AngloAmerican

THE ROLE OF METALLURGY IN ENHANCING BENEFICIATION IN THE SOUTH AFRICAN MINING INDUSTRY

Marek Dworzanowski, Presidential Address, SAIMM AGM, 22 August 2013

AngloAmerican

CONTENTS

INTRODUCTION

- From a metallurgy perspective beneficiation relates to processes used to upgrade the mined raw material or “run of mine” (ROM) ore.

- The fundamental objective of the application of metallurgy is to produce the materials required for fabrication and manufacturing. In the case of coal the objective is to produce a fuel and/or a reductant.

- The mining value chain essentially describes the path from discovering a mineral deposit to producing semi-fabricated products.

INTRODUCTION

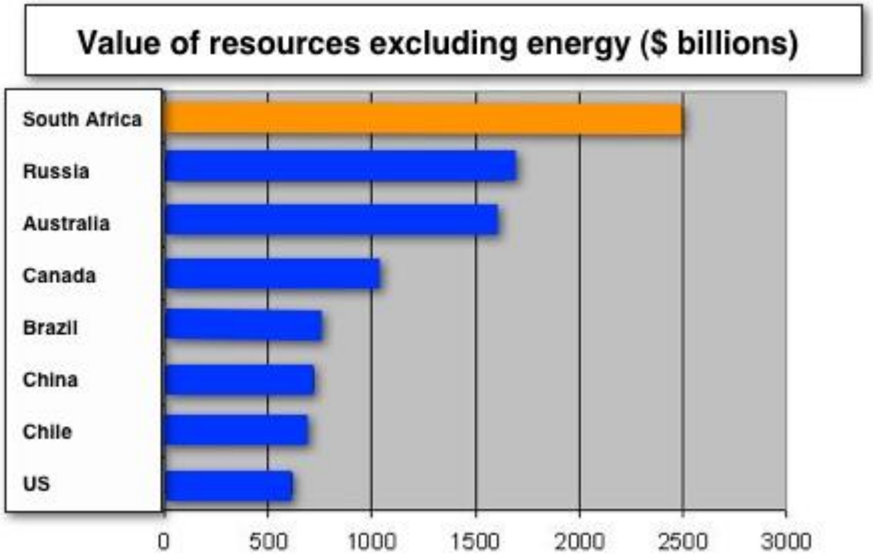
Mining value chain

Exploration	Mining	Extractive Metallurgy	Physical Metallurgy	Semi-fabrication
Discovery of mineral deposits	Extraction of ore from the deposit	Processing of ore to produce metal or mineral products	Producing steel and other alloys	Producing wire, coil, plate, pipe, etc

INTRODUCTION

- South Africa possesses the world's largest mineral resources by value.
- It is also a significant global producer of many mined commodities.
- The role of metallurgy in the mining value chain will be examined in terms of what is practised currently and the potential to expand.
- The optimum degree of metallurgical beneficiation is highly dependent on economic factors such as cost (capital and operating), appropriate skills availability, production scale and market considerations.

INTRODUCTION



COMMODITY	SOUTH AFRICA'S GLOBAL POSITION IN TERMS OF PRODUCTION IN 2012
Gold	5
Platinum	1
Coal	7
Iron Ore	7
Manganese	2
Chromium	1
Vanadium	2
Copper	19
Nickel	9
Titanium	2
Zirconium	2
Uranium	12
Diamonds	5

DEFINITIONS

A practical definition of extractive metallurgy is the extraction of minerals or metals from their ores by a combination of liberation, separation and transformation. The definitions of liberation, separation and transformation can be given as follows:

- LIBERATION - To prepare the ore for separating valuable minerals from waste or “gangue” minerals, achieved by reducing the particle size of the ore. For example, crushing and grinding

- SEPARATION - Achieved by taking advantage of differences in physical properties between the valuable minerals and the waste or “gangue” minerals in the ore. Examples are:
  - Density (light or heavy) which is covered by Dense Medium Separation and gravity concentration
  - Magnetic or non-magnetic which is covered by magnetic separation
  - Mineral surfaces being hydrophobic or hydrophilic which is covered by flotation

- TRANSFORMATION - To transform the valuable minerals to metals or other saleable products. Achieved by treating the valuable minerals that have been liberated and separated using thermal and or chemical processes.

DEFINITIONS

The practical definitions of physical metallurgy, “economic beneficiation” and beneficiation can be given as follows:

- Physical metallurgy is the transformation of metal products into alloys and or “semi-fabricated” products such as wire, coil, plate, pipe, etc.

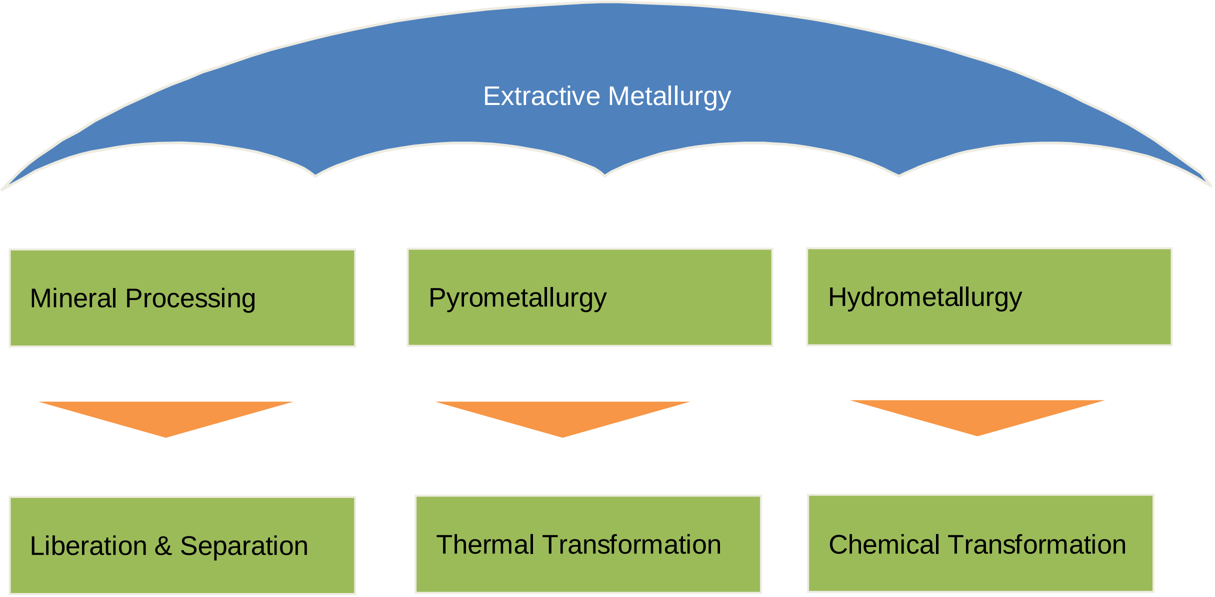
- Economic beneficiation” is the transformation of mined ore into a higher value product which can be consumed locally or exported.

- Beneficiation as related to metallurgy is the treatment of raw material (such as iron ore) to improve physical or chemical properties especially in preparation for smelting.

PHASES OF METALLURGICAL PROCESSING

- The application of extractive metallurgy through the steps of liberation, separation and transformation can be covered by the three sub divisions of extractive metallurgy.

- The effective application of extractive metallurgy to the beneficiation of ROM ore will generally involve all three sub divisions, coal and diamonds being the notable exceptions where only mineral processing is applied.



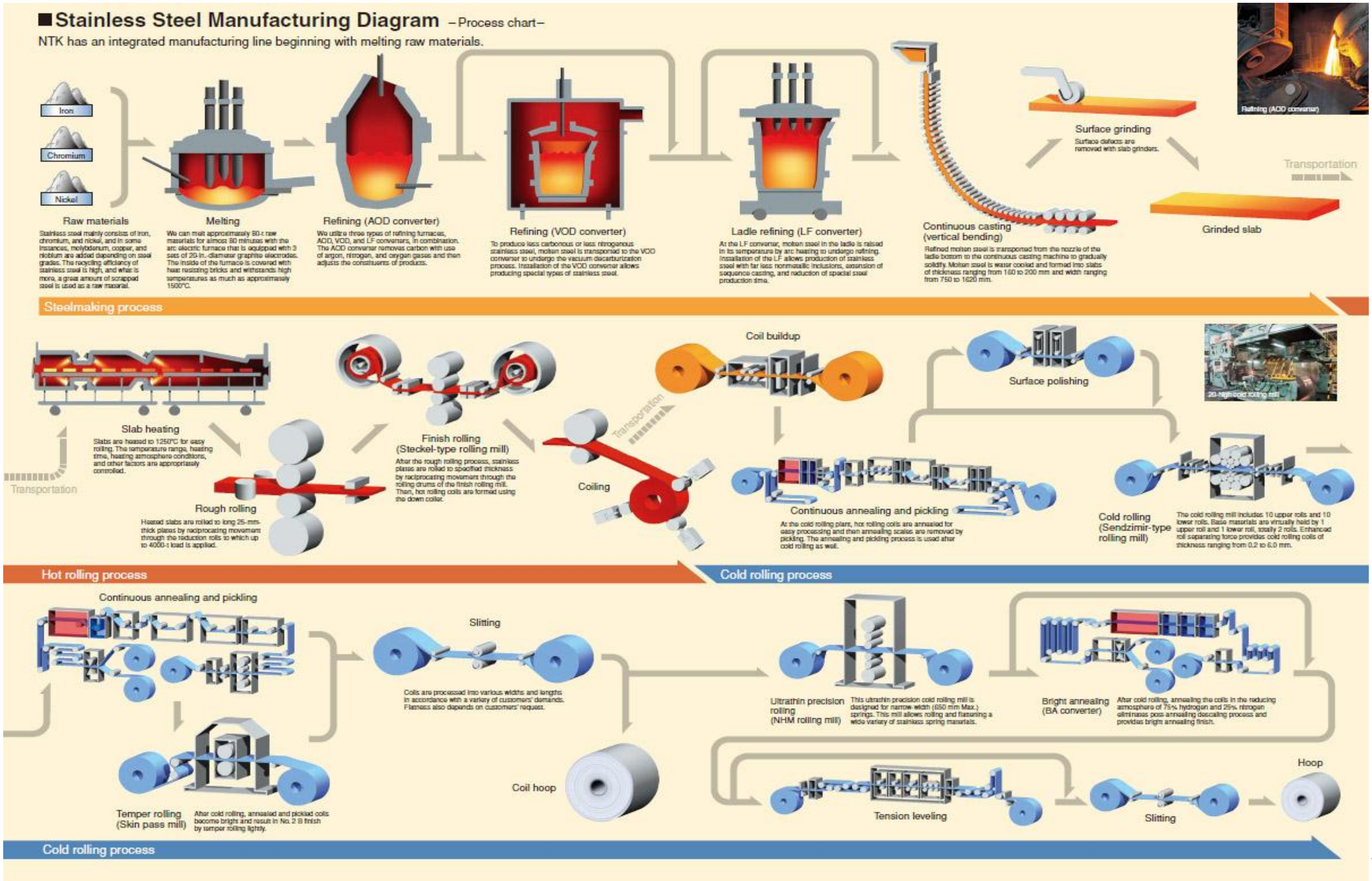
PHASES OF METALLURGICAL PROCESSING

- The metal products resulting from the application of extractive metallurgy will then proceed to the physical metallurgy processes.

- These processes can start with the production of alloys such as stainless steel, brass, bronze, etc, followed by semi-fabrication processes.

- Alternatively the metal products are taken straight to semi-fabrication processes, usually via melting. Semi-fabrication processes cover the production of plate, rod, wire, pipe, etc, via casting, drawing, forging, rolling, annealing, etc.

PHASES OF METALLURGICAL PROCESSING



PURITY OF PRODUCT RELATED TO COMPLEXITY OF METALLURGICAL PROCESSING

- The treatment of ROM ore by metallurgical processes to produce feed for alloying or semi-fabrication involves a series of steps whereby the concentration of the metal of value increases in each successive intermediate product.

- It is not just a case of upgrading but it is also the meeting of very specific chemical specifications. More often than not it is the removal of the last traces of certain impurities that introduces significant complexities to the metallurgical processing required.

UPGRADING STEP	COPPER CONCENTRATION
ROM ore	0.5 – 1.5%
Concentrate	25 – 35%
Furnace matte	50 – 60%
Blister copper	96 – 98%
Anode copper	99 – 99.5%
Cathode copper	99.99%

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Gold

- The ROM ore undergoes crushing and milling before the gold is dissolved using cyanide.
- The gold is extracted from the cyanide solution using activated carbon.
- The gold is removed from the activated carbon into a solution.
- This solution undergoes electrowinning to deposit the gold onto steel wool which is then smelted into an impure gold bar.
- These impure bars are sent to the Rand Refinery for final treatment to pure gold. This pure gold is suitable for alloying, semi-fabrication and fabrication.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Platinum

- The ROM ore undergoes crushing, milling and flotation to produce a concentrate.
- This concentrate undergoes smelting to produce a furnace matte which in turn undergoes a converting process to produce a converter matte.
- At this point the converter matte reports to a Base Metals refinery.
- All the major Platinum producers have differing flowsheets in their Base Metals refineries but they all produce nickel, copper and cobalt by-products.
- After the removal of base metals, the remaining material reports to a Precious Metals refinery.
- Pure platinum is produced as well as the platinum group metals by-products of palladium, rhodium, ruthenium and iridium. Pure gold is also produced.
- Except for the cobalt and some of the nickel, all the other metals produced by the Base Metals and Precious Metals refineries can be used for alloying, semi-fabrication and fabrication.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Coal

- Most ROM coal is crushed and then processed in dense medium separation (DMS) plants.

- In some cases gravity concentration and flotation are also used to increase production yield.

- Low quality thermal coal is produced for Eskom whilst high quality thermal coal is exported.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Iron ore

- Some iron ore only requires crushing and no processing. This is referred to as “direct shipping ore” (DSO).
- Most South African iron ore does require processing which involves DMS or gravity concentration, usually jigging.
- Arcelor Mittal South Africa uses lump (-25 +8 mm) iron ore in their blast furnaces and fine iron ore (-8 +0.2 mm) undergoes agglomeration in sinter plants before feeding to the blast furnaces.
- The blast furnaces produce pig iron which is then converted to steel in basic oxygen furnaces (BOF). The steel produced is then transformed into numerous semi-fabricated products. It is also used for alloying to produce speciality steels which in turn are transformed into numerous semi-fabricated products.
- Scaw Metals produces pig iron from the direct reduction, in long rotary kilns, of lump iron ore, using coal as the reductant. The pig iron is melted and converted to steel which is then in turn converted to numerous semi-fabricated products.
- Highveld Steel & Vanadium mine vanadium rich magnetite which is crushed and then undergoes pre-reduction, in long rotary kilns, followed by smelting in electric furnaces. The pig iron produced has its vanadium content removed before being converted to steel. The steel is then converted to numerous semi-fabricated products.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Manganese

- Manganese ROM ore undergoes crushing mainly followed by processing using DMS and gravity concentration.
- The manganese rich product is mainly smelted in electric furnaces to different grades of ferromanganese. Sometimes this is preceded by sintering of the manganese rich product.
- The ferromanganese is used for alloying with steel.
- A small amount of the manganese rich product undergoes chemical transformation to produce manganese metal and to produce battery grade manganese dioxide.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Chromium

- Chromite ROM ore undergoes crushing mainly followed by processing using DMS and gravity concentration.

- The chromium rich product is mainly smelted in electric furnaces to different grades of ferrochromium. Sometimes this is preceded by pelletising of the chromium rich product.

- The ferrochromium is used as the main ingredient for stainless steel production.

- Some of the chromium rich product is sold as a concentrate for foundry sand, for feedstock for chromium chemicals production, for feedstock for chromium metal production and for an ingredient in the manufacture of refractories.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Vanadium

- Vanadium is extracted from vanadium bearing magnetite. The ROM ore is crushed, milled and then undergoes magnetic separation to produce a concentrate.

- This concentrate undergoes roasting with sodium carbonate in a long rotary kiln to make the vanadium soluble.

- A chemical transformation process produces vanadium pentoxide.

- This is used as a catalyst in sulphuric acid plants or it is transformed into ferrovanadium which is used for alloying with steel.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Copper

- The ROM ore is crushed, milled and undergoes flotation to produce a concentrate.
- The concentrate is smelted to a furnace matte.
- The furnace matte is converted to produce blister copper.
- The blister copper is fire refined and cast into anodes.
- The copper anodes are refined in an electrolytic refinery to produce copper cathode.
- Copper cathode is also produced from the Base Metals refineries associated with the major platinum producers. The copper cathode is used to produce semi-fabricated products.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Nickel

- Most of the nickel produced in South Africa is derived from the Base Metals refineries associated with the major platinum producers.

- The nickel is produced as nickel sulphate or as nickel metal (cathode or briquettes).

- Most of the nickel metal is used as the nickel component in the alloying process for stainless steel production.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Titanium

- In South Africa titanium is sourced from mineral sands deposits.
- The ROM is processed via numerous stages of gravity concentration, magnetic separation and electrostatic separation.
- The titanium is produced as an ilmenite product and as a rutile product.
- The ilmenite is smelted in electric furnaces to pig iron and titanium slag.
- The pig iron is used mainly for steel production and the titanium slag is a feedstock for the production of titanium pigments.
- The rutile is a feedstock for titanium metal production.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Zirconium

- In South Africa zirconium is mainly sourced from mineral sands deposits.
- The ROM is processed via numerous stages of gravity concentration, magnetic separation and electrostatic separation.
- The zirconium is produced as a zircon product.
- The zircon is a feedstock for ceramics production and for zirconium metal production.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Uranium

- In South Africa uranium is associated with gold production from the Witwatersrand basin.

- Uranium can be extracted either before or after gold extraction, depending on the flowsheet preference as a result of ROM ore differences.

- After crushing and milling the uranium is dissolved by leaching with sulphuric acid.

- The uranium is extracted from the solution by using solvent extraction and from this concentrated solution the uranium is precipitated as ammonium diuranate or “yellowcake”.

- The “yellowcake” is converted to uranium oxide which is then the feedstock for the nuclear applications of uranium.

CURRENT INTENSITY OF METALLURGICAL PROCESSING IN SOUTH AFRICA

Diamonds

- Most of the diamonds production in South Africa is based on extraction from kimberlite pipes.
- The ROM ore is crushed and scrubbed.
- A DMS process produces a diamonds concentrate which undergoes numerous steps of screening, magnetic separation and X ray sorting.
- Sometimes chemical cleaning is also required. This results in a final concentrate which undergoes hand sorting into the different categories of diamonds.

POTENTIAL FOR INCREASING THE ROLE OF METALLURGY

Iron ore

- Iron ore produced in South Africa covers hematite based lump product (-25 +8 mm) and fine product (-8 +0.2 mm). These products can be utilised by the local iron & steel industry.

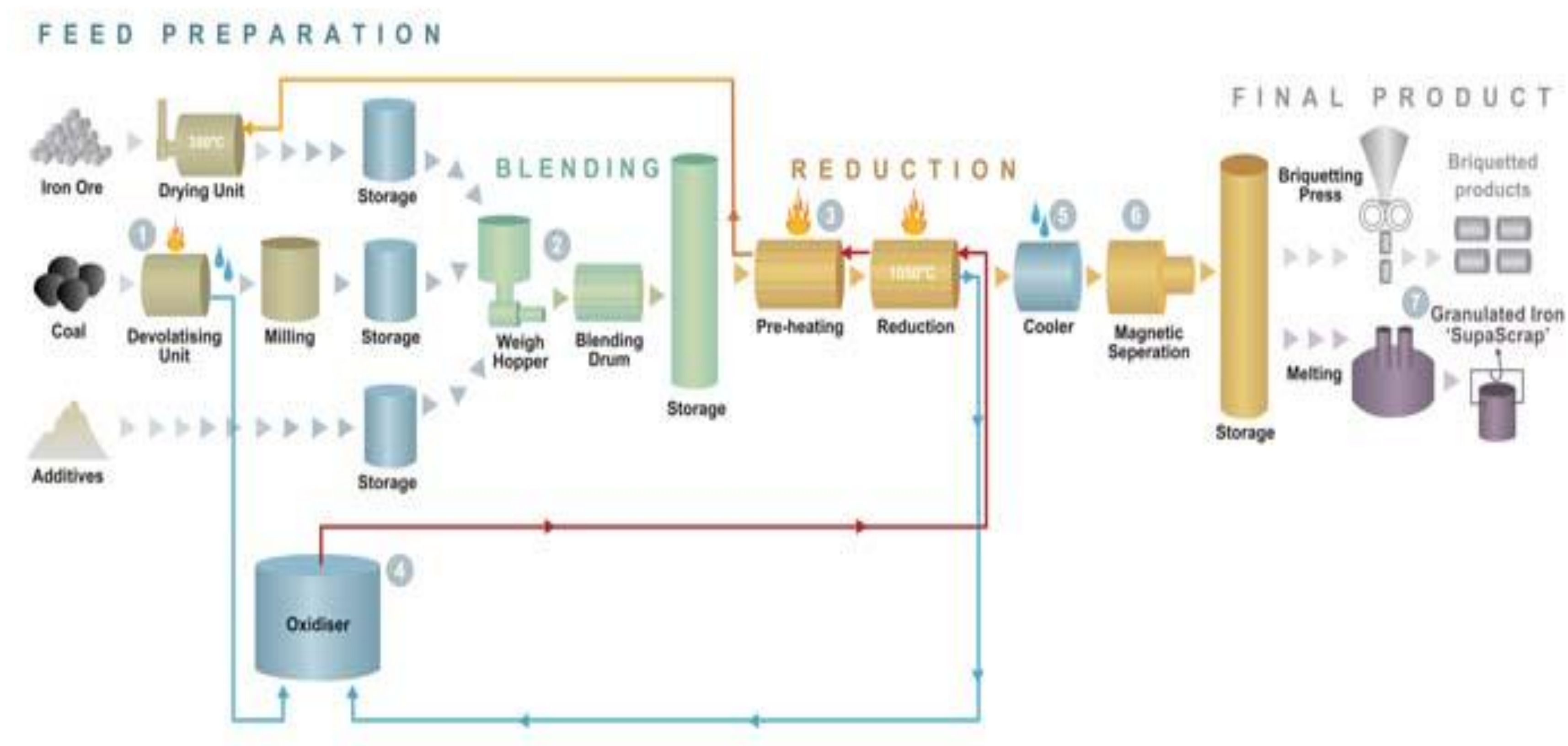
- However, future increases in iron ore production in South Africa will involve a good deal of concentrate production which is minus 200 microns and it will be based on hematite and magnetite.

- Currently there are no metallurgical facilities which can accommodate concentrate and convert it into products suitable for the local iron & steel industry.

- The first approach to this problem would be agglomeration of the concentrate into pellets.

- The second approach would be direct smelting of the concentrate to pig iron.

POTENTIAL FOR INCREASING THE ROLE OF METALLURGY



POTENTIAL FOR INCREASING THE ROLE OF METALLURGY

Chromium

- Whilst South Africa is the world's largest producer of ferrochrome, there is currently very limited production of chromium chemicals and no production of chromium metal.

- The feedstocks for these products are available and the metallurgical technology globally is well established.

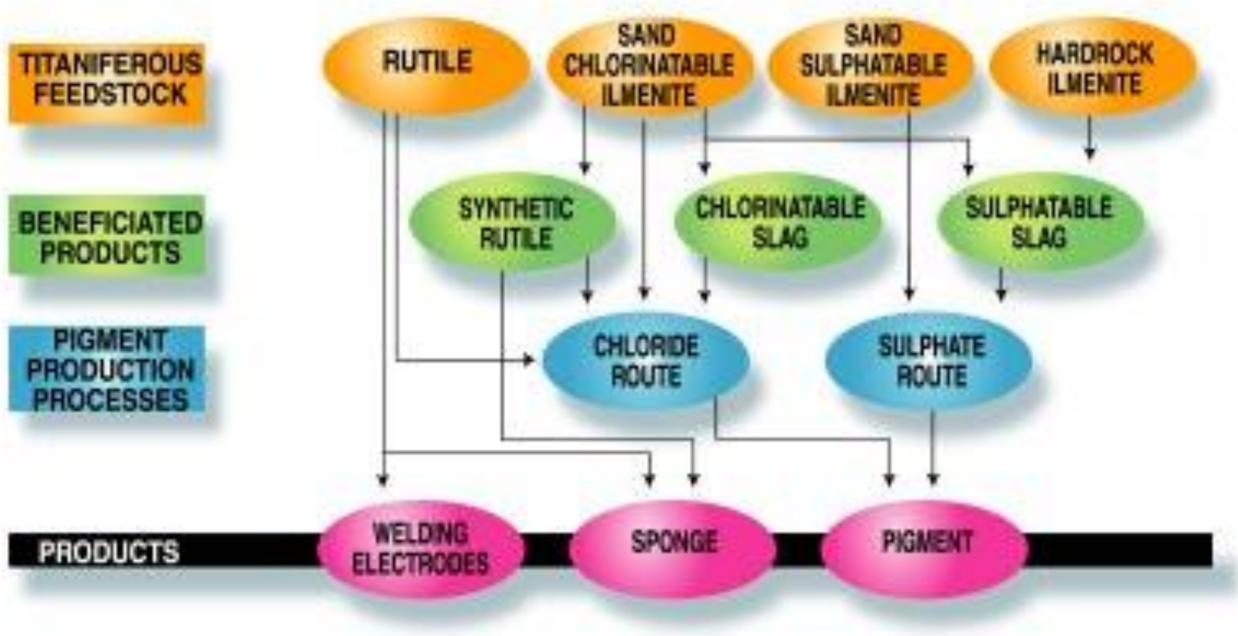
- Chemical grade chromite concentrate is roasted with sodium carbonate in a rotary kiln to make the chromium soluble. Leaching of the calcine with water produces sodium chromate. This provides the starting chemical for all the other commercial chromium chemicals.

- Metallurgical grade chromite concentrate is leached with sulphuric acid followed by selective crystallisation to produce chromium sulphate. Chromium metal is then produced by electrowinning.

POTENTIAL FOR INCREASING THE ROLE OF METALLURGY

Titanium

South Africa produces rutile and ilmenite as well as titanium slag. However, there is little titanium pigment production and no titanium sponge production.



POTENTIAL FOR INCREASING THE ROLE OF METALLURGY

Titanium pigment

- The metallurgical process for titanium pigment production is well established globally.
- The titanium slag is reacted with carbon and chlorine at high temperature to produce titanium tetrachloride.
- This is then decomposed to titanium dioxide which is the basis for titanium pigment.

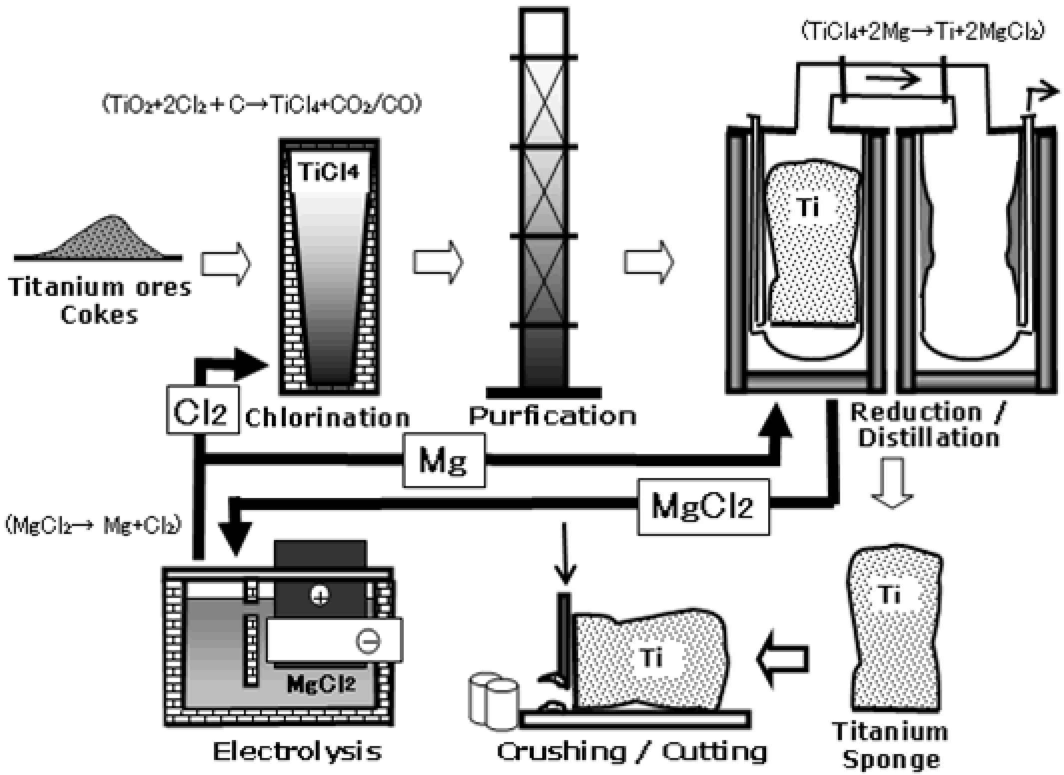
POTENTIAL FOR INCREASING THE ROLE OF METALLURGY

Titanium metal

- For titanium metal production, rutile is reacted with carbon and chlorine at high temperature to produce titanium tetrachloride.
- This is then reacted with magnesium metal to produce titanium metal sponge.
- The titanium metal sponge can be melted and cast into slabs and ingots.
- From these semi-fabricated titanium products can be derived.
- The current production route, known as the Kroll process, is not efficient and results in high production costs. Therefore, alternative process routes are being examined in South Africa.
- It must be noted that numerous previous attempts at developing alternative economic processes have not been successful. The cost issue not only relates to the production of the metal but also the cost of producing the semi-fabricated products from the metal.

POTENTIAL FOR INCREASING THE ROLE OF METALLURGY

Titanium metal



CONCLUSIONS

- South Africa possesses the world's largest mineral resources by value and is a significant global producer of many mined commodities.

- The current role of metallurgy in the South African mining industry is considerable and the same can be said in terms of the role of metallurgy in economic beneficiation.

- The application intensity of metallurgical processes in South Africa has established a platform for a wide variety of products which can be utilised in alloying and semi-fabrication.

- The application of metallurgical processes in the production of gold, platinum, coal, iron ore, manganese, chromium, vanadium, copper, nickel, titanium, zirconium, uranium and diamonds, to a very large extent, meet the requirements for alloying and semi-fabrication products.

CONCLUSIONS

Metal / Mineral	Alloying	Semi-fabrication
Gold	Pure metal	Facilities available
Platinum	Pure metal	Facilities available
Coal	Used for fuel	Not applicable
Iron Ore	Mild steel	Plate, wire, pipe, etc
Manganese	Ferromanganese for steels	Plate, wire, pipe, etc
Chromium	Ferrochromium for stainless steels	Plate, wire, pipe, etc
Vanadium	Ferrovanadium for steels	Plate, wire, pipe, etc
Copper	Cathode for alloying	Plate, wire, pipe, etc
Nickel	Cathode / Briquette for stainless steels	Plate, wire, pipe, etc
Titanium	No metal produced	No facilities available
Zirconium	No metal produced	No facilities available
Uranium	Uranium oxide for nuclear applications	Facilities available
Diamonds	Gem & industrial diamonds	Cutting for jewellery and industrial applications

CONCLUSIONS

- Although the role of metallurgy is significant, there are always opportunities for further expansion and three examples have been highlighted.

- The current utilisation of iron ore in South Africa for steel production is well established. To maintain this into the future will require developing the utilisation of iron ore concentrate since this will assume a greater significance in the near future.

- The utilisation of chromium resources can be expanded into the production of chromium chemicals and chromium metal.

- Titanium metal has potential globally. South Africa is not currently producing titanium metal as current commercial processes are not economic in this application. There is therefore a need to develop appropriate new technologies to enable economic production of suitable quality titanium metal and this is receiving attention in South Africa.

- More emphasis and funding should however be applied in the area of titanium metal. Implementation should be in conjunction with titanium pigment production, since this is closely linked from a metallurgical process point of view.

AngloAmerican

THANK YOU