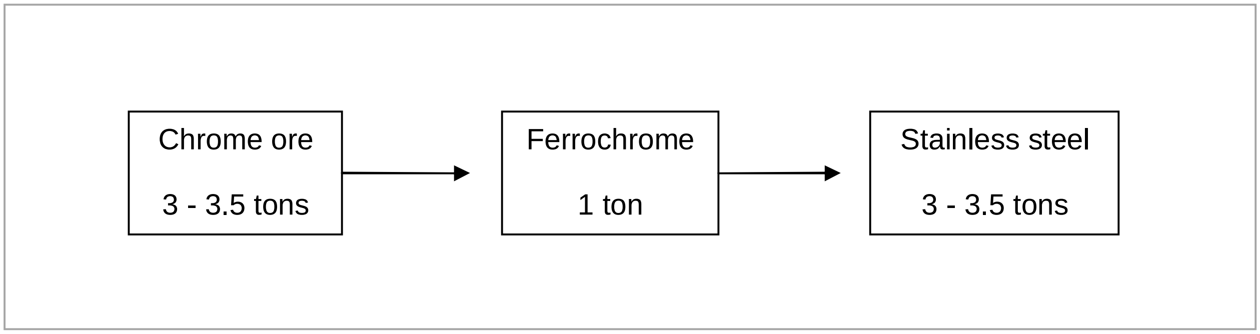


Source: The Journal of Southern African Institute of Mining and Metallurgy, 2010

3.1.3. Ferrochrome End-use Markets

The stainless steel industry consumes over 90 percent of ferrochrome produced. Approximately 3-3.5 tons of chrome ore is consumed in order to produce 1 ton of ferrochrome, while 1 ton of ferrochrome is needed to produce 3-3.5 tons of stainless steel (Fig. 6).

FIGURE 6: CHROME VALUE CHAIN



Stainless steel is in principle low carbon steel which contains a minimum of 10.5-11 percent of chromium and an average of about 18 percent. This unique steel does not corrode, rust or stain like ordinary steel due to the addition of chromium.The chromium forms a passive layer of chromium(III) oxide (Cr_2O_3) when exposed to oxygen, which is too thin to be visible, and the metal remains lustrous.The layer is impervious to water and air, protecting the metal beneath and reforms when the surface is scratched.

There are over 150 grades of stainless steel, of which 15 are most commonly used. The alloy is milled into coils, sheets, plates, bars, wire, and tubing to be used in cookware, cutlery, hardware, surgical instruments, major appliances, industrial equipment and as an automotive and aerospace structural alloy as well as construction material in large buildings.

- **Effects of Chromium on Steel Products**

The addition of chromium in steel improves:

- Strength
- Hardenability
- Toughness/Impact resistance
- Wear resistance
- Bright attractive finish

3.1.4. Ferrochrome Production Capacity

South Africa has a smelting capacity of approximately 3.7Mt for ferrochrome production with 13 metallurgical works. The chrome ore is produced from 19opencast and underground mines; in addition the ore is produced as a by-product from platinum mines.

4. MANGANESE ALLOYS

Manganese alloys are produced by the reduction ofan oxide ore in a blast furnace or electric arc furnace. Manganese is found in igneous rocks as well as in soils and sedimentary rocks. The predominant manganese ore is Pyrolusite (MnO_2), which is found in large quantities but distributed irregularly around the globe.

South Africa hosts about 80 percent of the world's manganese resources and was ranked 2^{nd} in terms of its contribution to world reserves at 19 percent.Over 90 percent of these reserves are found in the Kalahari Manganese Fields (KMF), which consists of an iron formation with inter-bedded units of manganese ore. Two main ore types are present in the Kalahari deposit, namely low-grade primary sedimentary Mamatwan-type ore and hydrothermally altered high-grade Wessels-type ore.

Mamatwan ore is rich in carbonates, primarily calcites and dolomite while the manganese-bearing mineral is predominantly braunite ($MnMn_6SiO_{12}$). The Wessels ore consists mostly of oxides, primarily braunite($MnMn_6SiO_{12}$)andbraunite II ($Ca(MnFe)_{14}SO_{24}$), but also some hausmannite(MnMn2O4), bixbyite($(Mn,Fe)_2O_3$) and hematite (Fe_2O_3).

4.1. MANGANESE VALUE SYSTEM

4.1.1. Manganese ore

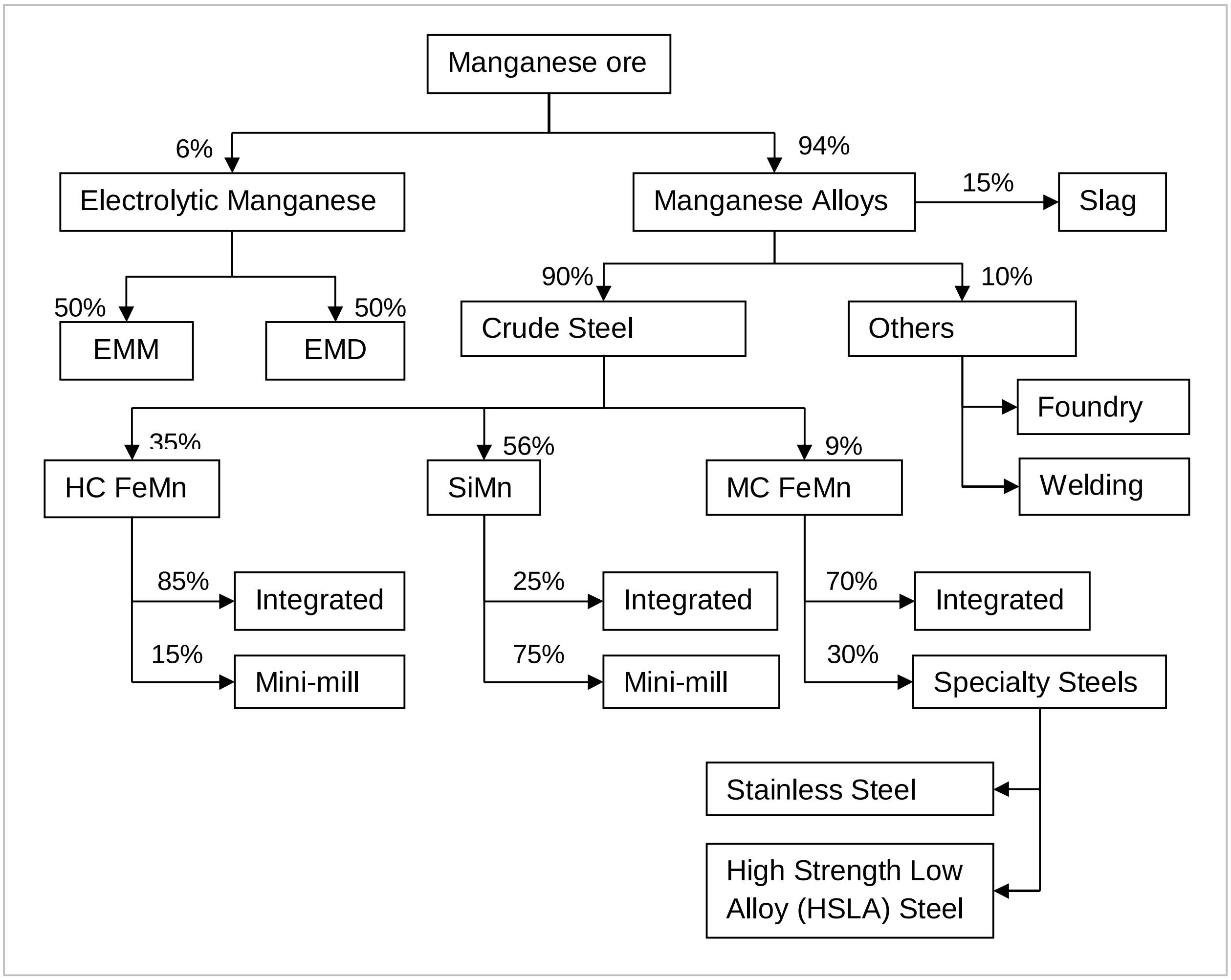
Manganese ore production is the first component of the manganese value chain. The ore is characterized by its contents of manganese, iron and various impurities into metallurgical (>35% Mn), ferruginous (15-35% Mn) and manganiferrous (5-10% Mn) ores. The ore is also commonly classified as high, medium and low grade ore (Table 3).

TABLE 3: MANGANESE ORE GRADES

Grade	Mn Content
High	>44%
Medium	30% - 44%
Low	<30%

The metallurgical grade ore accounts for 94 percent of the ore produced (Fig. 7). The ore is beneficiated by crushing and screening, resulting in various particle size fractions ranging from fines (<6 mm) to lump ore (<75 mm), and washed if necessary. Heavy media separation can be used for ores with a high content of gangue. The fine materials are then agglomerated by use of the sintering process to increase the manganese unit value per ton.

FIGURE 7: MANGANESE VALUE SYSTEM



Source: Ideasfirst Research, Manganese, 2010

***Note**: EMM – Electrolytic Manganese Metals*
EMD – Electrolytic Manganese Dioxides

4.1.2. Manganese Alloys Production

The metallurgical ore is converted into manganese alloys namely:high carbon ferromanganese (HC FeMn),silico-manganese (SiMn) and refined grades with medium carbon (MCFeMn) and low carbon (LCFeMn).These alloys vary in manganese, carbon, silicon, phosphorus and sulphur content (Table 4).

TABLE 4: CHEMICAL COMPOSITION OF MANGANESE ALLOYS

Grade	Manganese	Carbon	Silicon	Phosphorus	Sulphur
HCFeMn	65-79%	8% max	2% max	0.5% max	0.03% max
SiMn	57-77%	0.1-3.5% min	10-35%	0.05-0.35% max	0.03% max
Ref. FeMn	80-81%	0.1-2% max	2% max	0.15-0.35% max	0.03% max

Manganese alloys are produced by carbo-thermic reductionofeither high, medium or low grade ores in a blast furnace or a submerged electric arc furnace (SEAF).The burning of coke is the primary source of energy in the blast furnace, where the coke serves as a reducing agent as well as the energy source. In the submerged arc furnace, the heat requirement is supplied by the electrical energy and the coke is both the reducing agent and electrical resistant element.

- **High Carbon Ferromanganese**

High carbon ferromanganese is an alloy with high content of manganese and requires high grade ore for production in a blast furnace or SEAF. The raw material components are weighted out based on the chemical analysis of the ores, fluxes (limestone and dolomite) and carbonaceous agents and the required composition of alloy and slag.

The interior of the operating furnace is divided into pre-reduction zone and a coke bed zone. The higher oxides of manganese are pre-reduced in solid state tomanganese(II, III) oxide(Mn_3O_4) in the pre-reduction zone and preferably further to manganese(II) oxide (MnO) by carbon monoxide (CO) gas. The melting together of the ores and the fluxes takes place in the coke bed zone. The metal will collect at the bottom of the furnace from where it is tapped together with the slag.

- **Silico-manganese**

Silico-manganese has high contents of manganese and silicon and is produced using low grade ore in a SEAF. The SiMn production is often integrated with the production of HC FeMn so that the resulting slag can also be reprocessed to produce SiMn. Standard SiMn is typically produced from the blend of MnO-rich slag from the HC FeMn process, manganese ores, quartzite and coke.

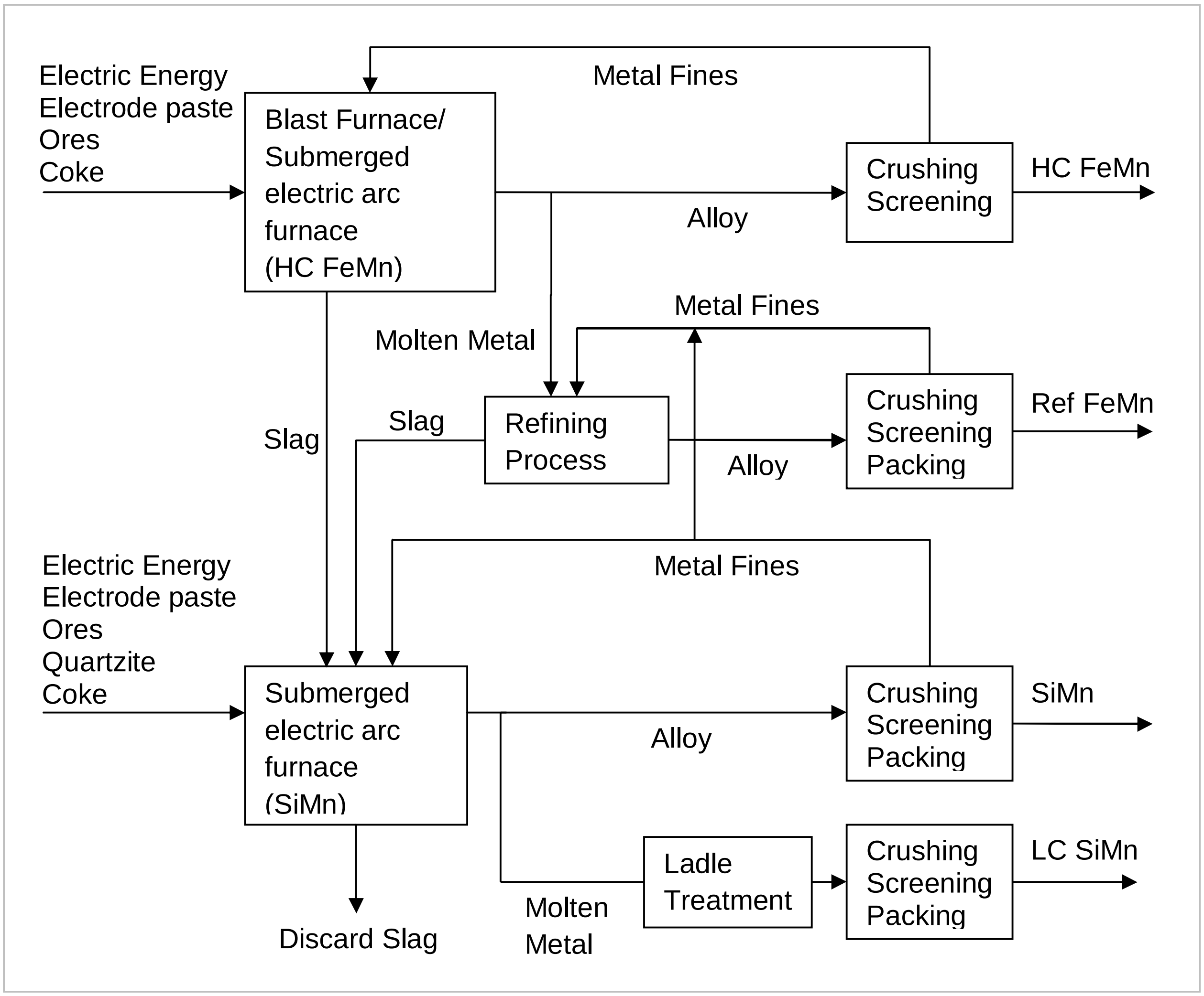
- **Refined Ferromanganese (Medium and Low Carbon)**

The high manganese content in refined ferromanganese is achieved by using high grade ore. Refined ferromanganese is either produced from HC FeMnthrough the oxygen blown converter (OBC) or SiMn through electro-thermic route.

- **Manganese Alloys Production Process**

A commonly used production process for manganese alloys is summarized in Figure 8.

FIGURE 8: MANGANESE ALLOYS PRODUCTION PROCESS

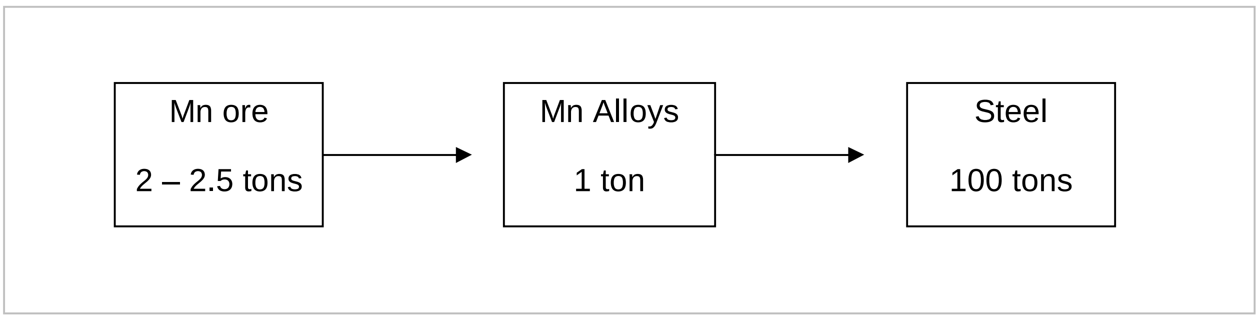


Source: Ideasfirst Research, Manganese, 2010

4.1.3. Manganese End-use Market

The steelmaking process consumes about 90 percent of manganese alloys produced. Approximately 2-2.5 tons of manganese ore is consumed in order to produce 1 ton of manganese alloys (Fig. 9).The apparent consumption of manganese is estimated at 10 kg per ton of steel produced. The amount varies significantly from region to region with the differences related to the steel production process, the quality of raw materials used, such as iron ore grades, and types of steel products produced.

FIGURE 9: MANGANESE VALUE CHAIN



Steel is an alloy of iron and carbon with high content of oxygen and sulphur. Insufficient manganese in steel results in the sulphur combining with iron to form a sulphide with low melting point, causing surface cracking. Out of the total manganese alloy that is added in steel making, 30 percent is used as a de-sulphurizing and de-oxidising agent while 70 percent is used as an alloying element.

Steel, with a manganese content exceeding about 0.8 percent, is categorized as an alloy steel. Manganese intensive steel can be classified into two groups. The first group contains low amounts of manganese as an alloying agent (0.8-2%) and the second group contains high amounts of manganese as an alloying agent (11-16%) and is known as austenitic steels (Table 5).

TABLE 5: CLASSIFICATION OF MANGANESE INTENSIVE STEEL

Low Mn Content Steel	High Mn Content Steel
Construction Steel	High Mn non Magnetic Steel
Engineering Steel	Hadfield Steel
High Strength Low Alloy Steel (HSLA)	200 Series Stainless Steel
Stainless Steel except 200 Series	

- **Effects of Manganese on Steel Products**

The addition of manganese in steel improves the following properties:

- Strength
- Elasticity
- Forging, welding and grain refining
- Wear resistance

4.1.4. Manganese Alloys Production Capacity

South Africa has a smelting capacity of approximately 1.3 Mt for manganese alloys production with 4 metallurgical works. The metallurgical grade manganese ore is produced from 9 opencast and underground mine operations.

5. FERROSILICON

Ferrosilicon (FeSi) is an alloy of iron and silicon with silicon content of between 15 and 90 percent. It is produced by the reduction of silica, an oxide of silicon (SiO_2). Silica occurs in minerals consisting of pure SiO_2 in different crystalline forms, such as quartz, amethyst, agate, rock crystal, chalcedony, flint, jasper and opal. These minerals constitute over 90 percent of the earth's crust, making silicon the second most abundant element.

In South Africa, the Witkop silica reserve, situated south of Polokwane in the Limpopo province, is a greenstone hosting quartz vein. As this reserve is almost exhausted, other silica reserves are increasingly used to supply raw material. Two significant silica reserves are known in the east of the province, near Gravelotte and Phalaborwa. Other reserves include those in the Sangqhu River Valley (near Port Shepstone), quartzite bands in the Nababeep area (near Springbok), in the Magaliesburg Formation between Silkaatsnek and Breedtsnek (North West), east of Pretoria on the farm Donkerhoek, as well as in the Delmas, Bronkhorstspruit, Belfast and Steelport area.

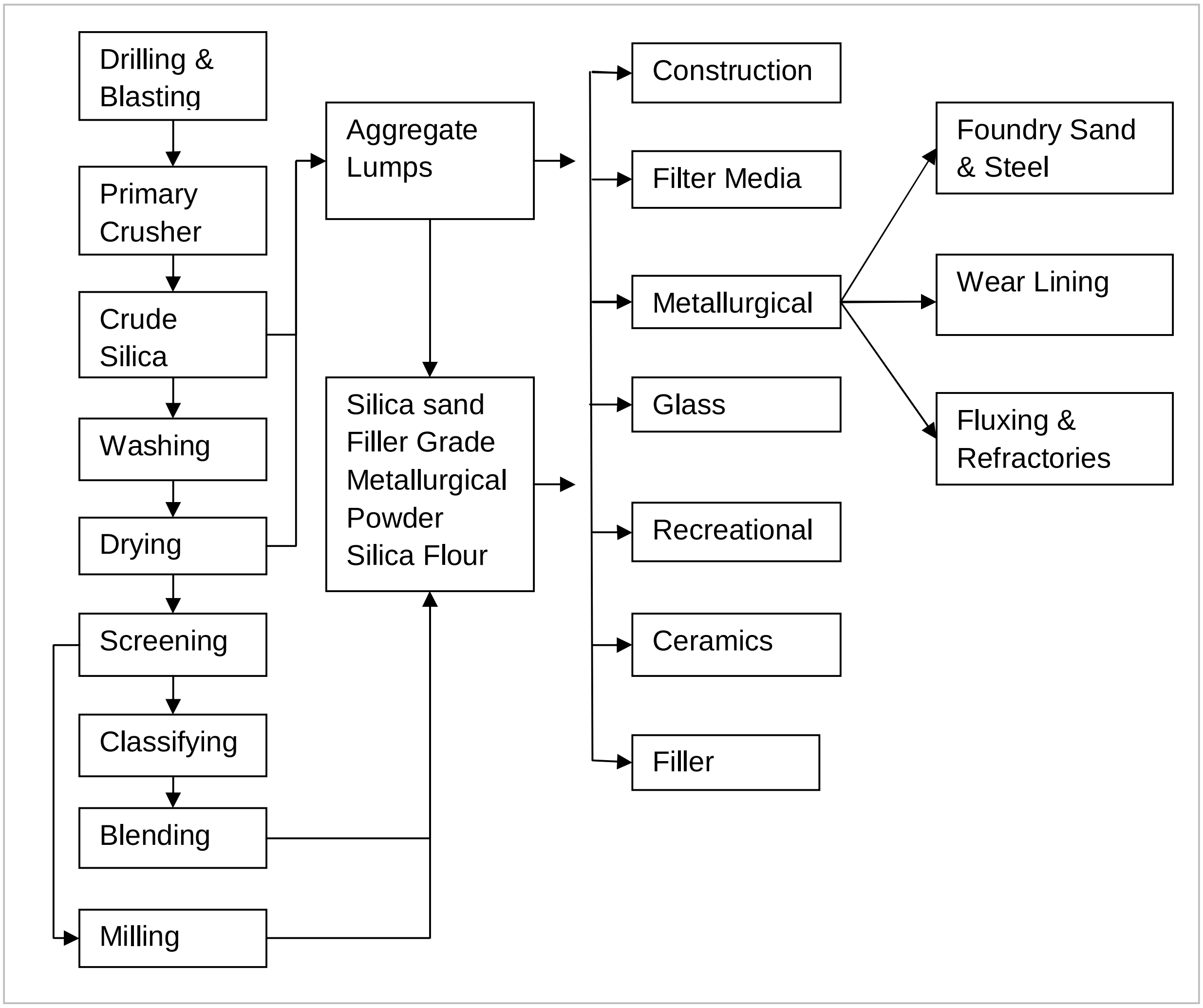
5.1. SILICON VALUE SYSTEM

5.1.1. Silica

Silica is extracted as silica sand or lumps, which are first crushed and sized to cobbles, pebbles and finer grades to form a crude or processed mineral that has a purity greater than 98 percent SiO_2. Processing of silica includes primary and secondary crushing, washing, drying, screening and possibly blending (Fig. 10). Milling is an additional step which is not often employed.

The silicon market is mainly divided into three sectors, the metallurgical (55%), chemical (40%) and electronic (5%) industries, which are basedon the ore quality as metallurgical grade, chemical grade and high grade for the industries, respectively.

FIGURE 10: SILICON VALUE SYSTEM



Source: The Silica Industry in South Africa, 2004

5.1.2. Ferrosilicon Production

Ferrosilicon, which accounts for 80 percent of the world's silicon produced, vary in silicon content. The most commonly produced gradescontain 15, 45, 75 and 90 percent silicon,with the remainder being iron and about 2 percent consisting of other elements (Table 6).

TABLE 6: FERROSILICON GRADE SPECIFICATIONS

Grade	Silicon	Carbon	Sulphur	Phosphorus	Aluminium
Stabilised/Unstabilised	43-47	0.10	0.03	0.03	1.5
Atomised	43-47	0.10	0.05	0.05	2.0
Steel	>72	0.15	0.05	0.05	1.5

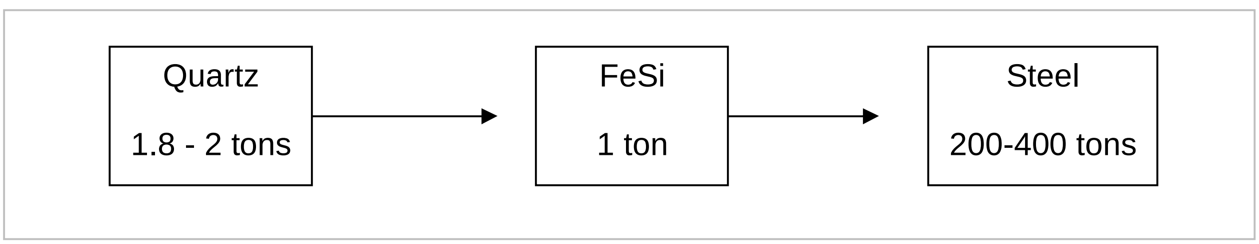
Source: Westbrook Resources Ltd

Ferrosilicon is produced by the reduction of metallurgical grade silica with coke in the presence of scrap iron, millscale or other source of iron. The alloy with silicon content of 15 percent or less is made in blast furnaces lined with acid fire bricks, while the content of higher than 15 percent is made in electric arc furnaces.

5.1.3. Silicon End-use Market

Ferrosilicon is mainly used as a source of silicon in the production process of carbon steels, stainless steels and other ferrous alloys. The production of 1 ton of ferrosilicon requires 1.8-2 tons of quartz, while1 ton of FeSiis required for the production of 200-400 tons of steel (Fig. 11).

FIGURE 11: SILICON VALUE CHAIN



Silicon is used to reduce metals from their oxides and to deoxidize steel and other ferroalloys in order to prevent loss of carbon from the molten steel. The alloy is also used to manufacture corrosion-resistant and high-temperature resistant ferrous silicon alloys and silicon steel for electromotors and transformer cores. In the production of cast iron, ferrosilicon is used for inoculation of iron to accelerate graphitisation.

- **Effects of Silicon in Steel**
  - It is the principal deoxidizing element.
  - Increases the resilience of steel for making springs.
  - Increases the strength property especially elastic limit without loss of ductility.
  - Decreases susceptibility of steel.

5.1.4. Ferrosilicon Production Capacity

South Africa has a smelting capacity of approximately 795kt for ferrosilicon production with 3 metallurgical works andsilica is produced from 14 operations.

6. FERROVANADIUM

Ferrovanadium (FeV) is aferroalloy,which represents a group of vanadium compounds and alloys.Vanadium can be produced from a number of sources, with the sedimentary and magmatic depositsbeing the main sources of vanadium ore. In the magmatic deposits, vanadium is associated with magnetite and varying quantities of titanium minerals. Vanadium-bearing sediments include deposits of asphaltite, crude oil, coal, phosphate and uranium-vanadium.

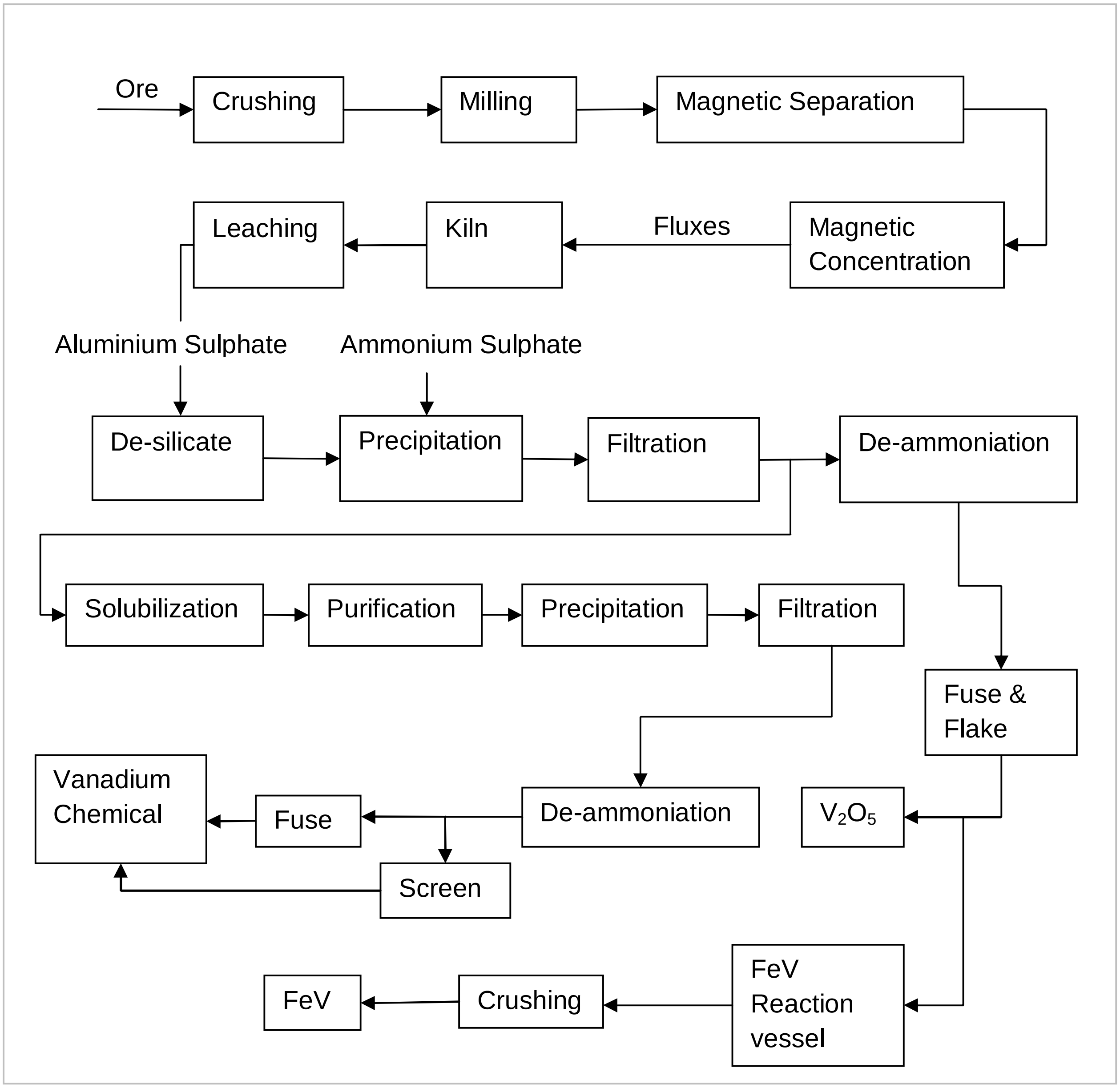
South Africa’s vanadium is hosted in the titaniferousmagnetites deposits of the Upper Zone of the Bushveld Complex. The principal commercial component is iron and the vanadium concentrator is titanomagnetite, which has vanadium content of less than 1.5 percent. These deposits account for 26 percent of the world’s reserves, making the country the third largest host of vanadium.

6.1. VANADIUM VALUE SYSTEM

6.1.1. Vanadium-bearing ore

The vanadium processingstarts by concentrating the magnetite ore through crushing, grinding and magnetic separation to produce a magnetic concentrate (Fig. 12). The concentrate is then blended with sodium salt and roasted in a kiln to produce a water soluble sodium vanadate, which is then leached with water to produce a pregnant solution containing sodium vanadate with high silica content.This is followed by the de-silication process, which removes silica to improve product quality of the solution. The solution is treated with ammonia sulphate to precipitate insolubleammonium vanadate, which is then filtered. The precipitation is either directed towards the drier or the de-ammoniator. In the drier, the moisture is driven off and then transferred to the vanadium(III) oxide (V_2O_3)reactors. The balance is fed into the de-ammoniators where the ammonium ions are driven off to form vanadium(V) oxide(V_2O_5) powder. The powder is then melted in a liquid fuel fired furnace, and cooled on a flaking table to produce V_2O_5 flakes.

FIGURE 12: VANADIUM PRODUCTION PROCESS



Source: Rhovan

6.1.2. Ferrovanadium Production

Ferrovanadium is produced by the reduction of vanadium oxides using carbon, silicon or aluminium as reductants. The oxides can be in a form of, vanadium(IV) oxide (V_2O_4),vanadium(III) oxide (V_2O_3),vanadium(V) oxide (V_2O_5) or a mixture of these oxides. Depending on the production process and the raw materials used, the vanadium content in the alloy ranges from 40-85 percent and it is classified into grades accordingly (Table 7).

TABLE 7: FERROVANADIUM GRADES SPECIFICATIONS

Vanadium	Carbon	Aluminium	Silicon	Phosphorus	Sulphur
50-60%	0.2% max	2% max	1% max	0.05% max	0.05% max
70-80%	-	1% max	2.5% max	0.05% max	0.1% max
77-83%	0.5% max	0.5% max	1.25% max	0.05% max	0.05% max

The production of FeV by the aluminothermic reduction process requires the addition of aluminium, lime and iron scrap to V_2O_5. The mixture is placed in a refractory lined ladle, which is ignited with the reaction being fully autogenous. On completion of the reaction, the FeVcollects at the bottom of the ladle and a high aluminum oxide (Al_2O_3) slag forms above the FeV. After cooling, the slag and metal are separated. The FeV is crushed, sized and packed to customer requirements.

The DC arc furnace is used to produce FeVwhich contains 80 percent vanadium. The furnace requires the addition of V_2O_3, aluminium, lime and scrap iron to produce the ferrovanadium product. Although the reaction between $V_2O_3$and aluminium is exothermic, the reaction still requires additional electrical energy which is supplied by the DC furnace. After completion of the furnace melt, the metal and slag are tapped out of the furnace into a tap pot. The pot is emptiedafter a cooling and solidification period, then the metal and slagare separated.

6.1.3. Vanadium End-use Market

Ferrovanadium is mainly consumed in the carbon steelmaking process, which accounts for about 90 percent of the world’s vanadium consumption. Vanadium has the ability to retard grain growth at elevated temperature and has an affinity for carbon and nitrogen to form carbides and nitrides. The precipitation of vanadium carbides and nitrites promotes finer grain size, increases hardenability and improves wear resistance.

These properties find extensive use in a large variety of steels, including the constructional alloy grades, carburizing steels, rail steels, heat-resisting tool and die steels, as well as creep resistant martensitic stainless steels. However, the largest consumption of vanadium is as a potent alloying strengthener in high strength low alloy (HSLA) steels. Vanadium usage continues to grow with the rapidly expanding application of HSLA steels, both as flat-rolled products and in forging and cold heading grades.

Normalized and controlled cooled HSLA grades contain about 0.05-0.15 percent vanadium. Tool and die steels, which are ranked second from HSLA grades in terms of vanadium consumption, contain a minimum of 0.3 percent vanadium (principally for grain size control during austenitizing) or more than 4 percent vanadium (for wear resistance through vanadium carbide formation).The wear resistance of rail steels improves considerably with the addition of 0.08-0.12 percent vanadium.

6.1.4. Ferrovanadium Production Capacity

South Africa'sproduction capacity for ferrovanadium isabout20 ktwith 3 metallurgical works and 3 opencast operations producing vanadiferrous magnetite.

7. CONCLUSION

The South African ferroalloys industry is competitive and is well placed for continued growth in line with the international growth in ferroalloys demand. The country's abundance of good quality raw material, efficient technology as well as developed infrastructure has resulted in the country being one of the leading suppliers of good quality alloys in the international market.

Over 70 percent of the ferrous materials produced in South Africa are exported, leaving less than 30 percent for downstream value addition in the country. Similarly, over 80 percent of the alloys produced are exported, as a result of poor demand from the domestic steel industry. The South African steel industry has a production capacity of about 9 Mt per yearwith an apparent steel use of5.3 Mt per year, which results in a surplus in production capacity. Consumption per capita in South Africa, at 108.4 kg, is almost half the world average at 215 kg.

The market outlook indicates that the country's steel demand will increase significantly by 2020, with consumption doubling or even increasing three-folds. In recent years, the government has developed industrialisation policies, which are aimed at economic growth and prioritise job creating sectors such as construction, mining and manufacturing. The planned developments in these sectors including infrastructure developmentare expected to drive local demand for steel.The anticipated higher demand resulting from the implementation of the planned infrastructure development projects could lead to an undersupplied market as steel consumption eclipses available production capacity. Such a situation would create an opportunity to expand the country's steel production capacity, should it eventuate.

Since access to raw material is essential to raise the levels of local beneficiation, various interventions including export quotas and raw material export levies could be necessary.The anticipated growth of the steel sector could ensure that the country's ferrous mineral wealth is developed to its full potential and help grow the country's economy as well as employment.

8. REFERENCES

1. A Beneficiation Strategy for the Mineral Industry of South Africa, June 2011
2. An Overview of South Africa's Vanadium Industry During The Period 1997-2006
3. Directory 8: Ferrous Minerals Commodities Produced in the Republic of South Africa, 2011
4. Ideasfirst Research, Manganese, 2010
5. South African Ferroalloy Handbook, 2006, Directorate Mineral Economics
6. South Africa's Ferroalloys Production Trends, 2001-2010, Directorate Mineral Economics
7. South Africa's Silicon Industry Developments, 2000-2009, Directorate Mineral Economics
8. The Journal of Southern African Institute of Mining and Metallurgy, 2010
9. The Mineral Resources of South Africa, 6th Edition, Handbook 16
10. Westbrook Resources, www.wbrl.co.uk
11. Wikipedia, http://en.wikipedia.org
12. World Steel Association, www.worldsteel.org
13. Xstrata, www.xstrataalloys.com

ANNEXTURE A: FERRO ALLOYS OPERATIONS IN SOUTH AFRICA

PRODUCERS OF FERROALLOYS – 1					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
FERROATLANTICA GROUP ***Controlling Company*** SILICON SMELTERS P. O. BOX 657 POLOKWANE, 0700 TEL: +27 (0) 15 290 3100 FAX: +27 (0) 15 290 3091	1296	1.1 Rand Carbide PO Box 214 Emalahleni, 1035 Tel: +27 (0) 13 656 6626 Fax:+27 (0) 13 690 1108 ***Mpumalanga***	Smelting RPC 40kt/a	Ferrosilicon % Si 75-78 max Al 1 max C 0.12 max Ca 0.50 max	Silicon Smelters P. O. Box 657 Polokwane, 0700 Tel: +27 (0) 15 290 3100 Fax: +27 (0) 15 290 3091
PRODUCERS OF FERROALLOYS – 2					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
2. DUFERCO GROUP ***Controlling Company*** VANCHEM VANADIUM PRODUCTS (PTY) LTD PO BOX 567 WITBANK, 1035 TEL: +27 (0) 13 656 1921 FAX:+27 (0) 13 656 2558	1270	2.1 Vanchem Ferrovanadium PO Box 567 Witbank, 1035 Tel: +27 (0) 13 656 1921 Fax:+27 (0) 13 656 2558 ***Witbank***	Roast/Leach RPC 10,8kt/a (From one only) RPC 12,5kt/a Electric Furnace and Aluminothermic RPC 3,5kt/a (gross)	Vanadium pentoxide 99,0% typical (fused flake and powder) Ferrovanadium 80% typical Potassium vanadate, sodium ammonium vanadate, ammonium	Vanchem Vanadium Products PO Box 567 Witbank, 1035 Tel: +27 (0) 13 656 1921 Fax:+27 (0) 13 656 2558

PRODUCERS OF FERROALLOYS – 3					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
3. AFRICAN RAINBOW MINERALS & ASSORE LIMITED ***Controlling company*** ASSMANG LIMITED PO BOX 782058 SANDTON, 2146 TEL: +27 (0) 11 779 1000 FAX:+27 (0) 11 779 1029	1201	3.1 Cato Ridge Works PO Box 21 Cato Ridge, 3880 Tel: +27 (0) 31 782 5136 Fax:+27 (0) 31 782 1306 Including: Cato Ridge Alloys (JV) ***Kwazulu- Natal***	Smelting RPC 240 kt/a (gross) Converter	HC Ferromanganese % Mn 76 C 6.7-7.2 Si 1.00 max P 0,1 max S 0,03 max Refined Ferromanganese % Mn 80,0 C 1,5 max	Ore & Metal Company Ltd Private Bag X03 Northlands, 2116 Tel: +27 (0) 11 770 6800 Fax:+27 (0) 11 268 6440 email: alloysales@assore.com
	1290	3.2 Machadodorp Works PO Box 152 Machadodorp, 1170 Tel: +27 (0) 13 256 5000/4 Fax:+27 (0) 13 256 5026 ***Mpumalanga***	Smelting RPC 230 kt/a (gross) Metal Recovery Plant RPC 20 kt/a (gross)	Charge Chrome Cr 51.5-52.5 C 6.3-8% Si 3-6% P 0,03% max S 0,06% max	Ore & Metal Company Ltd Private Bag X03 Northlands, 2116 Tel: +27 (0) 11 770 6800 Fax:+27 (0) 11 268 6440 email: chromesales@assore.com

PRODUCERS OF FERROALLOYS – 4					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
4. INTERNATIONAL MINERAL RESOURCES ***Controlling Company*** SAMANCOR CHROME POSTNET SUITE 803 PRIVATE BAG X9 BENMORE, 2010 TEL: +27 (0) 11 245 1000 FAX:+27 (0) 11 245 1200	1254	4.1 Ferrometals Private Bag X7228 Witbank, 1035 Tel: +27 (0) 13 693 7000 Fax: +27 (0) 13 696 2800 *Including:* Poschromejv, Chrometalsjv ***Mpumalanga***	Smelting RPC 550 kt/a (gross) pelletising, pre-heating smelting and slag Recovery Converter	HC Ferrochrome % Cr 52 Si 3-6 C 6,5 max P 0,02 max MC Ferrochrome % Cr 54 Si 1,5-5 C 6,5 max P 0,02 max S 0,05 m	Samancor Limited Chrome Division email: Sales@SamancorCr.com
	1307	4.2 Middelburg Ferrochrome Private Bag X 251846 Middelburg, 1050 Tel: +27 (0) 13 249 4400 Fax:+27 (0) 13 249 4837 ***Mpumalanga***	Smelting Slag Recovery RPC 285 kt/a (gross)	HC Ferrochrome % Cr 50-54 Si 6-9 C 1,5-6,5 max LC Ferrochrome % Cr 60-65 C 0,1 max N 0,4 max Si 1,0 max P 0,03 max S 0,05 max Silicochrome % Cr 27-31 C 0,1 max Si 45-50 typical Fe 18-22 Al 18-22 Al 1,5 max	Samancor Limited Chrome Division email: Sales@SamancorCr.com

PRODUCERS OF FERROALLOYS – 4 continued					
	Mine Code	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
	1176	4.3 Tubatse Ferrochrome PO Box 46 Steelpoort, 1133 Tel: +27 (0) 13 230 8200 Fax: +27 (0) 13 230 8370 ***Mpumalanga***	Smelting RPC 360 kt/a (gross)	HC Ferrochrome % Cr 50-54 Si 6-9 C 1,5-6 max P 0,03 max S 0,05 max	Samancor Limited Chrome Division email: Sales@SamancorCr.com

PRODUCERS OF FERROALLOYS – 5					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
5. BHP BILLITON ***Controlling Company*** SAMANCOR MANGANESE (PTY) LTD P. O. BOX 8186 JOHANNESBURG, 2000 TEL: +27 (0) 11 376 9111	2510	5.1 Metalloys PO Box 66 Meyerton, 1960 Tel: +27 (0) 13 360 2511 Fax: +27 (0) 13 362 3391 Including: Advalloy (Pty) - jv ***Gauteng***	Smelting Slag Recovery RPC 510kt/a (gross) Converter and Refining plant	HC Ferromanganese % Mn 76 C 7,5 Si 0,5 max P 0,1 max S 0,02 max -	Samancor Manganese Tel: +27 (0) 11 376 9111

PRODUCERS OF FERROALLOYS – 6					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
6. HERNIC FERROCHROME PTY LTD ***Controlling Company*** HERNIC FERROCHROME PTY LTD PO BOX 4534 BRITS, 0250 TEL: +27 (0) 12 381 1100 FAX: +27 (0) 12 381 1111	3055	6.1 Hernic Ferrochrome PO Box 4534 Brits, 0250 Tel: +27 (0) 12 381 1100 Fax: +27 (0) 12 381 1111 ***North West***	RPC 220kt/a (gross) Pelletising, pre-heating, smelting	Charge Chrome Cr 49% min C 6-8% min Si 3-7% P 0,025 max	Hernic Ferrochrome PO Box 4534 Brits, 0250 Tel: +27 (0) 12 381 1100 Fax: +27 (0) 12 381 1111 email: marketing@hernic.co.za

PRODUCERS OF FERROALLOYS – 7					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
7. GLENCORE XSTRATA PLC ***Controlling Company*** XSTRATA SOUTH AFRICA PTY LTD PRIVATE BAG 82288 RUSTENBURG, 0300 TEL: +27 (0) 14 590 6000 FAX: +27 (0) 14 590 6002	2221	7.1 Xstrata SA Chrome Division Rustenburg works Private Bag 82325 Rustenburg, 0300 Tel: +27 (0) 14 590 6000 Fax: +27 (0) 14 590 6002 ***North West***	Smelting Slag Recovery RPC 430 kt/a (gross)	HC Ferrochrome % Cr 47- 50 C 8,0 min Si 1,5-4,5 P 0,03 max S 0,05 max	Xstrata SA Chrome Division Private Bag 82288 Rustenburg, 0300 Tel: +27 (0) 14 590 2430 Fax: +27 (0) 14 590 6002
	3216	7.2 Xstrata SA Chrome Division Wonderkop works Private Bag 82288 Rustenburg, 0300 Tel: +27 14 572 0000 Fax: +27 14 572 0002/3 ***North West***	Pelletising and Smelting RPC 553 kt/a (gross)	HC Ferrochrome % Cr 47- 50 C 8,0 min Si 1,5-4,5 P 0,03 max S 0,05 max	Xstrata SA Chrome Division Private Bag 82288 Rustenburg, 0300 Tel: +27 (0) 14 590 2430 Fax: +27 (0) 14 590 6002

PRODUCERS OF FERROALLOYS – 7 continued					
	1316	7.3 Xstrata SA Chrome Division Lydenburg works PO Box 195 Lydenberg, 1120 Tel : +27 (0) 13 230 6000 Fax: +27 (0) 13 230 6002 ***Mpumalanga***	Pelletising and Smelting RPC 396 kt/a (gross)	HC Ferrochrome % Cr 50-53 C 8,0 min Si 1,5-6,0 P 0,025 max S 0,035 max	Xstrata SA Chrome Division Private Bag 82288 Rustenburg, 0300 Tel: +27 (0) 14 590 2430 Fax: +27 (0) 14 590 6002
	2169	7.4 Xstrata SA Chrome Division Lion works PO Box 218 Steelpoort, 1133 Tel :+27 (0)13 230 5052 Fax: +27 (0) 13 230 3108 ***Mpumalanga***	Pelletising and Smelting RPC 360 kt/a (gross)	HC Ferrochrome % Cr 50-53 C 8,0 min Si 1,5-6,0 P 0,025 max S 0,035 max	Xstrata SA Chrome Division Private Bag 82288 Rustenburg, 0300 Tel: +27 (0) 14 590 2430 Fax: +27 (0) 14 590 6002
	2667	7.5 Xstrata Alloys Rhovan works PO Box 3620 Brits, 0250 Tel: +27 (0) 12 318 0700 Fax: +27 (0) 12 318 0702 ***North West***	Pelletising and Smelting RPC 400 kt/a (gross)	Ferrovanadium also Vanadium pentoxide(V_2O_5)	Xstrata SA Chrome PO Box 3620 Brits, 0250 Tel: +27 (0) 12 318 0700 Fax: +27 (0) 12 318 0702

PRODUCERS OF FERROALLOYS- 8					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
8. GLENCORE XSTRATA PLC ***Controlling Company*** SILICON TECHNOLOGY (PTY) LTD P. O. BOX 1 BALLENGEICH, 2942 TEL: +27 (0) 34 377 7210 FAX: +27 (0) 34 377 7012	2927	8.1 Silicon Technology PO Box 1 Ballengeich, 2942 Tel: +27 (0) 34 377 7210 Fax: +27 (0) 34 377 7012 ***Kwa Zulu-Natal***	Smelting RPC 55kt/a (gross)	<u>Ferrosilicon %</u> Si 75-80 C 0,2 max Al 2,0 max P 0,05 max S 0,02 mx	Silicon Technology PO Box 1 Ballengeich, 2942 Tel: +27 (0) 34 377 7210 Fax: +27 (0) 34 377 7012

PRODUCERS OF FERROALLOYS- 9					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
9. MERAFE RESOURCES P. O. BOX 652157 BENMORE, 2010 TEL: +27 (0) 11 783 4780 FAX: +27 (0) 11 783 4789		9.1 Boshoek works Private Bag X4011 Boshoek, 0301 Tel: +27 (0) 14 573 1200 Fax: +27 (0) 14 573 1239 ***North West***	Smelting RPC 240kt/a (gross)	<u>Ferrochrome %</u> Cr 50-51 C 0,2 max Al 2,0 max P 0,05 max S 0,02 mx	Merafe Resources PO Box 652157 Benmore, 2010 Tel: +27 (0) 11 783 4780 Fax: +27 (0) 11 783 4789

PRODUCERS OF FERROALLOYS- 10					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
10. STRATEGIC MINERALS CORPORATION DANBURY, CONNECTUIT, USA ***Controlling Company*** EVRAS VAMETCO ALLOYS (PTY) LTD P. O. BOX 595 BRITS, 0250 TEL: +27 (0) 12 318 3200 FAX: +27 (0) 12 318 3201	0650	10.1 Vametco Alloys PO Box 595 Brits, 0250 Tel: +27 (0) 12 318 3200 Fax: +27 (0) 12 318 3201 ***North West***	Smelting RPC 5.25 kt/a (gross)	<u>Ferrovanadium and</u> <u>Nitrovan</u> also mixed oxides	Vametco Minerals Corp. PO Box 595 0250 Brits Tel: +27 (0) 12 318 3200 Fax: +27 (0) 12 318 3201

PRODUCERS OF FERROALLOYS- 11					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
11. ASA METALS (PTY) LTD POSTNET SUITE 782 PRIVATE BAG X9 BENMORE, 2010 TEL: +27 (0) 11 666 6000 FAX: +27 (0) 11 666 6194	3332	11.1 Dilokong Ferrochrome PO Box 169 Burgersfort, 1150 Tel: +27 (0) 13 230 7600 Fax: +27 (0) 13 230 7754 ***Mpumalanga***	Smelting RPC 125 kt/a RPC 400kt/a (gross)	Charge chrome	ASA Metals (Pty) Ltd Postnet Suite 782 Private Bag X9 Benmore, 2010 Tel: +27 (0) 11 666 6000 Fax: +27 (0) 11 666 6194

PRODUCERS OF FERROALLOYS- 12					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
12. IMF SOUTH AFRICA (PTY) LTD P. O. BOX 2223 MOOINOOI, 0325 TEL: +27 (0) 14 574 6300 FAX: +27 (0) 14 574 6401	4419	12.1 Ferrochrome Smelter Buffelsfontein JQ465 Mooinooi Tel: +27 (0) 14 574 6300 Fax: +27 (0) 14 574 6401 ***North West***	Smelting RPC 267 kt/a (gross)	Ferrochrome	IFMSA Pty Limited PO BOX 2223 Mooinooi, 0325 Tel: +27 (0) 14 574 6300 Fax: +27 (0) 14 574 6401

PRODUCERS OF FERROALLOYS- 13					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
13. RENOVA MINING INDUSTRIES ***Controlling Company*** TRANSALLOYS (PTY) LTD P. O. BOX 856 EMALAHLENI, 1035 TEL: +27 (0) 13 693 8000 E-MAIL LOCAL: Sandram@Transalloys.co.za TEL: +41 41 711 5990 E-MAIL INTERNATIONAL: roland_suter@afrominerals.ch	2466	13.1 Transalloys Clewer Road Emalahleni, 1035 Tel: +27 (0) 13 693 8000 Fax:+27 (0) 13 690 7411 ***Mpumalanga***	Smelting RPC 170kt/a (gross)	<u>Silicomanganese %</u> Mn 65- 68 Si 16-18 C 2.0 max P 0.15 max S 0.015 max	Transalloys (Pty) Ltd Tel: +27 (0) 13 693 8000 email local: Sandram@Transalloys.co.za Tel: +41 41 711 5990 email international: roland_suter@afrominerals.ch

PRODUCERS OF FERROALLOYS- 14					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
14.1 TATA GROUP ***Controlling Company*** TATA STEEL (KZN) (PTY) LTD P. O. BOX 9690 RICHARDS BAY , 3900 TEL: +27 (0) 35 788 0710/1 FAX: +27 (0) 35 788 0779	4838	14.1 Tata Steel (KZN) Alton North Richards Bay, 3900 Tel: +27 (0) 35 751 1861 Fax:+27 (0) 35 751 1895 ***Kwa-Zulu Natal***	Smelting RPC 150kt/a (gross)	HC FeCr	Tata Steel (KZN) (Pty) Ltd P. O. Box 9690 Richards Bay, 3900 Tel: +27 (0) 35 788 0710/1 Fax: +27 (0) 35 788 0779

PRODUCERS OF FERROALLOYS- 15					
Group Company	***Mine Code***	***Ferroalloys operations***	***Capacity***	***Products and Specification***	***Marketing: Local & Export***
15. SIYANDA INKWALI RESOURCES ***Controlling Company*** DMS POWDERS (PTY) LTD P. O. BOX 945 MEYERTON, 1960 TEL: +27 (0) 16 360 5200 FAX: +27 (0) 16 360 5314	1281	15.1 DMS Powders P. O. Box 945 Meyerton, 1960 Tel: +27 (0) 16 360 5200 Fax: +27 (0) 16 360 5314 ***Gauteng***	Smelting RPC 42 kt/a (gross)	***FeSi*** Atomised and milled	DMS Powders P. O. Box 945 Meyerton, 1960 Tel: +27 (0) 16 360 5200 Fax: +27 (0) 16 360 5314 Distribution@dmspowders.com