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VALUE CHAIN SYSTEM OF SOUTH AFRICA'S HEAVY MINERALS INDUSTRY, 2010

DIRECTORATE: MINERAL ECONOMICS

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VALUE CHAIN SYSTEM OF SOUTH AFRICA'S HEAVY MINERAL SANDS INDUSTRY, 2010

DIRECTORATE MINERAL ECONOMICS

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ABSTRACT

Heavy minerals are hosted in sand deposits formed by wind and alluvial currents into coastal dunes, containing 10 percent titanium and zircon minerals. South Africa's heavy mineral deposits are classified into two categories, magmatic- and beach- origin, with vast resources occurring along the coastal regions. The country is the second largest producer of heavy mineral sands in the world after Australia, and exports raw material with limited beneficiation. The absence of further downstream value chain industries in the country has been a result of high costs involved in manufacturing of value added products and insufficient demand for finished products. However, government is working with scientific organisations and other stakeholders in increasing downstream mineral beneficiation. Various initiatives by government (i.e. beneficiation strategy framework) and research and development progammes through scientific organisations have been established in order to assess and leverage benefit from raw materials.

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1 INTRODUCTION

Heavy mineral sands are widely distributed on almost every continent in the world.They are an important source of titanium- and zirconium- bearing minerals, with a significant amount of these deposits occurring in South Africa, Australia and North America. In South Africa, heavy mineral sands deposits are found in the extensive beach placer deposits located along the eastern, southern and north-eastern coasts. Smaller deposits are found along the west coast, in the north of Cape Town. Economically exploitable heavy minerals deposits occur as recent beach sand or fossilised dunes, though hard-rock resources are known.

TITANIUM BEARING MINERALS

Titanium was first discovered in 1791 and is the ninth-most abundant element in the earth's crust and the seventh-most abundant metal. It occurs predominantly in the form of ilmenite ($FeTiO_3$), rutile (TiO_2) and leucoxene ($CaTiSiO_5$). The bulk of the titanium bearing minerals are used primarily to produce pigments, while almost 10 percent is used as titanium metal and chemicals regarded as by-products of the white pigment industry.

Pig-iron is an intermediary by-product in the manufacture of titanium pigment, produced during the upgrading of TiO_2 content in ilmenite and is used in casting applications.

ZIRCONIUM BEARING MINERALS

Zirconium is the 18th most abundant mineral on earth. It generally occurs in the form of zirconium silicate or zircon (ZrSiO4), associated with small amounts of the chemically similar element hafnium. Zircon's applications are largely in ceramics and refractory industries and also in nuclear reactors and chemical processing equipment.

2 OCCURRENCE OF HEAVY MINERAL SANDS IN SOUTH AFRICA

2.1 Origin of Heavy Mineral Sand Deposits

Heavy mineral sands deposits typically contain less than 10 percent of heavy minerals, accumulated through winds and alluvial stream flow into coastal dunes. Weathered rocks from inland regions, degenerate into sand that is eroded by rain and wind, and ultimately washed into the rivers that eventually flow into the oceans.

South Africa's heavy mineral deposits are classified by origin into two categories: the magmatic- and beach-origin, with vast resources occurring along the coastal regions (Tab 1). Magmatic sand deposits are situated inland whereas the beach deposits are located on the coastal regions.

TABLE 1: REGIONAL OCCURRENCE OF HEAVY MINERAL SANDS IN SOUTH AFRICA

Province	**Mine operations**	**Reserves**
Kwazulu-Natal	2	[1]90 Mt
Western Cape	1	[2]50 Mt
Eastern Cape	Prospect (1)	88 Mt
Free State	Prospect (1)	50 Mt

Notes: [1,2]Estimated from 234 Mt reserve base reported in USGS

2.2 Structure of the Mining Industry

South Africa has two heavy minerals mining companies, viz. Richards Bay Minerals (RBM) and Exxaro Sands.

2.2.1 Exxaro Sands

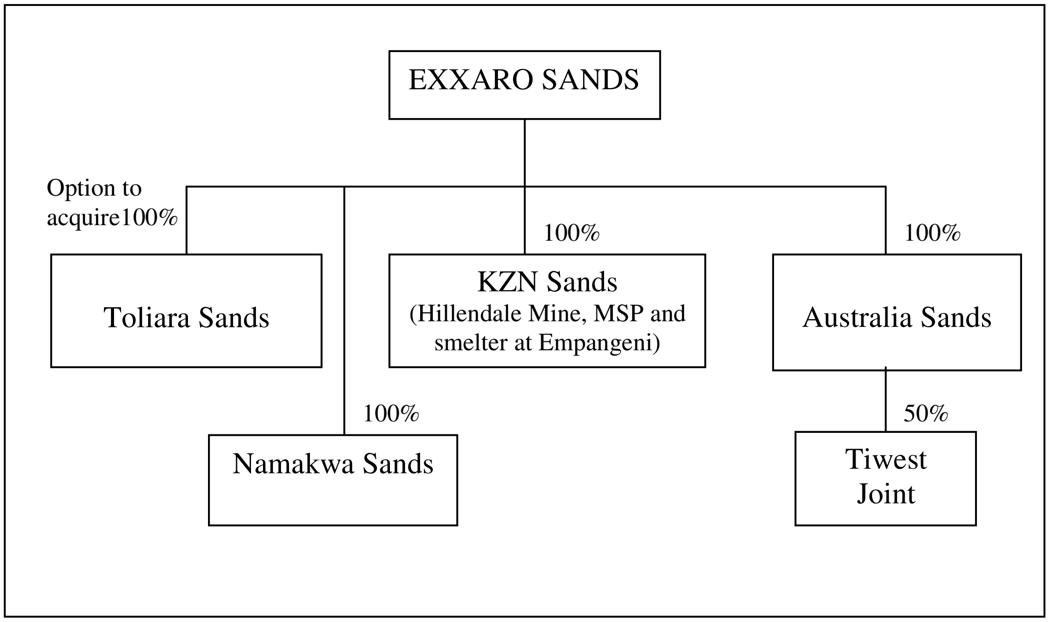

Figure 1: Exxaro Sands Asset Structure
(Source: Exxaro Sands)

Exxaro's South African mineral sands operations are comprised of KZN Sands, situated along the KwaZulu-Natal coastline, and Namakwa Sands, located along the Western Cape coastline. In Australia, Exxaro owns Australia Sands, whose principal asset is 50 percent of the Tiwest joint venture with Tronox (Fig 1).

2.2.1.1 KZN Sands

The Hillendale mine is located next at Esikhaweni close to Richards Bay. The heavy mineral deposits are of a littoral marine and aeolian coastal plain origin, located along the east coast of South Africa.

The Port Durnford mineral deposits are situated south of the Hillendale mine and are characterized by high slimes content, typically more than 20 percent of the expected run-of-mine (ROM).

2.2.1.2 Namakwa Sands

Namakwa Sands operation started in 1994 and is one of the largest mineral sand operations in the world. The heavy mineral deposits are located along the west coast of South Africa with three facilities operating at separate sites. The mine is a world class producer with high quality zircon, ilmenite and rutile concentrates from essentially unconsolidated marine and aeolian sands of cainozoic age. Sediments are deposited on a gently sloping arid coastal plain.

2.2.2 Richards Bay Minerals

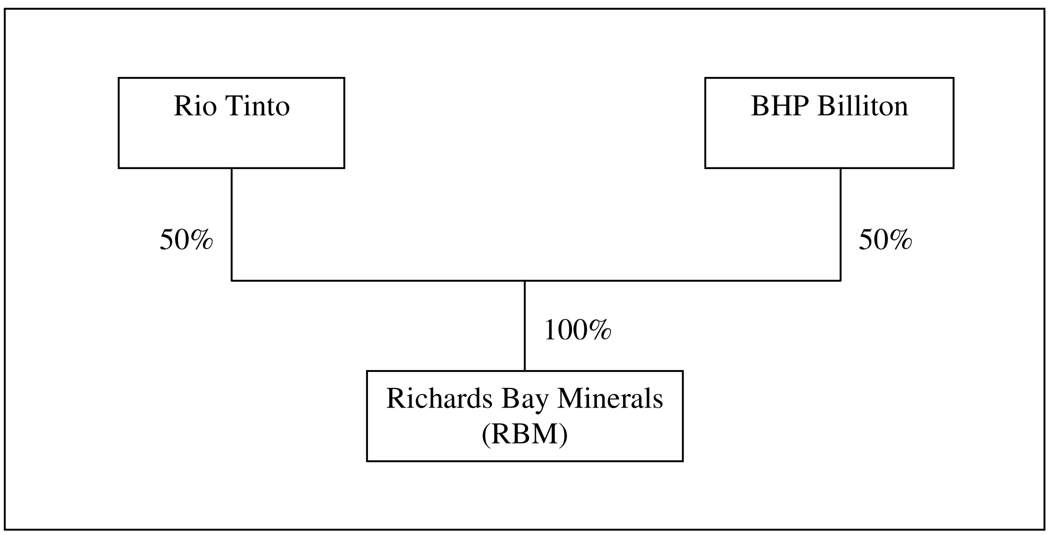

Figure 2: Richards Bay Minerals Asset Structure
(Source: Ricahrds Bay Minerals)

Richards Bay Minerals is the largest heavy mineral sands producer in South Africa, has enormous reserves along the KwaZulu-Natal coastlines, situated along the eastern coast of South Africa. The company is jointly owned by Rio Tinto plc (50 percent) and BHP Billiton (50 percent) (Fig 2).

Richards Bay Minerals deposits originate from coastal dunes formed by sand piled up by winds from the ocean as a result of currents and wave action. Economic heavy-mineral deposits are found in these sands and consist of colian sands, which are mostly holocene.

3 HEAVY MINERALS VALUE SYSTEM OVERVIEW

Heavy mineral processing involves gravity, magnetic and electrostatic methods to extract minerals of economic benefit from mined deposits, translating into concentrates of ilmenite, rutile and zircon.

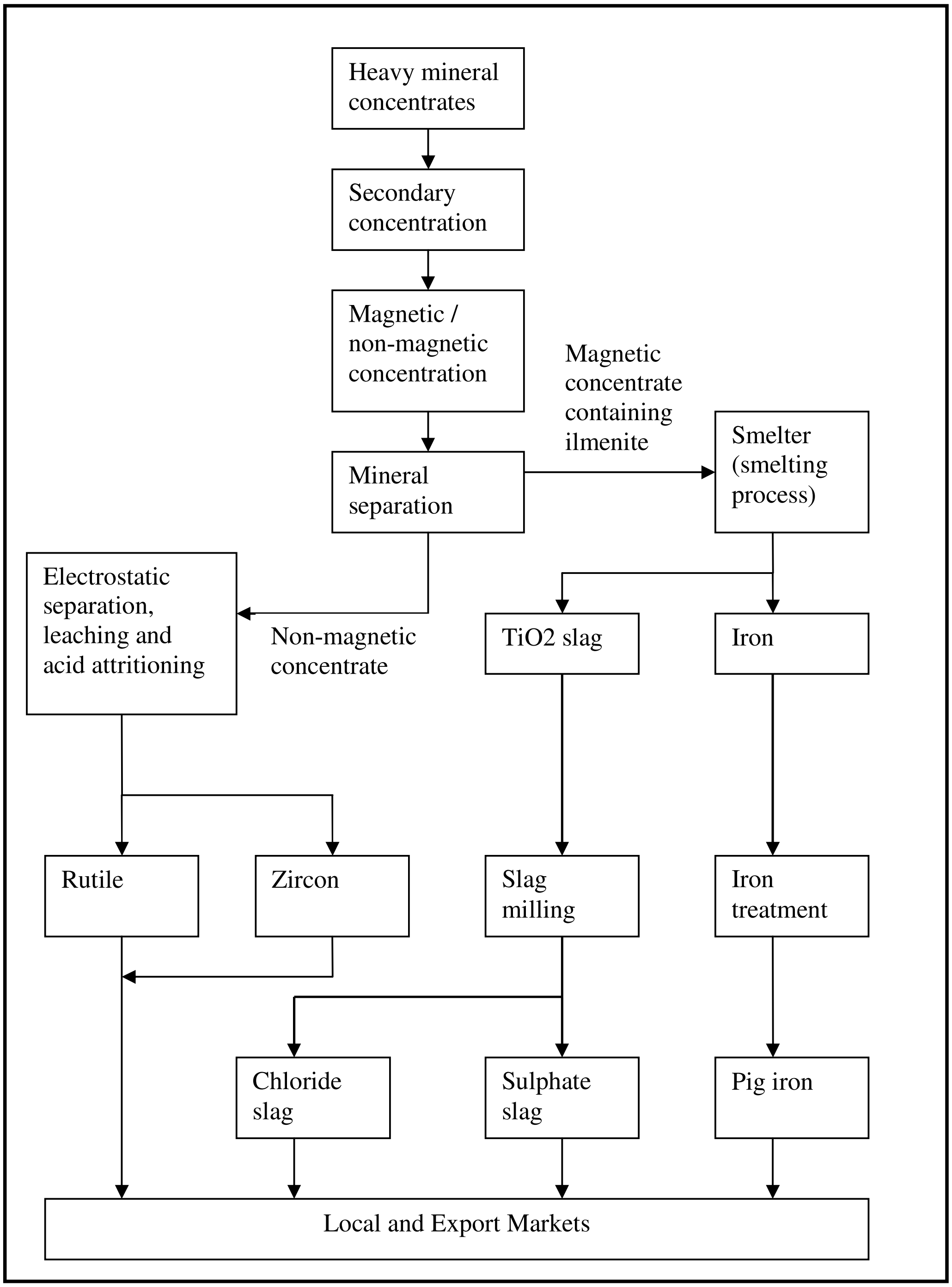

Figure 3: Basic flow diagram of heavy mineral sands processing

(Source: Southern African Pyrometallurgy, 2006)

3.1 Mining

Different mining methods are used on heavy mineral sand deposits, depending on the location and type of ore body. In South Africa, there are three main mining methods used on heavy mineral deposits:

1) **Monitoring method:** used by KZN Sands mining operations where the minerals occur in a sand form and no size reduction is needed. It employs water guns for reclamation of sand from the rock face (Fig 4). The slurry is directed to pumping stations and pumped to the primary processing plant.

Figure 4: Monitoring mining employing water Guns
(Source: KZN Sands)

2) **Mechanical method:** applied by Namakwa Sands mining operations where the ore is comprised of sand and rocks, are subjected to size reduction. Deposits are mined by front end loaders and diggers (Fig 5). The product is transported to a primary and secondary mineral separation plant where wet spirals (seawater) and magnetic and electrostatic separators are used to produce the marketable heavy mineral concentrates.

Figure 5: Mechanical mining employing front end loaders
(Source: Namakwa Sands)

3) **Dredging method:** used by Richards Bay Minerals operations where an artificial pond is constructed for the collection of beach sand deposits mined by a floating dreger (Fig 6). The slurry in the pond is pumped to the primary processing plant for flotation.

Figure 6: Dredge mining employing a floating dredger

3.2 Processing of Heavy Minerals

Mineral processing of the ore in a gravity separation circuit produce heavy mineral concentrates. The concentrates are conveyed to the mineral separation plant, in which successive stages of low and high intensity magnets separates the stream into non-magnetic and magnetic material. Magnetic ilmenite is smelted to produce titanium dioxide slag and pig iron mainly for export markets. The non-magnetic fraction from the heavy mineral concentrates is processed through electrostatic separation, hot acid leach and acid attritioning as well as high force magnetic separation to produce zircon and rutile products (Fig 3).

3.2.1 Titanium-bearing Minerals Value Chain

Crude ilmenite is charged in the smelter with a reductant, usually anthracite, to produce titania slag and pig iron. This process is predominantly used in South Africa and requires huge amounts of electricity to melt the furnace feed and to reduce most of the iron oxides to metallic iron. The slag and iron are tapped into moulds and ladles respectively, where titanium dioxide (TiO_2) slag is crushed and classified according to particle size, while pig iron is purified according to customer specifications.

Other processes of upgrading ilmenite, include the production of synthetic rutile. This process is employed in overseas industries where electricity costs are high and ore bodies are not suitable for smelting. The process produces material with high content of TiO_2, however, the iron emerges as iron oxide and not free iron, resulting in a loss of by-product in the process.

The bulk of South Africa's titanium slag is exported to international markets, for use in the pigment industry. Titanium slag was priced between \$ 337/t and \$ 432/t in 2009.

3.2.1.1 Titanium Dioxide Pigment Processing

Titanium dioxide pigment was first manufactured by utilising a fussion process. This process was subsequently replaced by the sulphate and the chloride processes, with the latter favoured because of the ability to produce premium grade pigments. The chloride route is also environmentally friendly compared to the sulphate route, it discharges minimal waste material and does not use sulphuric acid.

Huntsman Tioxide, situated in Umbogintwini, Kwazulu-Natal is the only company in South Africa producing titanium dioxide (TiO_2) pigment via the sulphate route.

- ***Sulphate process*** – uses sulphuric acid as extraction agent, whereby the titanium rich feed is leached in 85 percent to 92 percent sulphuric acid solution to produce titanium sulphate and iron sulphate. The titanium sulphate is subject to selective thermal hydrolysis to produce hydrated TiO_2, followed by calcination cleansing, to produce titanium pigments (Fig 7).

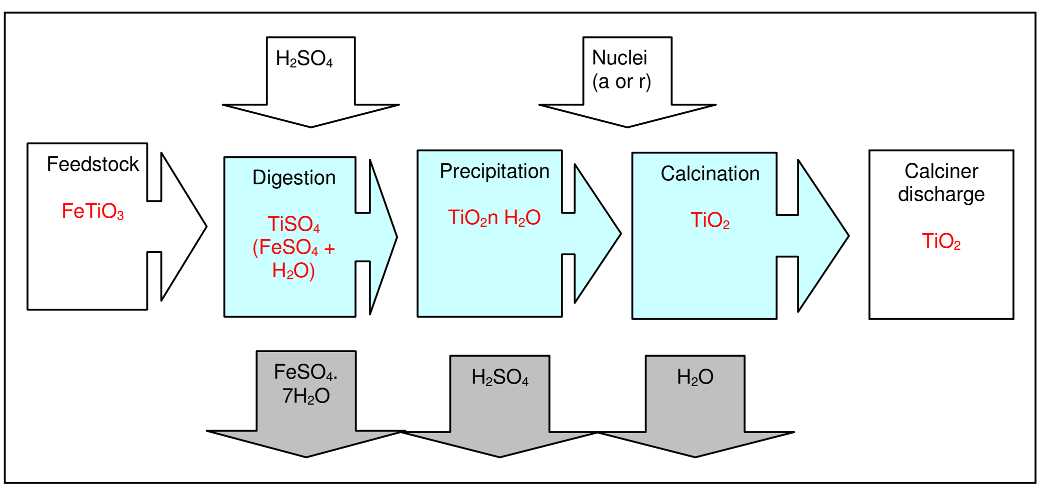

Figure 7: Titanium dioxide production – sulphate route process
(Source: Huntsman Tioxide)

- ***Chloride process*** – uses high quality grade feed roasted with chlorine and coke. Thereafter, impurities are separated from titanium tetrachloride ($TiCl_4$) through distillation process. The purified titanium tetrachloride is then agitated in the presence of oxygen to produce a titanium dioxide (TiO_2). This process is favoured because $TiCl_4$ is easily purified and oxidised to a superior pigment, which is used in premium grade coatings (Fig 8).

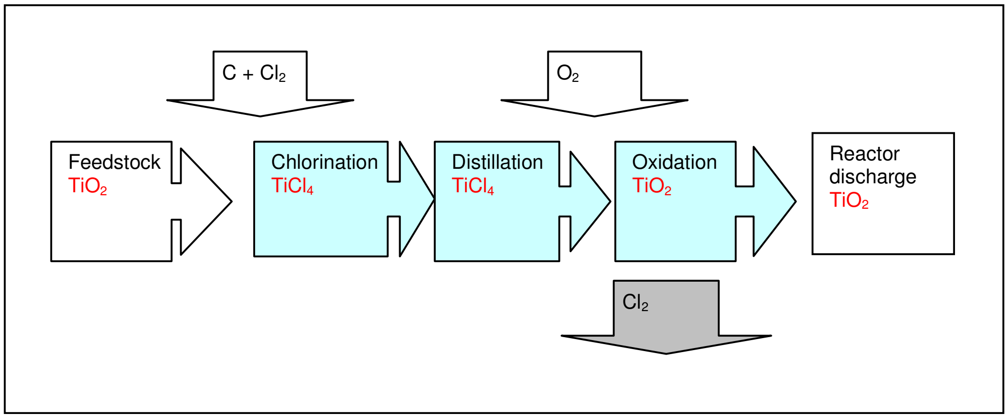

Figure 8: Titanium dioxide production – chloride route process
(Source: Huntsman Tioxide)

3.2.2 Zirconium-bearing Minerals Value Chain

As a non-magnetic material, zircon with rutile remains in the ore when ilmenite is separated by magnetic separation process. The ore is then subjected to dry milling, where zircon is separated from rutile using an electrostatic process, which takes advantage of the difference in the conductivity of the minerals.

The zircon can be dispatched and sold in various sectors, in particular the ceramics industry, where most of zircon is consumed. Other industries offering market option for zirconium include the nuclear industry, zirconium metal is used to clad fuel rods in the production of nuclear energy. Zircon was priced between $763/t and $900/t in 2009, while beneficiated products were sold between $1 600 and $3 000/t.

Geratech Zirconium Beneficiation is the only zirconium chemicals producer in South Africa. The plant is located in West Rand in Gauteng Province. The company uses local zircon as feedstock to produce a range of zirconium products, viz., zirconium chemicals and zirconium oxides, which are used in a variety of industry applications.

3.3 END USE MARKETS FOR HEAVY MINERAL PRODUCTS

3.3.1 Titanium bearing minerals

Ilmenite and rutile are sources of TiO_2 and titanium metal. TiO_2 is a whitening agent with various applications because of its high refractive index. Titanium metal functions in high-tech metallurgical applications for the aerospace and chemical processing industries involving high temperature and corrosive materials respectively.

Global demand for titanium mineral concentrates was estimated at 5.2 Mt in 2009, with 90 percent of consumption driven by the pigment industry. Most of titanium mineral concentrates are used as feedstock in the production of titanium dioxide pigment. The main titanium applications are in the manufacturing of paints (60 percent), paper (13 percent) and plastics (20 percent), (Fig 9).

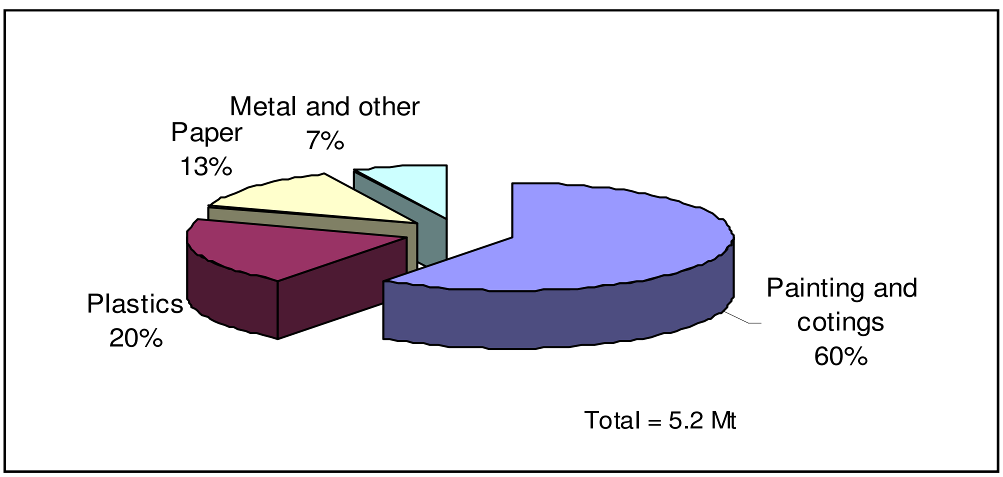

Figure 9: Global consumption of titanium dioxide, 2009
(Estimate from various sources)

Pig iron is produced as a co-product of titanium slag, and used in the foundry and steel industry.

3.3.2 Zirconium bearing minerals

Zircon is consumed in a variety of markets, including the ceramics industry, refractories, foundry, glass applications and chemicals (Fig 12). Zircon, which is also the starting point for zirconium metal contains zirconium and hafnium metals in nature at a ratio of about 50 to 1. Both hafnium and zirconium metals are used in the manufacture of control rods in nuclear reactors, because of their ability to withstand temperatures higher than 2 500^{o}C. Other applications include the manufacture of microchips, which are used in new generation fast computers.

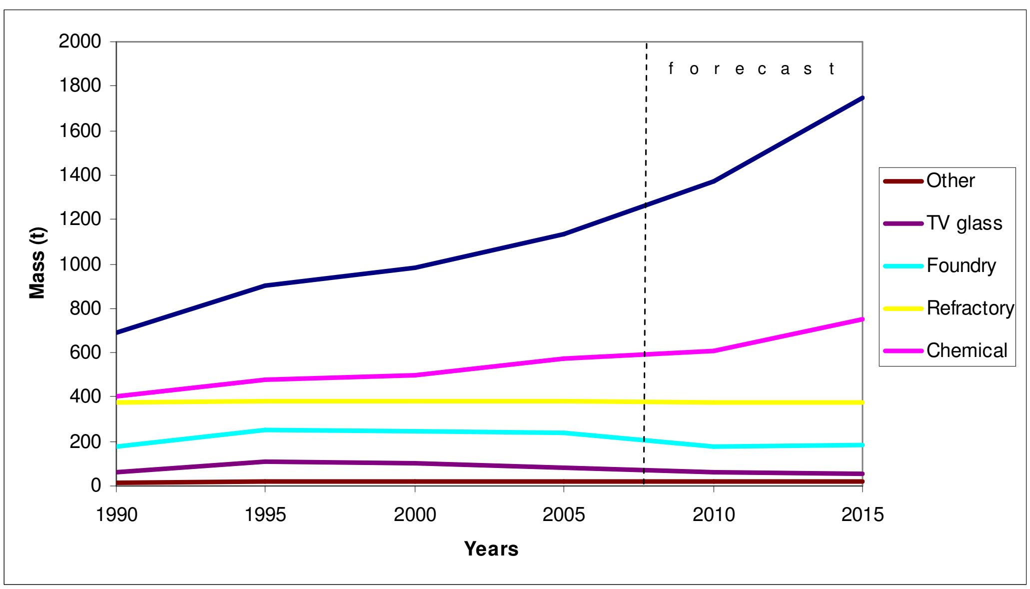

Figure 10: End-use trends for zircon consumption: 1990 – 2015
(Source : TZMI, Heavy Minerals Conference, 2009)

In 2009, the downstream industry for zircon in the form of Zr-oxides and Zr-chemicals was valued at about $500 million.

4 DOWNSTREAM BENEFICIATION OF ZIRCON AND TITANIUM IN SOUTH AFRICA

In 2008, mining contributed R199 billion, about 9.4 percent of gross domestic product (GDP), mainly through exports. South Africa, at 21 percent of world production, is the world's second largest producer of heavy mineral sands (Fig 11). Currently the country exports these minerals with very little value addition owing to the underdevelopment of the mineral and metal processing industry due to high costs involved in manufacturing value added products. The establishment of a titanium downstream beneficiation industry has a potential of contributing to enhanced national revenue generation, poverty alleviation and employment expansion. The success of a high technology manufacturing industry demands high-skills training development, which is essential and will contribute to employment creation.

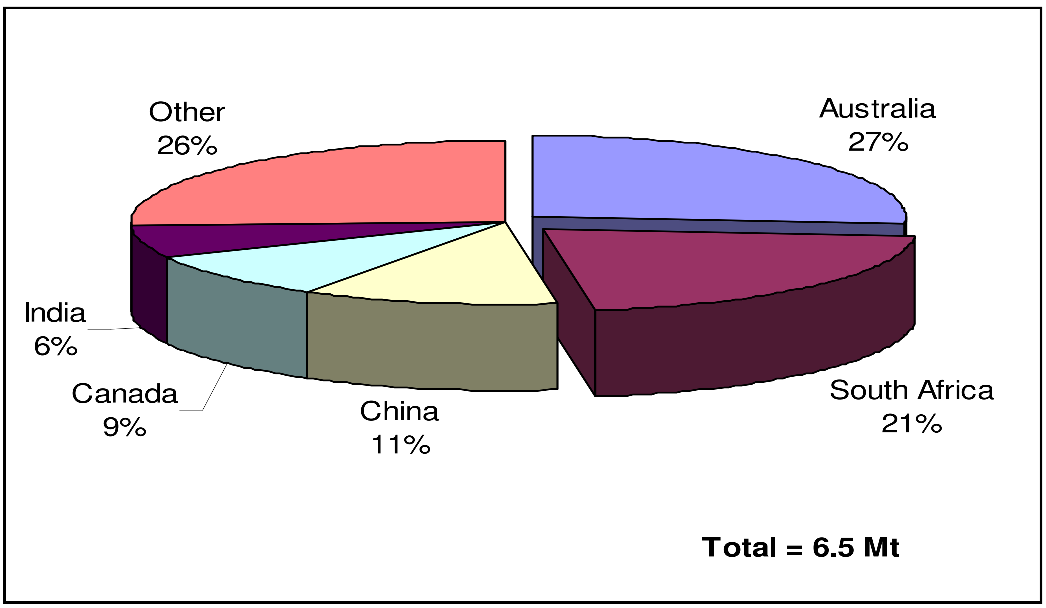

Figure 11: World accumulative production of heavy minerals by country, 2009 (Source: USGS Mineral Commodities Summary, 2010)

The Mineral and Petroleum Resources Development Act that was promulgated in 2004 support downstream mineral beneficiation in South Africa. The government together with its research organisations, viz., Mintek, CSIR and Necsa are driving for an orderly development of the country's mineral value chains in order to leverage benefit from inherent comparative and competitive advantages. Various task teams have been formed across the mining spectra to investigate and assess the potential of establishing downstream value addition industries in the country.

4.1 Zircon Beneficiation

South Africa produces 30 percent (about 400 kt per annum) of the world's zircon (Fig 12), however, limited beneficiation takes place in the country and hence more than 90 percent of the zircon mined is exported.

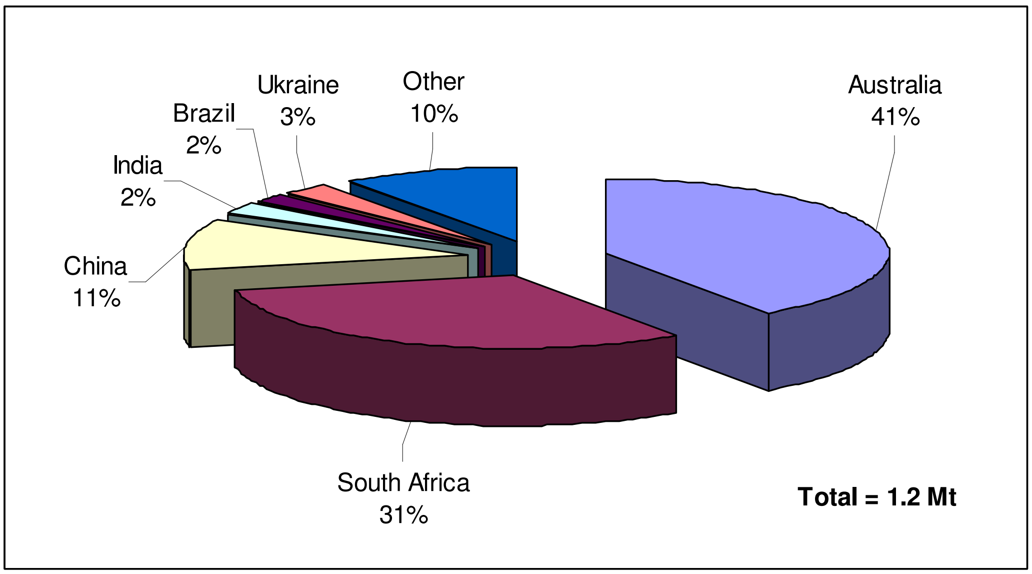

Figure 12: World zircon mineral production, 2009
(Source: USGS statistics, 2010)

Since 1992 the demand for Zr-chemicals continues to rise, owing to the increase in the metal intensity of use and the replacement of more toxic and expensive components with zircon. This presents an opportunity for a niche market to be exploited in terms of downstream beneficiation, since zircon products are used as substitutes. Other market sectors which showed potential growth for downstream value added products included the advanced ceramics and fibre optics in telecommunications.

South Africa may become an important player in solid oxide fuel cells industry, with production of catalytic converters expected to rise in future. Zirconium metal is used for cladding uranium rods in nuclear reactors to induce nuclei fission and generate heat, which produce steam from water and drives the turbine for electrical power generation.

The depletion of traditional resources for energy generation and a world drive to curb emissions from carbon fuels has raised demand for nuclear power. As a result, more than 40 reactors are under construction in many countries, mainly in Asia. The rising demand for nuclear power is likely to increase the demand for zirconium minerals since there is no close substitute with its unique properties.

4.2 Titanium Beneficiation

South Africa has no titanium sponge producer or any downstream value addition in the form of titanium metal. Titanium sponge is the basic feedstock in production of alloys, ferrotitanium, mill products or final components.

The establishment of a titanium downstream value addition industry was identified by government, through various studies, and has a potential to contribute positively in social development and sustainable economic growth of the country.

South Africa realizes only about 5 per cent from the approximately US$10.7 billion dollar pigment industry, in spite of the fact that it supplies 20 percent of the world's raw materials. Moreover, the country does not benefit from the $16.9 billion value added titanium metal production industry (Table 2). Therefore, establishing a local titanium industry, will give rise to enterprise development across all the segments of the industry (Fig. 13). However, the key enabler for the establishment of the industry will be the development of a more cost effective and proprietary primary titanium metal production process.

TABLE 2: TITANIUM RESERVES, PRODUCTION AND VALUE

	South Africa	World	Approximate value in millions US$ per annum	
	Mass TiO2 (kt)	Mass TiO2 (kt)	South Africa	World
Reserve base	244 Mt TiO2	1500 Mt TiO2		
Annual production (2008)				
Mineral	1 210	6 250	110	560
Concentrate	1 210	6 250	480	2 500
Pigment	20	5 100	42	10 700
Sponge		180		1 800
Ingot		7 179		3 600
Mill products		7 113		4 500
Final Products				7 000

(Source: Heavy Minerals Symposium Series S57, 2009, p 2)

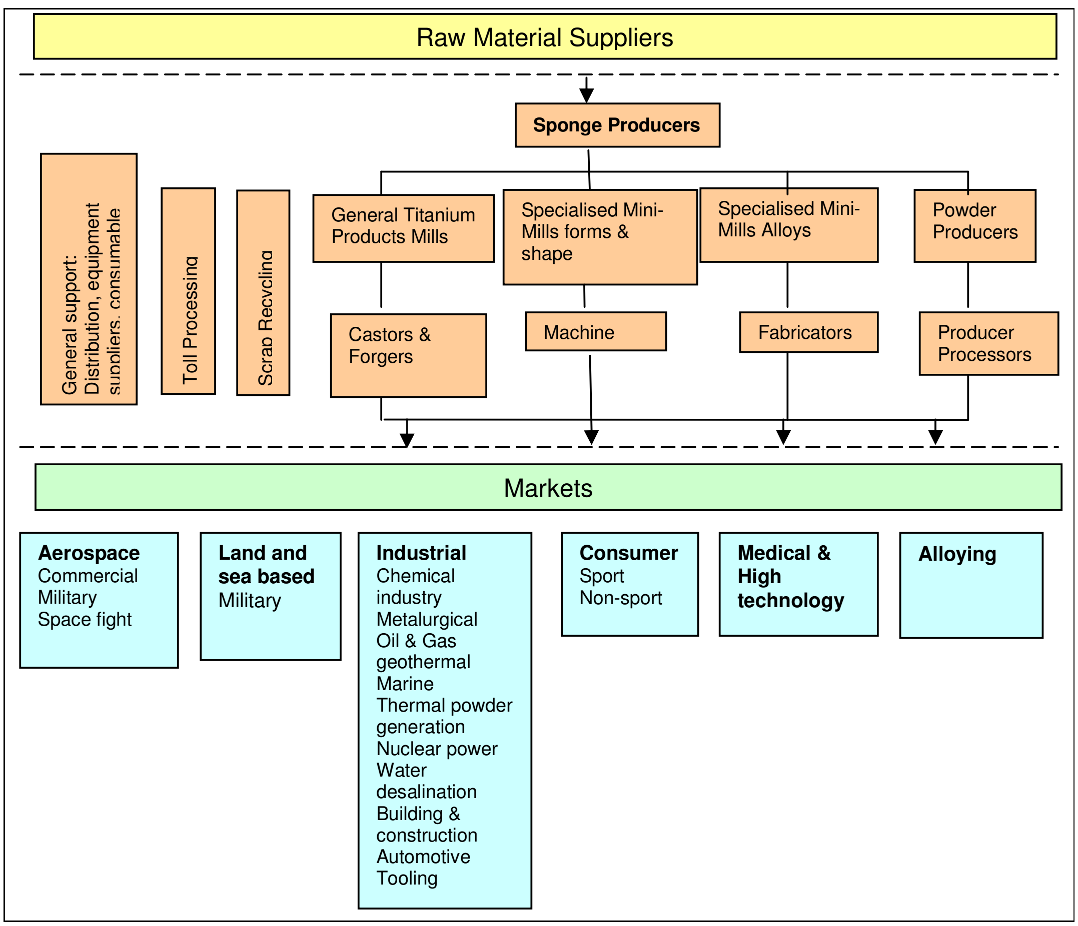

Figure 13: Structure of the titanium metal industry
(Source: Heavy Minerals Symposium Series S57, 2009, p 4)

The current metal industry is of little consequence to the raw material producers because it only takes about 5 per cent of world production of TiO2 feedstock, the rest is used in the TiO2 pigment Industry.

4.2.1 Research and Development

In the past 60 years various institutions have unsuccessfully performed research and development projects, to identify a cost effective route towards production of titanium metal on an industrial scale. However, over the past decade there were several renewed attempts at finding alternative lower-cost processes of producing titanium, with all those in the race closely guarding their technologies.

TABLE 3: R&D PROJECTS ON TITANIUM PRODUCTION PROCESSES

PROCESS NAME / ORGANISATION	COUNTRY	PROCESS	OUTPUT
Ono-Suzuki processes	Japan	Other	Powder
The JTS process	Japan	Other	Other
The FFC process	UK	Electrolysis	Powder
The Armstrong process	USA	Chemical	Powder
The ADMA process	USA	Other	Powder
The TiRO process	Australia	Chemical	Powder
The Peruke process	South Africa	Chemical	Powder
CSIR process	South Africa	Other	Liquid titanium/Powder

(Source Roskill (2007), Abare)

South Africa is one of the countries that undertake research programmes in reducing the cost of titanium metal production through initiatives driven by the Council for Scientific and Industrial Research (CSIR), Mintek and Anglo's Peruke processes. Other countries that are making strides and are at advanced stages of their research programmes are the USA, Australia, UK and Japan (Table 3). Most of the research projects currently performed are focused on the production of titanium powder, since it is assumed that it will ultimately replace titanium sponge as a much cheaper alternative to manufacture titanium metal.

5 CONCLUSION

The downstream value chain of heavy mineral sands in South Africa is limited, with the bulk of the country's production exported in raw state or with minimal beneficiation. In order to maximise benefit from the country's mineral resources the government has supported various initiatives aimed at increasing the country's technological capacity to improve the production of value added minerals. These include the establishment of a titanium metal industry and the manufacturing of zirconium products.

As soon as an alternative process of producing titanium metal at a reduced cost becomes available in South Africa, the titanium metal industry will have a potential of addressing issues of social and economic development, especially wealth and job creation. The initiative is not expected to go without its challenges, hence government together with the business community will have to work in partnership to achieve this goal.

With the world moving away from the burning of fossil fuels due to environmental concerns, there is a surge in capacity building of nuclear plants. This has resulted in increased demand for zircon products in the manufacture of control rods in nuclear reactors. The market for downstream value addition in South Africa is small with only a handful of companies beneficiating zircon. In 2009, zircon was priced from \$733/t to \$900/t, while beneficiated products were sold between \$1 600 to \$3 000 /t. Therefore, entry in this market presents good prospects for further downstream value addition. However, lack of expertise and technological barriers to entry in the field would first need to be overcome.

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