Mining Future Skills

MINING QUALIFICATIONS AUTHORITY

FINAL REPORT

FINAL REPORT

FOR

STUDY AIMED AT EXPLORING BENEFICIATION SKILLS THAT SHOULD BE PRIORITISED IN THE MINING AND MINERALS SECTOR

Prepared by: Wits Mining Institute

EXECUTIVE SUMMARY

Introduction and Purpose of Study

The Mining Qualifications Authority (MQA), as a Sector Education and Training Authority (SETA) for the mining and minerals sector (MMS) in South Africa, plays a crucial role in skills development and training. It ensures that the MMS has sufficient skills, both in terms of numbers and coverage along the mineral value chain. South Africa possesses vast mineral resources, but it has yet to achieve its goal of full participation in the entire mineral value chain, where complete value addition takes place. Several bottlenecks have been identified, including skills shortages. The MQA initiated a study aimed at identifying critical skills needed to support the mineral beneficiation on the country.

Part of the study included assessing policies and legal frameworks aimed at promoting mineral beneficiation in the country, mapping value chains of minerals undergoing beneficiation and subsequently identify skills gas across the different stages of the beneficiation value chain. These were done with the aim of making recommendations on how MQA can help build beneficiation related skills in the country to support value addition efforts.

Approach to the Study

The study employed desktop research where relevant literature was used. A systematic literature review was used to identify relevant reference material for the study. This is a structured approach which enables the researcher to identify, evaluate, and synthesise all available research on a specific topic. Different sources of data were used and these included peer reviewed papers, reports, online material, as well as grey literature. Information was sourced from the MQA, DMRE, Mineral Council of South Africa, Mintek and other stakeholders in the MMS.

Results and Key Findings

The results reveal the following insights:

- The government's strategic commitment to beneficiation aims to increase the mining sector's GDP contribution by encouraging local processing and manufacturing, shifting from raw material exportation to advanced value creation. Key sectoral policies include the Mineral and Petroleum Resources Development Act and the Beneficiation Strategy which promote mineral beneficiation in the country.
- The national beneficiation strategy has prioritised several minerals for mineral beneficiation, and these include Platinum Group Metals (PGMs), gold, diamonds, titanium, chromium, manganese, vanadium, nickel, coal, uranium, and thorium.
- Evidence of full value chain participation exists for some minerals, like coal (electricity generation) and PGMs (autocatalytic converters), but others, like titanium, remain underdeveloped. Overall, there is clear participation in mining and refining but limited involvement in semi-fabrication and final manufacturing.
- The skills required for mineral beneficiation encompass multiple disciplines and span various Occupational Framework for Occupations (OFO) categories. These skills exhibit commonalities across different stages of the beneficiation process and various commodities.
- Key skills that were identified include metallurgical engineering, chemical engineering, process control, material science, equipment operation, service and maintenance and laboratory analysis. The skills required for final manufacturing include industrial engineering, tool making, product design and some specialised ones such as battery chemistry for vanadium.
- Various public institutions and accredited training providers offer skill development opportunities along the full value chain for some minerals. However, there are gaps in training for emerging commodities and advanced technologies, indicating a need for more comprehensive and forward-looking educational programs to meet global demands.

Key Recommendations

The following recommendations were drawn from the study:

Recommendation 1: Create an inventory of mineral specific products for each stage of beneficiation

This study has focused on identifying end products from selected value chains based on applications from literature. Thus, some of the products identified in this study are not produced in South Africa. The MQA should consider creating an inventory of specific products produced in South Africa for each stage of beneficiation. This inventory can be turned into a live digital application which matches products produced locally with a complete list of industrial applications of a specific mineral.

Activity	Create a live inventory digital application from further research. This can be achieved by funding Master of Science in Engineering students.
When	Master of Science in Engineering duration varies from 1 to 2 years, but with clarity and aided access to data, this can be done in 18 months.

Recommendation 2: Evaluate beneficiation related skills using multiple criteria decision-making techniques

Given the non-linearity nature of mineral value chains, it is suggested that beneficiation related skills be evaluated using multiple criteria decision-making techniques. These techniques aid in evaluating alternatives based on multiple factors leading to a well-informed decision and robust framework. Moreover, these techniques often compliment literature very well because they enhance transparency and objectivity, reduce bias and foster better stakeholder engagement.

Activity	Conduct further research on this using proposed techniques, this can be achieved by funding Master of Science in Engineering students.
When	Master of Science in Engineering duration varies from 1 to 2 years, but with clarity and aided access to data, this can be done in 18 months.

Recommendation 3: Establish a National Beneficiation Skills Implementation Task Force

South Africa has several policy advocacy and skills development incentive mechanisms in place to support beneficiation. However, the country's limited participation, particularly in stage 4 of beneficiation, highlights potential gaps in the implementation of skills development initiatives. To address these challenges, the MQA should consider establishing a diverse national beneficiation skills implementation task force. Members of this task force should include representatives of various stakeholders such as government, beneficiation companies, other SETAs particularly MerSETA as well as training institutions or providers. Among functions, this task force would develop practical mechanisms for beneficiation skills planning in South Africa, ensuring alignment between industry needs and training programmes.

Activity	**Develop and implement sector-specific skills development programmes.**
When	Bi-annually or more frequently as needed.

Recommendation 4: Establish capacity of existing local beneficiation facilities

There are local processing and manufacturing facilities for the selected value chains. For example, Benteler South Africa (PTY) LTD and Mintek partake in manufacturing of autocatalytic converters/components producing exhaust & engine systems and PGM fuel catalysts, respectively. The MQA should consider engaging with these companies and other relevant entities to establish the type and number of exact skills they utilise. Moreover, an analysis of strengths, weaknesses, opportunities and threats of these entities can be considered to identify areas of improvements.

Activity	**Extend resources for this study to enable primary data collection and identify exact skills utilised by entities currently participating in beneficiation.**
When	Once off but the database should be updated at least once a year.

Recommendation 5: Establish a Beneficiation Skills Academy focused on identified value chains and/or strengthen existing training programmes

Most of the MQA-accredited training providers are linked to mining companies which produce products and mostly engage in stage 1 and 2 of beneficiation. As such, there is limited training for stage 3 and 4 of beneficiation among the training providers. It is important to note that the last stages of beneficiation are mostly manufacturing processes, accredited training programmes offered by MerSETA. Therefore, it is suggested that the MQA should consider engaging MerSETA and other related SETAs to establish a comprehensive list of beneficiation-related programmes currently offered in South Africa for selected value chains to identify gaps and potential synergies. Also, through collaboration with other SETAs and beneficiation companies, the MQA should consider establishment of the Beneficiation Skills Academy focused on identified value chains for which final manufacturing products are not yet produced locally. Consideration should also be made to establish a technology and innovation skills acceleration programme.

Activity	**Engage MerSETA and other relevant stakeholders. Source funds for the Beneficiation Skills Academy as well as the technology and innovation skills acceleration programme**
When	Strengthening existing training providers can take 1 – 2 years whereas a new academy would take up to 5 years.

Recommendation 6: Develop comprehensive beneficiation skills mapping framework & database based on primary data collection

This study has established the skills required along value chains of selected minerals as per the Beneficiation Strategy of South Africa using information in the public domain. However, specific skills as well as numbers can be obtained from primary data collection such as the key informant interviews. Primary data collection will enable design of a detailed skills mapping framework that integrates theory with current practices to identify critical beneficiation skills across the mineral value chain. The use of artificial intelligence should be considered so that possibly a live beneficiation skills database application can be created.

Activity	**Allocate additional resources for this study to enable primary data collection and design of the framework.**
When	Framework design is a one-off exercise, which can be achieved by extending this study. Establishing a database may be achieved in 6 – 12 months

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation/acronym	Description
ASGISA	Accelerated and Shared Growth Initiative for South Africa
AUC	African Union Commission
CSIR	Council for Scientific and Industrial Research
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
DMRE	Department of Mineral Resources and Energy
ESG	Environment, Social and Governance
ETDP	Education, Training and Development Practices
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GEAR	Growth, Employment and Redistribution
IPAP	Industrial Policy Action Plan
MerSETA	Manufacturing, Engineering and Related Services Sector Education and Training Authority
MICT	Media, Information and Communication Technologies Sector Education and Training Authority
MMP	Mining and Mineral Policy
MMS	Mining and Minerals Sector
MPRDA	Mineral and Petroleum Resource Development Act
MPRDAA	Mineral and Petroleum Resource Development Act as Amended
MPRRA	Mineral and Petroleum Resource Royalty Act
MQA	Mining Qualification Authority
NDP	National Development Plan
NGP	New Growth Path
NIPF	National Industrial Policy Framework
NSDP	National Skills Development Plan
OECD	Organisation for Economic Co-operation and Development
OFO	Organising Framework for Occupations

PGMs	Platinum Group Metals
PMA	Precious Mineral Act
R&D	Research and Development
RDP	Reconstruction and Development Programme
ROM	Run-of-Mine
SDT	State Diamond Traders
SETA	Sector Education and Training Authority
TVET	Technical Vocational Education and Training
WMI	Wits Mining Institute

1. INTRODUCTION AND BACKGROUND TO THE STUDY

1.1. Introduction

The Mining Qualifications Authority (MQA) is a Sector Education and Training Authority (SETA) for the mining and minerals sector (MMS) in South Africa. It was established in terms of the Mine Health and Safety Act No. 29 of 1996, and it is a recognised SETA in terms of the Skills Development Act No. 97 of 1998 as amended[1]. The MQA's vision is to lead skills development and training in the MMS to build a *"competent, health and safety-oriented mining and minerals workforce."* This is achieved through several programmes that are embedded within six strategic objectives which encompass the following:

Box 1: MQA's strategic objectives
• Promote efficient and effective governance and administration. • Improve skills development planning and decision-making through research. • Promote work-based skills development to support transformation in the mining and minerals sector. • Facilitate access to occupationally directed learning programmes for the unemployed. • Support mine community training initiatives to access economic opportunities. • Ensure the delivery of quality learning programmes in the mining and minerals sector.

In the 2024/25 Sector Skills Plan (SSP), the MQA identified skills priority areas at the back of the challenges facing the MMS in the country. Amongst these, is the need to *"monitor and support interventions aimed at developing the skills required for mineral beneficiation"* (Mining Qualifications Authority, 2023). This is in line with the country's efforts to maximise the benefits of mining for broader socioeconomic development. This can be achieved through increased participation in the mining value chain particularly in the final stages where more value can be created through mineral beneficiation. From the beneficiation strategy, government has identified several aspects that are essential in transforming raw mineral

[1] Source: https://mqa.org.za/company-overview/. [Accessed: 27 November 2024].

resources into high value finished products. The need for skills and knowledge to support mineral beneficiation is at the centre of the interventions promoted in MMS.

Against this background, the MQA has commissioned a study to identify critical skills that the MMS needs to prioritise for the successful implementation of mineral beneficiation in the country. This study was undertaken by the Wits Mining Institute at the University of the Witwatersrand.

1.2. Background and context

Africa is a major player in the global mining industry accounting for 30% of the world's mineral reserves (African Union, 2009). According to Ushie (2017), Africa supplies over 50% of mineral imports such as cobalt, manganese, chromium, diamonds and titanium to key commodity markets including the United States, China, the Middle East and Europe. Despite this position as a major source of the world's minerals, the continent has not maximised the full potential of its minerals and this has been attributed to several factors including limited mineral beneficiation. Most African countries export their mineral resources in a semi-processed or raw state, which results in significant economic value loss, as they forgo the potential added economic benefits of complete mineral beneficiation. These include added employment, increase in national revenue, and opportunities to foster industrial development by establishing downstream, upstream, and sidestream linkages between the mining sector and other sectors of the economy (African Union, 2009; Bastida, 2014).

Downstream linkages encompass a range of activities that are both capital and labour intensive and these include smelting and refining, as well as jewellery and metal fabrication (Department of Mineral Resources and Energy (DMRE), 2011). Sidestream linkages cover infrastructure, human resource development and research, upstream linkages include mining capital goods, consumables and services industries needed to support the transformation of minerals into high value saleable products (Department of Mineral Resources and Energy, 2011).

As is the case in most African countries, South Africa has strategically positioned mineral beneficiation as a key intervention area in the MMS because it presents a transformative mechanism that can be used to drive economic diversification, create sustainable employment opportunities, develop advanced technological capabilities, and address long-standing socioeconomic challenges in the country. In 2011, the DMRE developed the beneficiation strategy for the country, which aims to *“advance development through the optimisation of linkages in the mineral value chain, facilitation of economic diversification, job creation and industrialisation”* (DMRE, 2011: v).

The beneficiation strategy is supported by several policy and legal frameworks, including the Mineral and Petroleum Resource Development Act (MPRDA) and Broad-Based Socio-Economic Empowerment Charter for the Mining and Minerals Industry (i.e., Mining Charter). The strategy is also supported by the country’s industrialisation strategy that *“seeks to enhance the quantity and quality of exports, promote creation of decent employment and diversification of the economy, including promotion of the green economy”* (MQA, 2023).

1.3. Problem statement

South Africa is home to more than 50 economically exploitable minerals and total reserves are estimated to be worth 2.3 trillion USD (Department of Mineral Resources, 2018). While notable progress has been made in creating an environment that fosters value addition across the various mineral subsectors, the level of beneficiation remains low considering the country’s mineral endowment and position in the global economy. South Africa’s mining sector is still dominated by primary production and exports of raw or partially processed minerals (Tom, 2015). As highlighted by MQA (2023), most mining companies are concentrated in stage 2 and 3 of mining value chain which involve the exploitation of mineral resources and initial processing and transformation of raw mineral resources into intermediate products.

Several factors have been identified which present challenges to the expansion of beneficiation sectors, and these include power supply issues (i.e., the reliability and cost of electricity), infrastructure constraints, market access, research and development, and lack of entrepreneurship (Department of Mineral Resources, 2011; Tom, 2015; Department of Trade Industry and Competition, 2020). The shortage of skills is also amongst the key bottlenecks affecting beneficiation, and this is linked to several factors (Department of Mineral Resources, 2011).

According to MQA (2023), there is a shortage of professionals with specialised skills particularly in the areas of metallurgy, mineral processing and chemical engineering. Mineral beneficiation involves the establishment of processing plants and related industries and hence the implementation of the various beneficiation activities will require skilled professionals with expertise in engineering, metallurgy, geology and process optimisation (MQA, 2023). There has been a decline in the number of graduates in both chemical and metallurgical engineering, is concerning given the critical need for their skills in mineral beneficiation (MQA, 2023).

The other issue that has been raised speaks to beneficiation-related qualifications which are offered by different tertiary institutions including universities, Technical Vocational Education and Training (TVET) and Community Education and Training (CET) colleges. According to MQA (2022), there is a significant mismatch between the education provided by these institutions and the skills required by the beneficiation sector. Specifically, the scope of the programmes often does not adequately equip graduates with the necessary skills and knowledge to meet the demands of the MMS. To this end, the MQA (2023) has highlighted the need for a well-developed TVET system that provides practical and technical skills to meet the demands of the MMS.

Considering these challenges, there is a need to direct attention to skills as a critical input in mineral beneficiation. The findings of this study are crucial in supporting the implementation of interventions that are evidence-based and targeted to the skills needs of different mineral subsectors.

1.4. Aim and objectives

The aim of the study is to determine the critical skills that the MMS should prioritise for the successful implementation of mineral beneficiation in South Africa. The objectives of the study include:

- Assessing the existing government policies and strategies aimed at promoting and supporting mineral beneficiation in South Africa.
- Identifying and mapping the common minerals currently undergoing beneficiation in South Africa, including specific value chains and product types.
- Assessing the economic impact of current beneficiation efforts, including job creation, value addition, and export diversification.
- Mapping the required sub-sectoral skills across different stages of the beneficiation value chain, considering exploration and resource analysis, mineral processing and purification technologies, product design, manufacturing, quality control, business development, marketing, and logistics.
- Assessing the current availability and adequacy of relevant skills within the South African workforce, including the following:
    - Educational and training programmes currently offered for beneficiation-related skills.
    - Potential skills gaps and mismatches between existing workforce and future needs.
- Assessing the adequacy and effectiveness of existing skills development programmes and training institutions catering to beneficiation-related skills.
- Identifying best practices and transferable lessons learned from international experiences that can be adapted to the South African context.
- Recommending interventions that the MQA can implement to support beneficiation-related skills in the MMS.

1.5. Significance of the study

As previously noted, skills shortage is amongst the bottlenecks affecting the levels of beneficiation in the country. By identifying critical skills needed to advance beneficiation, this study will directly contribute towards the transformation of the MMS from a primary mineral exporter to a producer of finished goods. This comes with many benefits including revenue generation, job creation, economic diversification, and increased industrial activity. Mineral beneficiation also presents opportunities for entrepreneurship as the demand for local supplies increases (Department of Mineral Resources and Energy, 2020). The findings of this study could also inform policy interventions that support the implementation of the beneficiation strategy. This is particularly relevant in the current context where the demand certain minerals, such as PGMs and critical minerals like nickel, vanadium, and chrome, is expected to rise due to their importance for the Just Energy Transition.

1.6. Structure of the report

The report is structured into eight chapters as outlined below:

Chapter 1 provides introduction and background to the study. This chapter also includes the problem statement, aim and objectives of the study. The significance of the study is also discussed.

Chapter 2 presents the literature and policy review. In the chapter, government policies and strategies supporting mineral beneficiation are outlined. An overview of the MMS is provided, and particular attention is given to mineral beneficiation in the MMS.

Chapter 3 discusses the research methodology employed in the study. The chapter also outlines data collection and analysis methods as well as ethical requirements and challenges and limitations of the study.

Chapter 4 discusses the value chains of selected minerals, and the processes and/or equipment are discussed as the inform skills required along these value chains.

Chapter 5 incorporates the critical skills and/or occupations required for different processes into the value chains presented in chapter 4.

Chapter 6 identify and discusses beneficiation related programmes.

Chapter 7 summarises the key findings matched with particular focus on the study's objectives.

Chapter 8 concludes the report and presents recommendations that can be taken forward to support implementation of mineral beneficiation in South Africa.

2. LITERATURE AND POLICY REVIEW

2.1. Introduction

This chapter begins with an overview of the MMS. The chapter then provides the theoretical framework within which the study is situated. Further, it introduces mineral beneficiation as a critical stage of the mining value chain. In this discussion, definitions and key activities encompassing beneficiation are highlighted as well as the status of beneficiation. The chapter also discusses beneficiation skills, government policies and initiatives, and concludes with case studies that provide that provide international experiences and lessons applicable to South Africa.

2.2. Overview of the mining and mineral sector in South Africa

South Africa is endowed with several of the world's top mineral resources and reserves, as such, it leads global production of some minerals. The country holds the largest reserves of platinum-group metals (PGMs) at 88% and manganese at 32% chromium at 70% globally (Mahlangu, 2022; Statista, 2024; Sun et al., 2021). By volume, the country is the largest global producer of manganese, platinum, rhodium, chrome, aluminosilicates and vermiculite (Nex and Kinnaird, 2019; Statista, 2024). Additionally, in 2019, the country was the "second largest producer of palladium, antimony, vanadium, rutile, ilmenite and zirconium; world's third largest iron ore producer and sixth largest coal exporter by value" (Nex and Kinnaird, 2019).

Major advantages of mineral resources endowment include contribution to economic growth, attraction of significant foreign direct investment while fostering technological advancements and infrastructure development (Makgetla & Patel, 2021; Statista, 2024). Figure 1 shows the contribution of the MMS to employment and gross domestic product.

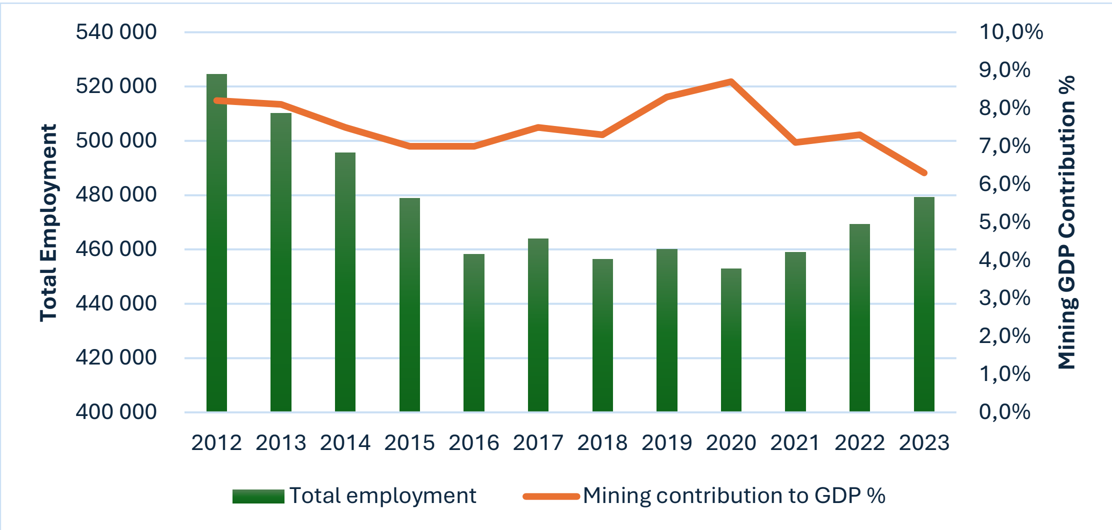


Figure 1: MMS contribution to national GDP and employment

(Source: Minerals Council South Africa, 2022, 2023)

In 2023, the sector contributed 6.3% to gross domestic product (GDP), providing direct employment to over 479 000 people and generating approximately R782 billion in exports which is about 25% of the country's total exports (Minerals Council South Africa, 2023). Figure

2 shows employment contribution of selected mineral commodities, namely, PGMs, coal, gold, iron ore and chrome. These represent the top five mineral subsectors in terms of contribution to MMS total employment.

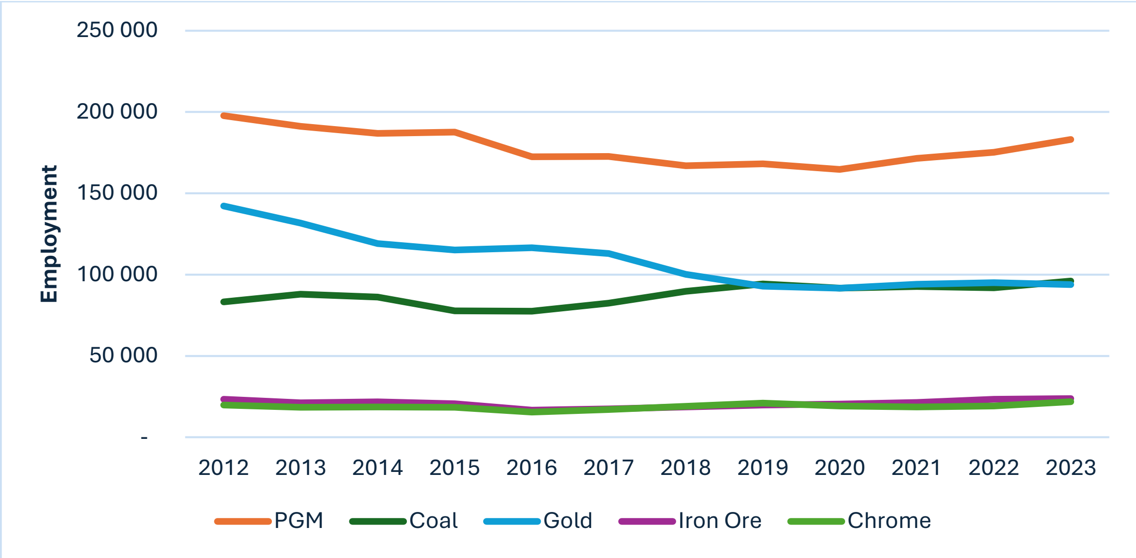


Figure 2: MMS employment by mineral subsector

(Source: Minerals Council South Africa, 2022, 2023)

As seen on figure 2, PGMs are leading and currently employ about 183 444 people. This equates to 38% share of the total employment. In the study period, the PGM subsector lost 14 608 jobs. The gold subsector was the second largest employer in MMS but has been overtaken by the coal subsector. Employment in the gold subsector declined from 142,201 in 2012 to 93 909 in 2023. This has been attributed to several factors including interruptions in the electricity supply, illegal mining, high input costs and difficult working conditions such as deep level underground mining (Minerals Council South Africa, 2023). According to Minerals Council South Africa (2023), gold export and local sales volumes declined by 1.9% and 17.1%, respectively because smelters were unable to maintain production outputs due to unstable electricity supply. The coal subsector is currently the second largest contributor to MMS employment and in 2023, a total of 96,050 people worked in coal mining operations. It is followed by the gold subsector and then iron ore and chrome which employ 23 762 and 21 842 respectively. Overall, there has been stability in terms of employment in MMS, looking at the period from 2019 to 2023.

While the South African MMS contributes significantly to the country's economy, the sector continues to face global and local challenges which threaten its sustainability (Lumandi and Nyasha, 2024). According to Lumandi and Nyasha (2024: 163), "these challenges vary from high production costs, low profitability, labour unrest, to increasing demands by government."

A combination of the challenges mentioned above, and other issues have necessitated the exploration of solutions to supplement current activities in MMS. Mineral beneficiation has been identified as a key policy intervention crucial to the realisation of the country's industrial policy and NDP. Given the presence of diverse minerals in the country, beneficiation opportunities are vast, spanning multiple subsectors such as PGMs gold, diamonds, rare earth elements, manganese, and chromium, each offering potential for advanced processing and value addition.

2.3. Theoretical framework underpinning the study

The study draws inspiration from the theory of comparative advantage which was created by British economist David Ricardo in the 19th century (Montevirgen, 2024; Gupta, 2015). Comparative advantage is defined as the "ability of an economy to produce a particular good or service at a lower opportunity cost than its trading partners" (Hayes, 2024). In this context, opportunity cost is the loss of potential gain from other alternatives when one alternative is selected. According to Widodo (2019), the theory of comparative advantage is based on the premise that a country should export goods or services to which it has the greatest comparative advantage and import those goods in which it has least comparative advantage.

A major determinant of comparative advantage is factor endowment, and this is described as the quantity and quality of the resources that countries possess. Factor endowment encompasses resources such as labour, agricultural land, mineral resources, capital or technology (Wilson, 1997). Gupta (2015) also identified technological superiority, human capital, demand patterns and commercial policies as aspects that can constitute comparative advantage. In this context, technological advantages that support the production of specific commodities that countries have may be presented as comparative advantage (Gupta, 2015). In line with the theory of comparative advantage, The Hecksher-Ohlin model also known as factor endowment theory, posits that maximum economic outcomes can be achieved if countries specialise in industries where they have comparative advantage (Ancheta et al., 2023; Gandolfo, 1986). It is within this context that mineral rich countries recognise the need to participate in the whole mining value chain to maximise the benefits of exploiting mineral resources.

According to Ushie (2017), Africa supplies more than 50% of mineral imports such as cobalt, manganese, chromium, diamonds and titanium to key markets including the United States, China, the Middle East and Europe. Most of these minerals are exported as raw ore or semi-processed products without complete value addition (African Union, 2009). A significant opportunity is lost in terms revenue generation and employment that come with beneficiation and value addition of minerals. The other benefits that can be leveraged from establishing a beneficiation sector is economic diversification brought by the establishment of new industries and technology transfer as advanced mineral processing technologies are introduced. This will lead to skills development and local industry development as the demand for local supplies increases. In view of these benefits, there is an opportunity for mineral rich countries through beneficiation and value addition to maximise the contribution of the MMS in socioeconomic development. South Africa is well endowed with minerals, and this constitutes comparative advantage which the country can use to leverage benefits that comes with mineral beneficiation and value addition.

While the availability of mineral resources provides a foundation through which mineral beneficiation can be established, it has been argued that comparative advantage is not enough to enable mineral rich countries to move beyond primary mineral exports. There is need to translate comparative advantage into competitive advantage which is described as conditions that would allow countries to perform better than their competitors (Gupta, 2015). There are a several factors that contribute to establishing competitive advantage and one aspect that has been highlighted by Heeks (2007) is factor conditions. These are defined as "inputs necessary to compete in any industry," factor conditions include human, physical, capital and knowledge resources as well as infrastructure such as transport, power and communications (Heeks, 2007). In line with this theory, skills have been identified as a major determinant of mineral beneficiation.

The human capital theory recognises individuals' skills, knowledge, and experiences as economic assets. According to Nafukho et al (2004), the human capital theory is premised on the foundation that investment in training and education is crucial in increasing labour productivity. To this end, human capital theory can be used to identify and assess skills needed to support the value addition across the various beneficiation activities. The study adopts value chain analysis as a framework for mapping beneficiation skills. Porter (1985) introduced the concept of value chain to describe activities undertaken across the different phases of production from inception to distribution and final disposal after use (Elvira, 2016).

Value chain can be used to identify major activities within a business thereby allowing the identification of areas that present competitive advantage (Brown, 1997). According to Elvira (2016), value chain analysis allows businesses to analyse the roles played by different actors and the contribution that they make to the production processes. It provides a systematic way of understanding key actors and environment within which activities take place. In this context, the enabling environment includes factors such as infrastructure, policies, and regulations, as well as institutions and processes that are required to support businesses. Against this background, value chain mapping and analysis will be used to map the common minerals undergoing beneficiation in South Africa, as well as the required sub-sectoral skills across different stages of the beneficiation value chain.

2.4. Beneficiation in South Africa

2.4.1. Beneficiation – Definitions, stages and activities

A value chain is broadly a process of adding value to products or services that companies trade for profit and/or other benefits. Figure 3(a) illustrates a typical intra-company mineral sector value chain, where the multiple value-adding processes are performed by a single company, including all steps involved; drilling, blasting, loading and hauling, sorting and concentrating, and transporting to market or it can be across different sectors, e.g. mining, refining, manufacturing, and sales. Figure 3 (a) depicts the former scenario where a product is transformed through various nodes or value-adding processes within a single company. Note that every node or process attracts inputs, and the rationale is that the longer the chain, the greater the opportunity to draw more inputs (products and services) from several suppliers, ideally from the domestic market if a better value is to be realised across the various stages of value chains.

In this scenario, Figure 3 (b) depicts a scenario where mined products are transformed across various companies in different sectors thereby creating value through downstream processes and inputs. It is worth noting that each company in Figure 3 (b) consists of processes depicted in Figure 3 (a). It can therefore be realised that, firstly, if the value chain in Figure 3 (b) is within the borders of a mineral-endowed country, the opportunity for local value creation will be enhanced provided local content input value is greater than the import input value. In this context, local content value is the value of goods, services, and even labour sourced locally. Secondly, there must be local beneficiation skills to support the creation of value chains.

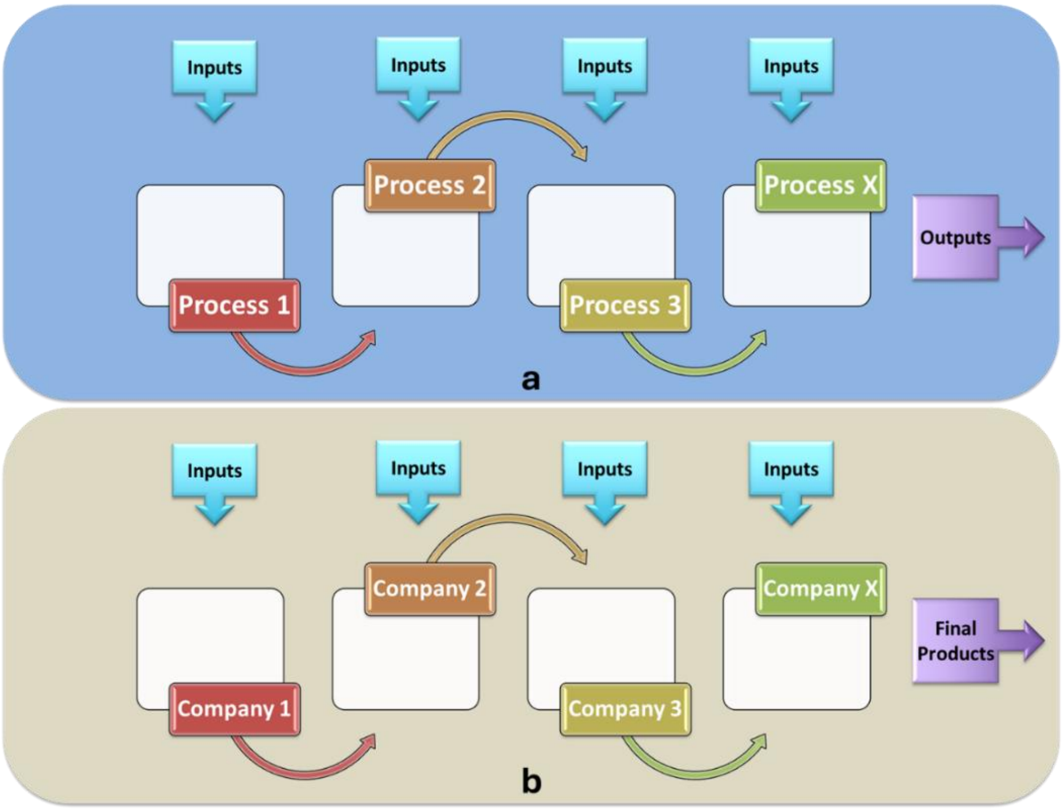


Figure 3: Mineral value chain. (a) A typical mineral value chain within a mining company from internal exploration to concentration. (b) A typical mineral value chain at the industry level from exploration to end-consumer

(Source: School of Mining Engineering, 2024)

The Department of Minerals and Energy (DME), (2009:2) in the Mineral and Petroleum Resources Development Amendment Act, 2008 (MPRDAA), states that "*beneficiation, in relation to any mineral resource, means the following—*

"(a) primary stage, which includes any process of the winning, recovering, extracting, concentrating, refining, calcining, classifying, crushing, screening, washing, reduction, smelting or gasification thereof;

(b) secondary stage, which includes any action of converting a concentrate or mineral resource into an intermediate product;

(c) tertiary stage, which includes any action of further converting that product into a refined product suitable for purchase by minerals-based industries and enterprises; and

(d) final stage, which is the action of producing properly processed, cut, polished or manufactured products or articles from minerals accepted in the industry and trade as fully and finally processed or manufactured and value added products or articles"

This clearly points out that mineral beneficiation in the context of the South African government, goes beyond the value-adding processes of beneficiation plants, concentrators and refineries and extends into the manufacturing and sale of mineral-based products. The four stages of beneficiation defined in the MPRDAA are demonstrated in Table 1.

Table 1: The example of beneficiation stages in South Africa

Stages of Beneficiation	Metals	Industrial Minerals
Primary	Saleable smelted products (copper cathode)	Processed raw material (granite blocks)
Secondary	Fabricated alloys and metals (copper tubes)	Basic final products (granite slabs)

Tertiary	Semi-manufactures articles (armatures)	Refined products (polished granite tops)
Final	Fabricated articles (electric motors)	Fabricated articles (granite workstations)

(Source: Leeuw, 2012)

The classification system in table 1 is not precisely applicable to all commodities but is sufficient to summarise beneficiation processes for most commodities. According to Tshabalala and Nyembwe (2024), primary stage involves the initial processing of minerals to produce sing crushing, grinding, and screening to prepare material for further refinement. Secondary stage uses methods such as flotation, magnetic separation and leaching to concentrate minerals. Smelting, electrolysis, and chemical processing are used to produce refined metals during tertiary stage whereas the final stage transforms products from stage 3 into finished goods. In case of chromium, stage 1 produces ferrochromium by smelting the ore; ferrochromium is melted with other alloying elements into stainless steel billets during stage 2. Further, the stainless-steel billets are rolled into flat stainless-steel products, and these are then transformed into several fabricated articles such as teaspoons in tertiary and final stages, respectively (Robinson and von Below, 1990).

Figure 4 provides more details on the various stages of the mining value chain moving from stage 1 (i.e., primary beneficiation) to stage 4 (i.e., final beneficiation). The figure also depicts typical activities and/or processes within various stages. Stage 1 starts with run-of-mine (ROM) undergoes processing to produce concentrates including smelted products such as copper cathodes and granite blocks for metals and industrial minerals, respectively. This is followed by stage 2 where the concentrate is converted into matte/slag, and this is followed by the production of alloys which are transferred to stage 3 and 4 to be worked in different shapes of steel products. The other components captured on the figure are labour intensity and capital intensity which influence the level of beneficiation.

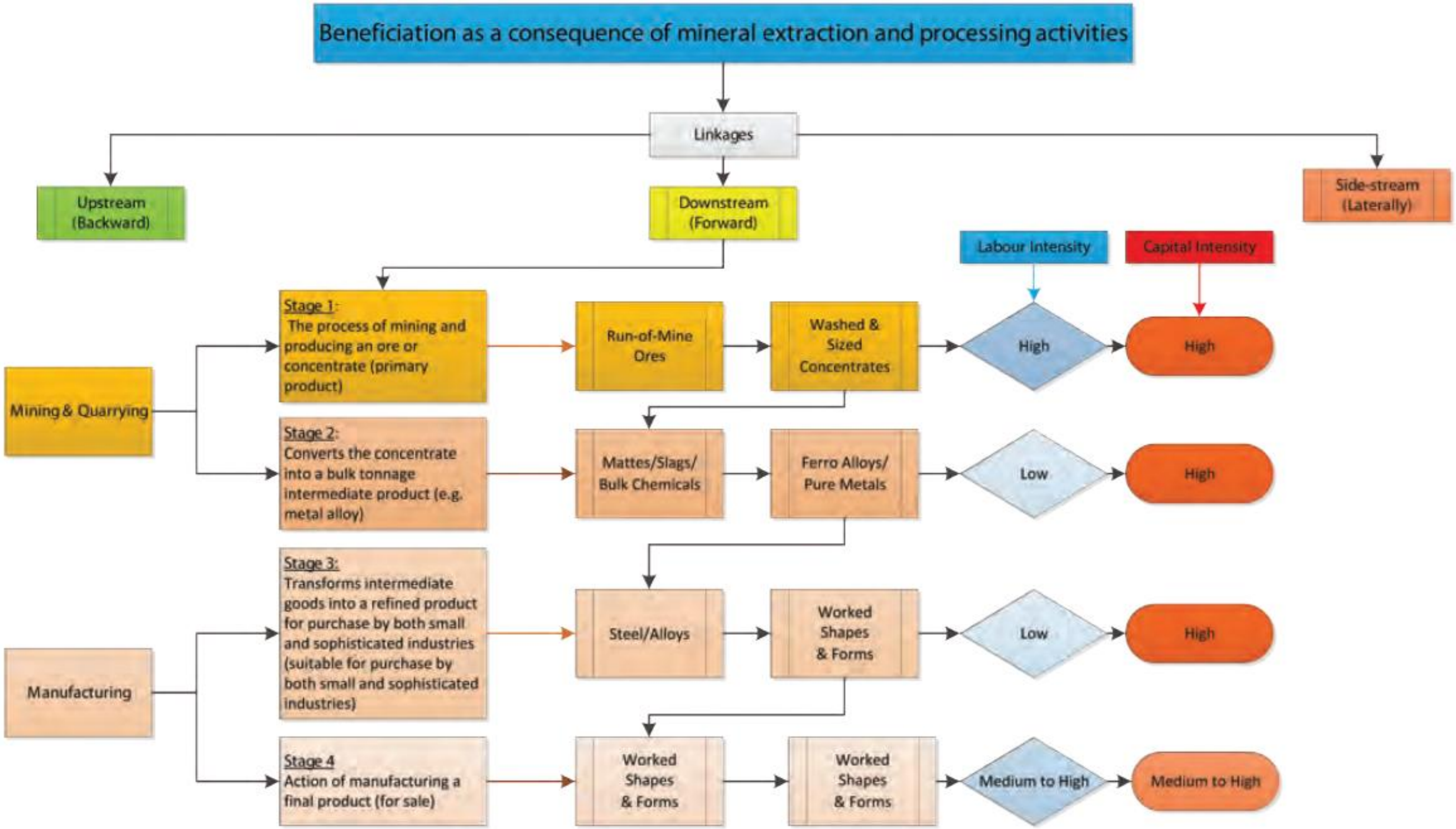


Figure 4: Beneficiation stages and associated activities

(Source: Mining Qualification Authority, 2014)

2.4.2. Current state of beneficiation in South Africa

The promotion of mineral beneficiation and its recognition as a key policy intervention is not new in South Africa. According to Robinson and Von Below (1990) large scale processing of chromium and manganese ores to produce ferro-alloys can be traced to the early 1960s. The discussions around the need to increase the levels of beneficiation across mineral commodities started gaining momentum in the early 1990s (Robinson and Von Below, 1990). The concern has always been that South Africa is amongst the leading producers of primary minerals and hence its position within the production of processed mineral products is expected to be high, which is not the case. Since then, there has been calls for the MMS to extend its participation in the mining value chain beyond the primary stage (i.e., as defined in figure 4).

First, in 1994, the Reconstruction and Development Plan (RDP) which is an integrated socio-economic development framework aimed at eradicating past injustices inherited from the apartheid government identified mineral beneficiation as a key intervention area in MMS. The need to increase the level of mineral beneficiation to support employment and revenue generation in the country was highlighted in the RDP (O'Malley, 1994). Secondly, in 1998, the Mineral and Mining Policy for South Africa urged the government to "develop South Africa's mineral wealth to its full potential and to the maximum benefit of the entire population. Government, therefore, will promote the establishment of secondary and tertiary mineral-based industries aimed at adding maximum value to raw materials" (Department of Minerals and Energy, 1998:30).

This policy intent was translated into legal requirements as seen in the MPRDA as well as initiatives implemented by several stakeholders including government, mining companies and others. In 2011, the Department of Mineral Resources developed a beneficiation strategy which is aimed at providing framework for the development of strategic mineral value chains (Department of Mineral Resources, 2011). In the strategy, five mineral value chains are identified as being critical to the country's mineral beneficiation agenda. These value chains are captured in table 2 alongside the key input minerals needed to support them.

These include the energy production cluster which was identified as being critical in terms of taking advantage of global energy demand which is expected to grow alongside population growth. The key minerals identified in the strategy is coal, uranium and PGMs. South Africa has large reserves of coal and produces 250 million tonnes per annum (US Geological Survey, 2019; Minerals Council South Africa, 2023). As reported by Minerals Council South Africa (2023) coal production output comprise of bituminous coal which accounts for 99% of the output and anthracite coal which takes the remaining 1%. In 2023, 80% of coal was sold locally for power generation and 20% was exported (Minerals Council South Africa, 2023). In terms of the value chain, run-of-mine (ROM) coal goes through crushing, washing, and screening before it is sold to the market. According to the Department of Energy (n.d), the level of beneficiation depends on properties of the coal and its intended use. As such, processing may require crushing or ROM coal may be required to go through a treatment process to reduce impurities (Department of Energy, n.d.). In this case, gravity concentration and flotation may be used to increase the product yield (Dworzanowski, 2013). Major use of coal is power generation where coal constitutes 90% of the country's energy supply. Coal is also used in the chemical industry and in steelmaking. Coal is also used to produce liquid fuels (Sasol, 2005).

Table 2: Selected value chains and input mineral commodities

Selected value chains	Key mineral commodities										
	Coal	Uranium and thorium	PGMs	Gold	Diamond	Iron ore	Manganese	Nickel	Vanadium	Titanium	Chrome

Energy commodities	**X**	**X**	**X**								
Iron and steel						**X**	**X**	**X**	**X**		**X**
Pigment and titanium metal production										**X**	
Autocatalytic converters and diesel particulate filters			**X**								
Jewellery fabrication			**X**	**X**	**X**						

(Source: Department of Minerals and Energy, 2011)

While there are calls for South Africa to move away from fossil fuels to cleaner energy sources, there are opportunities brought by the carbon capture technology. According to the Department of Science and Innovation, (2024), the carbon capture and use technology supports the country's Just Energy Transition Implementation Plan. There are currently two CoalCO2-X technology demonstration centres in Kelvin Power Station in Gauteng and PPC Cement plant in Dwaalboom in Limpopo (Department of Science and Innovation, 2024). Another key energy mineral is uranium which is currently produced as a by-product in gold mining operations. With South Africa looking at complementary sources for power generation, this presents beneficiation opportunities for uranium to be used in nuclear power generation (Department of Minerals and Energy, 2011). PGMs have also been identified key energy sources and this is growing with the use of PGM in hydrogen production.

In the beneficiation strategy, PGMs are at the centre of the production of auto catalysts and diesel particulate filters. As alluded, the country is ranked top in the world in terms of PGM reserves and production output. In 2023, PGM production was reported at 253 tonnes and this compared to 269.5 tonnes in 2022 (Minerals Council South Africa, 2023). The decline in the PGM production is attributable to several factors including electricity interruptions and rising cost of electricity. More so, production was affected by high input costs (Minerals Council South Africa, 2023). According to Tom (2015), ROM PGMs are refined to the highest level before being sold to the market. In terms of processing, they undergo crushing, milling, and flotation to produce a concentrate. This concentrate is smelted to produce a furnace and a converter matte (Dworzanowski, 2013). This is then taken to base metals refinery where nickel, copper, and cobalt are recovered as by-products. This is followed by precious metals refinery where pure platinum and other PGMs (i.e., palladium, rhodium, ruthenium, and iridium) are produced (Dworzanowski, 2013). The opportunities for beneficiation in the PGM value chain are in the production of hydrogen and fuel cell technologies (Department of Mineral Resources, 2013). According to Energy Capital and Power (2024), the global market for PGMs is expected to increase by over 4% leading up to 2029. This will be driven using PGMs in the hydrogen value chain.

The production of steel and stainless steel is another key intervention area in the country's beneficiation strategy. Several input ferrous minerals have been identified and these include iron ore, manganese, chrome, nickel, and vanadium for which South Africa is a major producer (Department of Mineral Resources and Energy, 2011). According to Dworzanowski (2013), some ROM iron ore contains high iron content and low impurities, making it suitable for direct use in steel production without the need for extensive processing. In some cases, iron ore is processed and goes through pyrometallurgy (i.e., high temperature heating) to produce pig iron, which is then converted to steel. The steel produced can then be transformed into numerous semi-fabricated products (Dworzanowski, 2013). In the case of manganese, it is also processed to produce ferromanganese which can be used for alloying with steel. Chrome also undergoes a similar process where through pyrometallurgy, ferrochromium is produced. This is used in the production of stainless steel. Ferrochrome can also be used as an ingredient in chemical production and the manufacture of refractories (Dworzanowski, 2013). According to the South African Iron and Steel Institute (n.d.), the country is ranked 27th in terms of the production of crude steel globally. Given this position, it has been highlighted that the country's stainless-steel sector is best positioned to compete with global competitors and supply African markets (Burger, 2023).

Pigment and titanium production is the other beneficiation cluster being promoted in the country. According to the Department of Mineral Resources and Energy (2011:17), ‘titanium dioxide pigment industry consumes 95% of the titanium mineral concentrates production”. According to Dworzanowski (2013), titanium is mined from mineral sand deposits. The ROM is processed to produce ilmenite and rutile concentrates which are smelted to produced pig iron. This is used in steel production, as noted and titanium slag is used in the production of titanium pigments (Dworzanowski, 2013). The pigment finds used in the manufacturing of paints, paper and plastics (Department of Mineral Resources, 2008). The need to establish a titanium beneficiation value chain is driven by the fact that South Africa exports ilmenite and rutile to Japan and the United States to be used for titanium sponge production (Roux et al, 2020). According to Roskill (2019), it does not produce titanium metal and as such must import titanium processed products.

The application of gold and diamond in jewellery fabrication has also been promoted in MMS. According to the MQA (2023), there are 221 licenced diamond manufacturers in the countries. This is small given the country's gold and diamonds mineral resources. The MQA (2023) highlighted that, in 2023, the country’s jewellery sub-sector accounted for $0.72 billion in revenue compared to US$76.77 billion which was generated by India. Despite the low values from South Africa’s jewellery sub-sector, there is opportunity brought by the manufacturing of non-luxury goods which will account for 92% of sales in the jewellery segment (MQA, 2023). The jewellery manufacturing subsector employed 1 853 people in 2019, and this increased to 2 317 people in 2023. From the MQA’s Sector Skills Report (2024/25), the jewellery manufacturing subsector was amongst the five subsectors that reported a growth in employment of about 25%. There have been several initiatives in the country to support local jewellery manufacturing such as the Diamond Act. The Diamond Act was introduced in 2005 to support downstream value addition and amongst the key provisions was ensuring the supply diamonds to local beneficiators. According to the Department of Mineral Resources (2014), the Act requires that diamond producers supply 10% of their ROM production to State Diamond Traders (SDTs).

While significant inroads have been made to foster mineral beneficiation across different mineral commodities, the level of beneficiation does not match the mineral endowment of the country. Mineral beneficiation is affected by several challenges that need to be addressed to enable the country to leverage benefits across strategic mining value chains.

2.4.3. Key constraints affecting mineral beneficiation

Several factors have been identified as key challenges affecting the level of beneficiation in the country. These include limited access to raw material for local beneficiation, infrastructure constraints, regulatory environment, access to international markets for beneficiated products, access to capital, research and development and skills shortages (Department of Mineral Resources, 2011; Anglo American, 2017). According to Department of Mineral Resources (2011), the implementation of beneficiation project is hindered by existing, long-term contracts that mining companies have with international clients that require them to continue to export raw mineral products. Minister Gwede Mantashe announced that government is looking into measures (e.g. tax on primary mineral exports) that can be put in place to encourage value addition in the mining sector. In response to this announcement, the Minerals Council South Africa (2024) indicated that mining companies have long term supply contracts and the proposal to tax primary mineral exports will have adverse effects on the performance of the mining sector for several reasons. Among others, these reasons include erosion of returns and deterrence of both, local and offshore investments. The Mineral Council South Africa (2024), stated that "local and offshore interest may be curtailed in investing in exploration and existing mining operations generally, and specifically for those minerals suitable only for the export market or where there are committed supply contracts in place."

Infrastructure constraints are a major bottleneck to mineral beneficiation. Specifically, there is a shortage of critical infrastructure such as rail, water, ports and electricity supply which are needed to support mineral beneficiation projects. Mineral beneficiation projects are energy intensive and require large amounts of stable electricity supply that is affordable to make a business case. According to Baxter (2019), electricity cost increased by over 500% in the past ten years. Minerals Council South Africa (2023a) also indicated that electricity cost is expected to account for 12.5% of the total mining cost by the end of 2024. This comes at the back of the electricity tariff announcement by National Energy Regulator of South Africa. According to Minerals Council South Africa (2023a), the tariff increase will translate into high cost of the production of intermediary products in gold, iron ore and PGM subsectors. To this end, processing, smelting and refining will be adversely affected (Minerals Council South Africa, 2023a).

The regulatory environment is crucial in creating a favourable environment for the promotion of mineral beneficiation. To this end, Minerals Council South Africa (2024) has highlighted the need for "*pragmatic, investor-friendly policies that will drive the reindustrialisation of our economy to attract domestic and foreign investment and skills".* Access to international markets for beneficiated products has also been identified as a key bottleneck that affects the business case for mineral beneficiation. While South Africa remains a dominant mineral producer in the global market, it will be competing with countries that have long established themselves as manufacturers of finished mineral products. More so, South Africa may be presented with trade restrictions that limit access in the global market (Department of Mineral Resources, 2011).

The limited access to capital and skills shortages are also affecting the state of beneficiation in the country. Depending on the mineral commodity, beneficiation involves several activities which require expertise in diverse fields such as engineering, metallurgy, geosciences and others. According to the Mining Qualification Authority, (2023), there is a shortage of professionals in the country with specialised skills particularly in the areas of metallurgy, mineral processing and chemical engineering. To this end, there is a need for skilled professional with the required knowledge to lead beneficiation processes with the mining sector. Figure 5 shows enrolment of students in key qualifications in the MMS. The figure shows the number of students that have enrolled for chemical engineering, metallurgical engineering, geology and mining engineering between 2017 and 2021. As can be seen in the figure, chemical engineering has the largest share of students' enrolments. It is followed by geology, mining engineering and metallurgical engineering. Overall, the number of students enrolling for the four programmes has declined.

Figure 6 shows the number of graduates across the four qualifications in the period 2017 to 2021. Again, chemical engineering has the largest share, followed by geology, metallurgical engineering and mining engineering. As seen on the figure, many students graduated in 2018. Overall, there is also a decline in the number of graduate students from the four programmes.

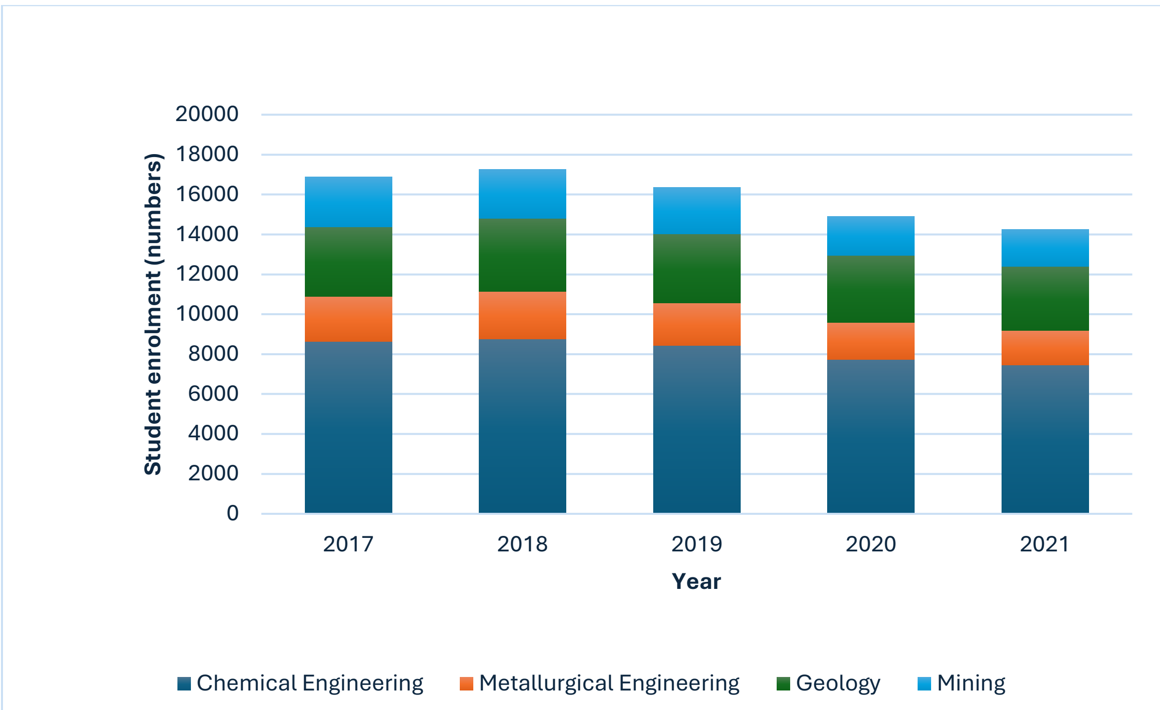


Figure 5: Students' enrolment in MMS-related qualifications

(Source: Mining Qualification Authority, 2023)

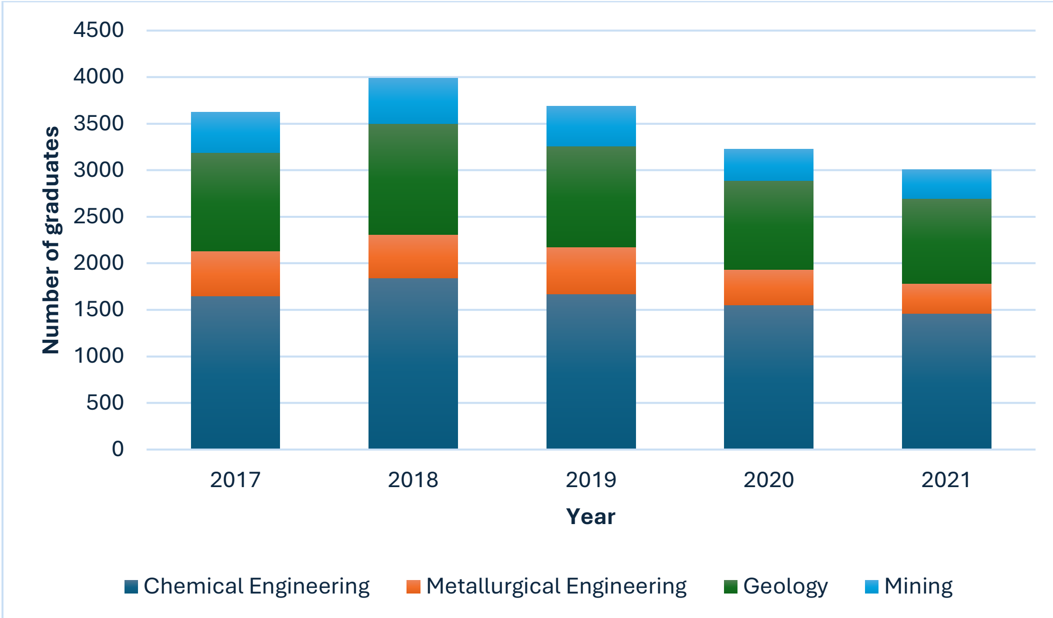


Figure 6: Graduates in MMS-related qualifications

(Source: Mining Qualification Authority, 2023)

2.5. Mineral beneficiation skills

2.5.1. Definitions

Mineral beneficiation skills, like all other work-related skills, are associated with job and occupation. Statistics South Africa (2012:2) defined a job as a "set of tasks and duties performed, or meant to be performed, by one person, including an employer or person in self-employment". On the other hand, occupation is defined as a "set of jobs whose main tasks and duties are characterised by a high degree of similarity".

To be able to perform jobs within an occupation and achieve satisfactory outcomes, a person employed in such an occupation must have skills. Oxford Dictionary (2024) defines a skill as "the ability to do something well". Shah and Burke (2010:320) describe skills as "ability to perform a productive task at a certain level of competence". According to Shah and Burke (2010), skills are often linked to formal qualifications. However, skills can be obtained through informal learning and on-the-job training (Shah and Burke, 2010). The Department of Higher Education and Training (20130 highlighted that a skill has two dimensions, namely skill level and skill specialisation. A skill level is defined as a “function of the complexity and range of tasks and duties to be performed in an occupation” (Department of Higher Education and Training, 2013:6). As such, an assessment of skills level considers the level of education and on-the-job training and/or experience required for competent performance (Leeuw, 2021).

Skills specialisation is about “in-depth knowledge (compared to general knowledge) required in the execution of tasks defining an occupation. This can be cognitive ability, subject knowledge, or knowledge of usage of specialised machines or tools” (Leeuw, 2021:129). In line with this characterisation, Becker (1962) cited in Shah and Burke (2010) highlighted two set of skills, namely, general and specific skills. General skills comprise of skills that are useful to many industries while specific skills are those that are useful to a particular industry providing training (Shah and Burke, 2010). Further differentiation is made between basic skills (i.e., literature, numeracy and computer literacy), generic skills (i.e., problem solving, team working, and ability to improve personal learning and performance) and vocational and/or occupational-specific skills (Shah and Burke, 2010). The different skill sets are crucial in undertaking higher levels of strategically chosen mineral beneficiation value chains in South Africa.

2.5.2. Beneficiation skills

As depicted in figure 4, the outputs of mining (primary stage) are inputs into subsequent stages. Manufacturing, heavy and light engineering, spans across secondary, tertiary, and final stages of mineral beneficiation envisaged in Section 26 of the MPRDAA. In these stages, manufacturing and services are core skills required to extract maximum value from the mining value chain. There are four skill levels under the Organising Framework for Occupations (OFO) classification, and they are mapped against the South African Education Band, School Grade and National Qualification Framework (NQF) in Table 3.

There are three bands covering general, intermediate and higher education levels. The OFO classifies skills under four levels. From table 3, level 4 coincides with the higher education band which covers NQF levels 5 to 10. The range of qualifications in this level starts from a higher certificate to doctoral degree. OFO level 3 is equivalent to NQF level 4 which is a national certificate. OFO level 2 falls within general and intermediate bands and covers NQF levels 1 to 3. This is equivalent to grade 9 to 11. OFO level 1 is within the general band and covers grade R to grade 8. In terms of entry, grade 10 can be admitted into TVETs and as such, grade 10 certificate holders are trainable in the use of specialised equipment and machinery. Matriculants have the option of being trained at the university advancing their knowledge from NQF level 4 to 10. There is also an option of pursuing the TVET route where they are trained to become artisans.

Table 4 shows beneficiation activities across different minerals and provides high-level examples of skills required. The typical occupations covering beneficiation include material scientists, metallurgical engineers, chemical engineers, electrical engineers, mechanical engineers, metal making operators, and material and smelter operators (AUC and OECD, 2024). The specific occupations for jewellery fabrication include gem cutters, jewellery mould makers, jewellery wax carvers, jewellery die stamper, diamond and gemstone setters, diamond graders and goldsmiths (Mining Qualification Authority, 2015). The occupations required to support manufacturing of end-products include welders, machinists, solar panel installers, electrical vehicle engineers, computer scientists and nuclear engineers (AUC and OECD, 2024).

Table 3: The mapping of education and qualification levels to OFO skill levels in South Africa.

Levels of education in South Africa				Skill levels
Education Band	**School Grade**	**NQF level**	**Qualifications**	
Higher		10	Doctoral degree;	4
		9	Masters' degree	
		8	Honours degree; Postgraduate diploma	
		7	Bachelor's degree; Advanced diploma	
		6	Diploma; Advanced certificate	
		5	Higher certificate	
Intermediate	12 (School leaving)	4	National certificate	3
	11	3	Intermediate certificate	2
	10	2	Elementary certificate	
General	9	1	General certificate	
	8			1
	7			

	6			
	5			
	4			
	3			
	2			
	1			
	R			

(Source: Leeuw, 2021)

Table 4: Beneficiation activities and examples of skills

Value chain	Mining		Beneficiation		Manufacturing	
	Main ores	Mining activities	Beneficiation activities	Examples of occupations	Final products	Examples of occupations
Aluminium	Bauxite	Refining into alumina, smelting (electrolysis)	Rolling, spinning, casting	Materials scientist, metallurgical/ mechanical/chemical engineer	Construction, consumer durables, aluminium foil	Metallurgist, welder
Coal	Raw coal	Crushing, screening, processing	Fuel, metallurgical coke	Mechanical/ metallurgical engineer	Thermal power, steel production	Machinist, maintenance technician
Cobalt	Cobalt oxide, cobalt sulphate	Pyrometallurgy, hydrometallurgy	Cobalt sulphate/ oxide refining	Chemist, process engineer	Lithium-ion batteries	Materials scientist, chemical engineer
Copper	Copper oxide, copper sulphate	Drilling, blasting	Copper processing: pyrometallurgy, hydrometallurgy, electrorefining	Materials scientist, metallurgical/chemical/ electrical engineer	Solar panels, wind turbines, heating/ cooling systems, electric wires, electric cars	Electrical engineer, solar panel installer, electric vehicle engineer
Diamonds	Diamond-bearing ore obtained from pipe, alluvial or marine mining	Magnetic susceptibility, X-ray luminescence, crystallographic laser fluorescence	Cutting and polishing	Gemcutters (both traditional and using high-tech equipment)	Jewellery, drills, cutting tools	Jewellery designer, jewellery maker
Gold	Amalgam, gold-bearing solution	Amalgamation, cyanidation	Purification with gaseous chlorine, electrolysis or pyrometallurgy	Chemist, process engineer	Jewellery, dentistry, electronic transistors, semiconductor silicon chips	Jewellery designer, jewellery maker, dentist, computer engineer
Iron	Iron ore	Concentrating: obtaining ores richer in iron	Blast furnaces, smelting reduction	Metal making and treatment process operatives	Machinery, construction, agriculture	Engineer
Natural gas	Natural gas	Vertical/horizontal drilling, hydraulic fracturing	Oil, condensate, water, sulfur and carbon dioxide removal, separation of natural gas liquids	Process engineer	Electricity, cooking, heating	Engineer, computer scientist
Nickel	Sulfides, laterites (nickel-bearing ores)	Drilling, blasting	Pyrometallurgy, smelting, hydrometallurgy	Materials scientist, metallurgical engineer, chemical engineer	Stainless steel, batteries, mobile phones	Materials scientist, chemical engineer
Petroleum	Crude petroleum	Drilling	Oil refining: separation, conversion, treatment	Process engineer	Transportation, electricity, heating	Engineer, computer scientist
Platinum	Platinum ore	Blasting and ore crushing, flotation separation, drying, smelting	Refining: separation and purification	Material operator, smelter operator	Automobile exhaust systems, jewellery	Mechanical/ electrical/chemical engineer
Uranium	Uranium-bearing ores	Roasting then hydrometallurgy	Precipitation, refining, conversion to uranium metal, conversion to plutonium	Mechanical maintenance technician, dynamic test engineer	Nuclear power	Chemical/nuclear engineer

(Source: African Union Commission and Organisation for Economic Co-operation and Development, 2024)

2.6. Overview of education and training institutions

South Africa has 12 public universities, six comprehensive universities and eight universities of technology. There are also 50 public Technical Vocational Education and Training (TVET) colleges that offer OFO Level 3 and 4 skills training. Public universities are research focused universities which offer several academic programmes, universities f technology focus on technical and vocational training whereas comprehensive universities offer a combination of academic and vocational programmes. A combination of these institutions provides higher education training. Additionally, Sector Education and Training Authorities (SETAs) in South Africa play a crucial role in facilitating skills development across various sectors by engaging industry stakeholders, developing relevant curricula, and providing funding for training programmes. Moreover, SETAs accredit skills development providers and implement performance metrics to ensure the effectiveness and alignment of training with industry needs. In particular, the SETAs that can collaborate to support the development of beneficiation skills are the Mining Qualification Authority (MQA) and Manufacturing, Engineering and Related Services Sector Education and Training Authority (MerSETA). Media, Information and Communication Technologies Sector Education and Training Authority (MICT SETA), Services SETA, and Education, Training and Development Practices Sector Education and Training Authority (ETDP SETA) are providing skills development programmes that are relevant to mineral beneficiation.

Different institutions provide educational training and subsequently skills acquisition for specified OFO levels based on different entry requirements as discussed in chapter 5. Broadly, engineering programmes at university level require grade 12 Mathematics, Physical Science and English. The Admission Point Score (APS) differs across institutions. For TVET colleges, grade 12 with Mathematics, Physical Science and English are required. There are TVETs that accept grade 9 for N1 programmes. N1 programmes are part of the National Accredited Technical Education Diploma (NATED) framework in South Africa which are designed to provide foundational skills and knowledge in a specific vocational or technical field, typically at NQF Level 2. In line with skills specialisation considerations as defined by Department of Higher Education and Training (2013) and Leeuw (2012), universities offer subject and/or process knowledge whereas TVETs offer hand-on courses which are aligned with usage of specialised equipment. According to Montja (2019), beneficiation requires practical skills that can be obtained from TVET colleges and as such, it is crucial to promote education across different levels.

Notwithstanding beneficiation skills required to enable inputs from linkages such as electrical and mechanical engineering, metallurgy and chemical engineering are amongst the key beneficiation skills. While both metallurgy and chemical engineering cover similar fundamentals, aspects of chemical engineering include process design, plant operations, thermodynamics, reaction engineering and separation processes. The key aspects of metallurgy offered in the various institutions are mineral processing which include crushing and grinding; metal extraction; material science; process control such as mass balance; and quality assurance. Table 5 shows institutions offering metallurgy and/or chemical engineering. From the table, it is observed that chemical engineering and related programmes are offered in more institutions compared to metallurgical engineering and related programmes. This reconciles with figures 5 and 6, where chemical engineering accounted for the largest students' enrolment and graduate outputs.

Table 5: Institutions offering metallurgy and chemical engineering

Institution	Metallurgical engineering and related programmes	Chemical engineering and related programmes
University of South Africa	X	X
University of Pretoria	X	X
University of the Witwatersrand (Wits)	X	X
University of Johannesburg	X	X
Vaal University of Technology	X	X
University of Cape Town		X
Stellenbosch University		X
University of KwaZulu-Natal		X
Tshwane University of Technology		X
Nelson Mandela University		X
Mangosuthu University of Technology		X
Durban University of Technology		X
Cape Peninsula University of Technology		X
College of Cape Town		X
South West Gauteng TVET College		X
Northern Cape Urban TVET College	X	
Ekurhuleni West TVET College	X	X
False Bay TVET College		X
Northlink TVET College		X
Goldfields TVET College	X	
Orbit TVET College	X	

2.7. Government policies and strategies

This section provides an overview of policies and strategies currently in place to promote and support mineral beneficiation in South Africa. The various pieces of policy and legislation frameworks are discussed at two levels – national and sectoral levels.

2.7.1. National level

The Constitution of South Africa provides the foundation, the principles and parameters for policy, legislation, and development strategy are formulated (South African Government, 1996). The initial development programme was the Reconstruction and Development Programme (RDP) white paper that provided guidance for policy formulation in various sectors of the economy. In the minerals sector, the Minerals and Mining Policy for South Africa was adopted in 1998 (Department of Minerals and Energy, 1998).

There have been a few national development strategies at different stages since democratic dispensation in 1994. These are the following: RDP, The Growth, Employment and Redistribution (GEAR), The Accelerated and Shared Growth Initiative for South Africa (ASGISA), The New Growth Path (NGP), and The National Development Plan: Vision 2030 (NDP). The strategies provided a framework for public policy development, and legislative, and regulatory reform. The later strategy (NDP) was launched in 2012 as an action plan securing the future of South Africans as crafted in the Constitution (National Planning Commission, 2012). The NDP was based on a comprehensive diagnosis of South Africa's achievements and shortcomings since 1994. It is founded on six pillars that represent the broad objectives of the plan to eliminate poverty and reduce inequality (National Planning Commission, 2012). It sets out a vision and sector specific goals to be achieved by 2030 and advocates both collaboration by all social partners and the redirection of policy making from short-term symptom-based policies to longer-term policies based on some evidence and reason. The NDP emphasises the need to change the structure of economy and growth pace while addressing challenges of transformation and job creation. To this end, it gives priority to the sectors with substantial potential for growth or employment or both, and where advantages may be leveraged to improve country's economic growth particularly in terms of trade and stimulate domestic linkages.

The mining sector is amongst the critical economic sectors that are the centre of the attainment of the NDP objectives. Against this, the NDP has recognised the potential of the minerals and metals cluster to be a key driver of growth and development despite the challenges the mining sector faces (National Planning Commission, 2012). While this is the case, it also notes that realising this potential will require improvements in transport, energy and water infrastructure to enable the deployment of capital that will lead to growth in output, employment, industrial linkages, exports and increased tax revenues. In addition, there is recognition that the successful growth and development of this cluster will require that it be supported to reduce its carbon footprint, improve the efficiency of its use of water, ensure adherence to environmental standards, and address the emerging skills gaps associated with modernisation.

The National Industrial Policy Framework (NIPF), launched in 2007, set out government's vision for South Africa's industrial economy and provided strategic direction with respect to industrial development. In short, this vision foresaw diversification beyond a historical reliance on commodities, the promotion of increased value-addition, a movement into non-traditional tradeable goods and services, the promotion of a more labour absorbing, broader-based and less spatially concentrated industrialisation path (Department of Trade and Industry, 2016). In the context of the need for a developmental state to transform the South African economy, the NIPF highlighted the fact that industrial policy is not the domain of a single government department but that it requires coordination across government. Policy coordination to ensure a conducive macro-economy, enabling infrastructure, technology and skills development was seen as being essential for the successful implementation of industrial policy (Department of Trade and Industry, 2016).

The NIPF therefore advocated prioritising and addressing sector specific and cross-cutting constraints and leveraging the opportunities through thirteen strategic programmes to accelerating industrialisation. It set out key principles and processes to guide the formulation and prioritisation of sector strategies and acknowledged the need for a multi-stakeholder determination thereof and collaboration in implementation through the pooling of resources. In addition to providing a framework for industrial development, the NIPF also provided an implementation mechanism, the Industrial Policy Action Plan (IPAP) for addressing the sector-specific and cross-cutting constraints to growth. Now into its tenth iteration, successive rolling three-year IPAPs have supported industrial development through strategic interventions and customised support to priority industries, especially within the manufacturing sector (Department of Trade and Industry, 2018).

The country's development agenda is supported by the National Skills Development Plan (NSDP) which serves as framework for improving "access to occupations in high demand and priority skills aligned to supporting economic growth, employment creation and social development whilst also seeking to address systemic considerations" (Department of Higher Education and Training, 2019:5). The NSDP is supported by Skills Development Act No. 97 of 1998 which sets out the framework for developing a coordinated approach to skills development in the country (Department of Higher Education and Training, 2019).

2.7.2. Sectoral level

This section captures a selection of supporting mechanisms or frameworks for effective implementation of the mineral beneficiation initiative in South Africa at a sectoral level.

Minerals and Mining Policy for South Africa of 1998

In the *1998 White Paper on Minerals and Mining Policy (MMP) of South Africa,* government sought to transform the mining sector by broadening access to the country's mineral resources. The country's mining policy specifically provides the intent for mineral beneficiation as (Department of Minerals and Energy, 1998:29 of 71):

"The aim of the policy will be to develop South Africa's mineral wealth to its full potential and to the maximum benefit of the entire population. Government, therefore, will promote the establishment of secondary and tertiary mineral-based industries aimed at adding maximum value to raw materials."

To actualise this, the government specifies policy statements which include the following (Department of Minerals and Energy, 1998):

Box 2: Policy statements outlined in the MMP
• Increase cooperation between the DMRE and the DTI. • Introduce supply measures, e.g., lower royalty rates. • Provide competitive and stable costs of public goods and services. • Support research into improved techniques and new applications of local mineral products. • Make available relevant non-confidential information to the private sector. • Establish joint-venture research and training programmes with universities and the private sector for the necessary skills. • Decisions regarding beneficiation must be based on sound economic principles. • Mineral prices and products will be market determined.

The Mineral and Petroleum Resources Development Act, 2002 (MPRDA):

The MPRDA is the primary legislation governing mining activities in the country. Mineral beneficiation is explicitly stated in Section 26 of the Act (South African Government, 2002):

- 26. (1*) "The Minister may initiate or prescribe incentives to promote the beneficiation of minerals in the Republic."*
- *26. (2) "If the Minister, acting on advice of the Board and after consultation with the Minister of Trade and Industry, finds that a particular mineral can be beneficiated economically in the Republic, the Minister may promote such beneficiation subject to such terms and conditions as the Minister may* determine"
- *26 (3) "Any person who intends to beneficiate any mineral mined in the Republic outside the Republic may only do so after written notice and in consultation with the Minister."*

The wording is not strong in the Act as in the Minerals and Mining Policy to empower the Minister to direct or enforce the beneficiation of minerals in South Africa.

The Mining Charter, as amended (2018)

The Broad-Based Socio-Economic Empowerment Charter for the Mining and Minerals Industry (i.e., Mining Charter) encourages both downstream and side stream value addition through the following provisions (Department of Mineral Resources, 2018):

- Beneficiation element: The provision allows mining companies *to offset up to 11% of their* ownership requirements against the value of their levels of beneficiation
- Procurement and enterprise development element: This element requires mining companies to procure a minimum of 70% of total mining goods on South African manufactured goods (Department of Mineral Resources and Energy. 2018).

Precious Metals Act, 2005 (PMA)

The Precious Metal Act provides for the acquisition, possession, smelting, refining, beneficiation, use and disposal of precious metals.

Section 6(1) of the Act states that, in considering an application for any trading license, permit or certificate, the Regulator (South African Government, 2006):

- (a) must have regard to the promotion of equitable access to and the orderly local beneficiation of precious metal;

Section 12 of the PMA provides the Minister with the powers to only permit export of unwrought precious metals if he/she is satisfied the extent of the applicant's facilitation of access for local beneficiation. The export approvals being granted currently have a validity period of one year and the section states (South African Government, 2006):

- (1) No person may export any unwrought or semi-fabricated gold except with the approval of the National Treasury in terms of the Exchange Control Regulations made under the Currency and Exchanges Act, 1933 (Act No. 9 of 1933), granted with the concurrence of the (DMR) Minister.
- (2) No person may export any unwrought or semi-fabricated metals of the platinum group except with the written approval of the (DMR) Minister which shall be granted

subject to the promotion of equitable access to, and the orderly local beneficiation of such metals."

The Mineral and Petroleum Resources Royalty Act (MPRRA), No.28 of 2008

The Act imposes a royalty on the transfer of mineral resources and regulates the calculation thereof (South African Government, 2008). For this purpose, the Act distinguishes between a 'refined mineral resource' and 'unrefined mineral resource' and caps royalties at five percent for the former and seven percent for the latter (South African government, 2008).

Beneficiation strategy (2011)

The country's beneficiation strategy was developed in 2011. The strategy outlines a *"framework that will enable an orderly development of the country's mineral value chains, thus ensuring South Africa's mineral wealth is developed to its full potential and to the benefit of the entire population*"(Department of Mineral Resources, 2011:v) and its overarching goals are to:

- *Advance development* through the optimisation of linkages in the mineral value chain, facilitation of economic diversification, job creation and industrialisation.
- Expedite progress towards knowledge-based economy and *contribute to an incremental GDP growth* in mineral value addition per capita in line with the vision outlined in the National Growth Path (NGP), NIPF and Advanced Manufacturing Technology Strategy (AMTS).

The strategy identified ten strategic mineral commodities and outlined five value-chains that would demonstrate the multi-tier value proposition inherent in embracing beneficiation as a policy priority (Department of Mineral Resources, 2011). Notably, the strategy explicitly recognised a dependence on intensive coordination across a range of government departments as well as other key mining stakeholders including business and labour, and the resolution of a range of cross-cutting constraints, for its success. The strategy also highlighted a number of intervention areas including investment in human capital development and implementation of programmes that support National Skills Development Strategy and the Sector Skills Plans in MMS.

2.6.3. Government incentives

The government provides several incentives, and these cover the following (Department of Trade, Industry and Competition (2023):

- Special Economic Zones
- Critical Infrastructure Programme
- The manufacturing Competitiveness Enhancement Programme
    - Production Incentives
    - Industrial Financing and Loan Facilities
- Manufacturing Investment Programme (MIP)
- Section 12i Tax incentive - This provides support for capital investments and training.
- Scientific and Technical Research and Development Tax Incentive in South Africa – Through this incentive, a company undertaking in research and development (R&D) in South Africa qualifies for a 150% tax deduction of its operational R&D expenditure.
- Through international trade agreements including bi-and multi-lateral agreements, there are programmes established to support mineral beneficiation. This is at the back of the need for governments to create an enabling environment for the country's beneficiated products.

2.8. Case studies and international experiences

Several countries have successfully implemented mineral beneficiation strategies, adding significant value to their natural resources and boosting their economies (Nkoe and Montja, 2019). The Department of Minerals (2011) note that beneficiation is not a new phenomenon to South Africa as 50% of the coal produced in the country goes to local electricity generation. While South Africa can learn from successful beneficiation initiatives within the country, it is also important to understand and learn from international experiences. As such, four countries are used here to provide key lessons from international case studies. Botswana, Australia, Chile and Sweden are chosen because they are among countries considered to have long and strong history of mining with well-established linkages along the mining value chain (Leeuw, 2021; Patrick, 2022). Furthermore, these countries were chosen to represent different geographic regions which will provide a broader context regarding enablers of beneficiation.

2.8.1. Botswana

In 2023, Russia and Botswana were the largest producers of diamond with production volumes of about 37.3 million carats and 25 million carats, respectively (Statista, 2023). The largest contributors to Botswana's GDP are Services and Diamond Mining which contribute 48.8% and 40%, respectively (Ngewa and Obama, 2024). Grynberg (2013) further noted that historically, Botswana exported most of its diamonds, for example, in 2011, Botswana exported 25 million carats of diamonds. A shift was noted in 2012 as the country was cutting about 20% of its rough diamonds (Grynberg, 2013). These efforts align with the value addition strategy which the country has put in place in the 1960s. According to Bakwena (2023:116) "in order to intensify efforts to derive more diversity in the mining sector, the Government of Botswana's strategy is to enhance value-addition in the mining sector locally through the concept of local content or downstream beneficiation activities." Thus, as early as 1971, Debswana established the Botswana Diamond Valuing Company (which transformed with additional mandate in subsequent years) to sort and value Debswana diamonds to implement the above-mentioned strategy (Bakwena, 2023).

Despite failed attempts since the inception of the beneficiation strategy, lessons were learned and negotiations continued until a notable breakthrough in 2005 (World Bank, 2020). Through a partnership between De Beers and the government, Botswana has made significant progress in beneficiation of diamonds, subsequently improving the country's economic stability (Grynberg, 2013; Oluyeju and Tshiamo, 2018). The country's GDP per capita grew from about 4000 USD in the 1990s to reach about 6500USD in 2024 (Ngewa and Obama, 2024).

The government invested in training programmes to develop a skilled workforce, enhancing the country's capacity for high-value diamond processing (World Bank, 2020). Through focus on diamond cutting and polishing, Botswana transforms rough diamonds into polished gems, reducing dependence on diamond mining alone (Oluyeju and Tshiamo, 2018). A range of finished diamond products such as rings, earrings and bracelets are produced (Oluyeju and Tshiamo, 2018). In addition to beneficiation of diamonds, there is research to beneficiate other minerals in Botswana such as copper (Coetzee, 2023).

2.8.2. Australia

According to Leeuw (2021: 68), "Australia is endowed with different minerals including gold, iron ore, coal, copper, bauxite, diamonds, and uranium." Australia holds the world's largest resources of gold, iron ore, lead, nickel, rutile, uranium, and zircon, and the second-largest resources of brown coal, cobalt, copper, ilmenite, lithium, silver, tungsten, and vanadium (Denhere, 2021; Geosciences Australia, 2020). The Australian mining sector experienced several evolutions over the years to reduce dependence on extraction of finite and non-renewable mineral resources (Patrick, 2022). Several economic linkages along the mining value chain were identified along with relevant strategies. Notable for this study, is the upstream linkage for which the strategy is promotion of local content to enhance linkages between mining and manufacturing industries (Patrick, 2022). Mineral beneficiation in Australia enhances the value of raw minerals, generating higher export revenue and creating job opportunities while supporting regional development (Baawuah et al., 2020).

For more than eight decades, Australia's steel industry has succeeded, consistently meeting the country's domestic steel demand (Talkin, 2016). The steel industry is prominently in three locations, namely, Lithgow, Newcastle and Port Kembla which are all characterised by proximity to inputs, easy market access, available labour, and low transport costs (Talkin, 2016). The steel industry contributes significantly to the economy employing over 100 000 Australians and generating over A$29 billion in annual revenue (Australian Steel Institute, 2024). In addition to favourable locations, the steel industry in Australia can also be attributed to the Steel Industry Protection Bill of 2015 which states that states that "*the object of this Bill is to ensure, as far as practicable, that all steel used in public works or infrastructure constructed by or on behalf of public authorities is manufactured in Australia*" Talkin (2016:19).

Venkataraman et. al. (2022) note the relevance of steel production to global economic development. The authors further state that steel production accounts for 7-9% of global greenhouse gas emissions despite the application of sophisticated, established and highly optimised blast furnace technology. Venkataraman et. al. (2022) concurring with Talkin (2016) also note that government interventions worked well for the local market, but these interventions may have hindered the industry's ability to expand internationally, as such, the export market struggled to gain traction. It is therefore suggested that the Australian steel industry requires implementation of forward-thinking environmental and industrial policies as well as funding for research and development (Venkataraman et. al., 2022). While the steel industry is discussed here because of its long history and strength, it should be noted that Australia beneficiates other minerals including but not limited to coal, gold, nickel, bauxite and lithium. Denhere (2021) mentions that the country engaged in battery minerals and processing research related activities and supports downstream processing of lithium.

2.8.3. Chile

Chile is renowned for its large endowment and production thereof of copper, but the country also hosts other minerals such as gold, silver, molybdenum, iron, coal, lithium, iodine, and nitrate (Dentons, 2024; Leeuw, 2021). Leeuw (2021) describes Chile as a mineral dependent country as its mining contributed 66% to total exports in 2010. This is also affirmed by the Natural Resource Governance Institute (2024) which stated that Chile's economy heavily relies on mining, with copper and lithium being pivotal due to their strategic importance in the energy transition and electromobility sectors. Copper mining is integral to Chile's sustainable economic development contributing 10% to the country's GDP and employing about 400,000 people.

Chile is the world's largest producer of copper producing both, copper concentrates and cathodes from sulfide ores (Barros, et al., 2022). Copper processing involves crushing, and grinding, followed by froth flotation, roasting, smelting, converting, and electrolysis (Barros, et al., 2022). Chile's success in linkages along the mining value chain can be attributed to strong policy framework, large-scale government investment in infrastructure and transport as well as availability of highly trained and skilled mining specialists (Denton, 2024). In addition to mineral/resources endowment, Chile's effective governance, stable political framework and public-private partnerships have leveraged assets to drive economic growth, employment, and investments in education, healthcare, and infrastructure (Voetmann, 2018).

Chile is facing several challenges in the production of copper which are likely to affect copper beneficiation. These challenges include declining ore grade, resource depletion, water scarcity, energy management and environmental concerns (Leiva Gonzalez and Onederra, 2022; Veliz et al., 2022). Therefore, there is a need to invest in technology and sustainable practices (Leiva Gonzalez and Onederra, 2022).

2.8.4. Sweden

With mining and refining dating back to over 1000 years, Sweden is known for its large production of iron ore in the European Union, but the country is also host to other minerals such as copper, zinc, lead, silver and gold (Geological Survey of Sweden, 2020). Goclawska (2023) notes that the mining and minerals sector contributed about 0.16% to the country's GDP and employed 6 996 and 7 434 people in 2018 and 2019, respectively. Leeuw (2021) and International Trade Administration (2023) note that manufactured goods accounted for over 75%, as such, Sweden can be classified as a manufacturing intensive country. Sweden's robust manufacturing sector, which contributes about 20% of the GDP and provides over 1 million jobs is being modernised by the government through initiatives in digitalization, sustainable production, resource efficiency, talent development, and innovation (International Trade Administration, 2023).

To remain globally competitive, Swedish manufacturers are continuously digitalising their production processes, services and products. Also, International Trade Administration (2023) Some of the key skills across different industries include system integration, digital thread, intelligent machining, computer aided design, computer aided manufacturing and advanced analytics (International Trade Administration, 2023).

2.8.5. Summary of key lessons

Some of the key lessons emerging from these case studies include, public-private partnerships, strong institutions and policy framework, sustainable practices and focusing on skills development (Mbabazi, 2018). Additionally, it is beneficial to embrace digitalisation and innovation, implement resource efficient production methods as well as continuously develop skills to keep up with technological advances (International Trade Administration, 2023). The countries discussed beneficiate some of the minerals which have been identified for downstream value addition in the South African beneficiation strategy. Therefore, these case studies form a good basis to understand skills required for successful beneficiation, subsequently enabling positioning of the South African MMS in terms of gaps in skills. For example, the manufacturing intensive Sweden, highlight the need for the fourth industrial revolution technical skills. Furthermore, some of the beneficiation enablers as well challenges highlighted in the case studies emphasise the global need to prioritise environmental, social, and corporate governance (ESG) issues and skills thereof.

2.9. Summary and conclusion

The chapter discussed various aspects of literature underpinning beneficiation, from the theoretical framework to international case studies. Mineral beneficiation is underpinned by the theory of comparative advantage which is mainly determined by factor endowment. South Africa is well endowed with minerals, and it is against this base that mineral beneficiation is promoted in the country. While South Africa is amongst the leading countries in terms of global mineral reserves and production outputs, it is recognised that mineral abundance is not a determinant of competitive advantage. As such, there is a need to translate the country's comparative advantage into competitive advantage which encompasses conditions that allow countries to perform better than their competitors. Skills is a key component of competitive advantage and based on the human capital theory, individual skills, knowledge and work experience are economic assets.

Against this context, it is recognised that skills are a critical input that is required to support mineral beneficiation in the country. Amongst the key concerns surrounding skills are that there is a shortage of professionals in the country with specialised skills particularly in the areas of metallurgy, mineral processing and chemical engineering. As such, there is a need to build a pool of skilled professional with the required knowledge to lead the different beneficiation processes undertaken in the MMS. As defined in the MPRDAA, beneficiation occurs in primary, secondary, tertiary and final stages producing a concentrate, intermediate product, refined product and manufactured product/article, respectively depending on the type of mineral commodity. Within the beneficiation value chain, two categories are mapped – those that are required to support beneficiation activities and those that are needed to support the manufacturing of end-products. The typical skills covering beneficiation include material scientists, metallurgical engineers, chemical engineers, electrical engineers, mechanical engineers, metal making operators, and material and smelter operators. The skills required to support manufacturing of end-products include welders, machinists, solar panel installers, electrical vehicle engineers, computer scientists and nuclear engineers.

Against these sets of skills, it is seen that beneficiation skills encompass both subject knowledge such as electro-refining and knowledge of usage of specialised equipment such as faceting machines. The OFO classifies skills under four levels with OFO level 1; level 2; level 3; and level 4 coinciding with NQF level 1; 1 – 3; 4; and 5 – 10, respectively. These skills required for beneficiation can be obtained from universities and TVET colleges. Several SETAs also provide skills development and training programmes that are cover various components of mineral beneficiation. The role of SETAs, particularly the MQA is supported by several policies and legislation. In South Africa, beneficiation as a key intervention area is supported by the National Development Plan and Industrial Policies at the national level.

These align to the objectives of Minerals and Mining Policy, MPRDA, MPRRA and Mining Charter. Beneficiation efforts in the country are also supported by the beneficiation strategy which serves as a framework for leveraging the country's comparative advantage to translate these into socioeconomic benefits that respond to the NDP. In recognising the potential role of beneficiation, the strategy highlights several intervention areas, and these include investment in human capital development. From the case studies provided, several enablers of beneficiation were identified, and these include strong institutions and policy framework, sustainable practices, investment into research and development as well as skills. It is important to identify and map the skills requirements across the stages of mineral beneficiation. This will be achieved through value chain analysis which provides a systematic framework for identifying key actors and establishing their roles and contribution to production processes.

3. APPROACH TO THE STUDY

3.1. Introduction

Research methodology is a systematic approach that is employed to address research problems. This is done through collection, analysis, interpretation, and presentation of data. The selection of an appropriate methodology is informed by the objectives of the study ensuring that accurate data is collected, analysed and used to respond to aspects being investigated in a particular study. This chapter presents the methodology that was followed in the study. The components discussed in the chapter include research design, data collection and analysis methods, research reliability and validity, ethical requirements as well as study limitations.

3.2. Research design

The study employed a qualitative research approach. This method involves collecting and analysing non-numerical data to understand concepts, opinions or experiences. It is embedded in constructivism paradigm (also referred as interpretivism) which is based on the view that truth and knowledge are subjective (Gemma, 2018). According to Vishnevsky and Beanlands (2004), qualitative research focuses on human experiences to provide holistic and in-depth perspectives. There are various methods falling under qualitative research design and, in this study, desktop research comprising of literature and policy review was used.

3.3. Data collection methods

A systematic literature review was used to identify relevant reference material for the study. This is a structured approach which enables the researcher to identify, evaluate, and synthesise all available research on a specific topic. Different sources of data were used and these included peer reviewed papers, reports, online material, as well as grey literature. Information was sourced from the MQA, DMRE, Mineral Council of South Africa, Mintek and other stakeholders in the MMS.

3.4. Data analysis

In this study, content analysis was employed to extract and analyse the data from the different reference material. Content analysis is described as a research method used to systematically analyse and interpret the content of communication. This can include texts, images, audio, or video. According to Bengtsson (2016), the purpose of content analysis is to elicit meaning from the data collected and to draw realistic conclusions from it. Using this method, reference material was collected, and this was followed by reading to extract relevant information which was organised in line with the objectives of the study.

3.5. Research Reliability and Validity

There are various methods that can be used to establish validity and reliability of quantitative and qualitative research. In this study, reliability and validity was established through the use the triangulation method. There are different triangulation methods, namely, data triangulation (i.e., the use of multiple data), investigator triangulation (i.e., involves multiple researchers collecting and analysing the data), theory triangulation (i.e., application of multiple theories to test the findings) and methodological triangulation (i.e., the use of different approaches to collect and analyse data) (UNAIDS, n.d; Heale and Forbes, 2013). This research study used multiple sources of data (i.e., reference material) as well as different investigators to collect, analyse and cross check the data.

3.6. Ethical considerations

It is important to adhere to ethical requirements when conducting literature and document review to maintain the integrity and ensure trustworthiness of the research process. Ethical considerations encompass obtaining necessary permissions for accessing and using documents, ensuring informed consent from relevant stakeholders, and protecting the confidentiality of sensitive information. It is important that researchers must accurately represent original sources accurately, provide proper citations to avoid plagiarism, and ensure that intellectual property rights of scholarly works are adhered to. The study was conducted in line with the University's research requirements. During the research, ethical requirements were followed particularly in terms of acknowledging the sources of the material used in the study through proper citations.

3.7. Study limitations

When the research study was conceptualised, two data collection methods were identified as being appropriate for the study and these encompassed literature and document review as well as key informant interviews. It was planned that key informant interviews will be conducted with mining companies, government and related institutions as well as institutions of higher education and training to obtain insights on beneficiation skills considering current skills profiles, skills gaps and challenges as well as training and skills development. Due to time constraints and availability of key informants, the interviews were not conducted.

2.8. Summary and conclusion

The chapter provided insights into the methodology that was used to carry out the research. Data collection and analysis was completed using qualitative methods. Literature and document review were used to collect data for the study and content analysis was used to analyse and respond to the objectives of the study. The research was carried out in line with the University's ethical requirements.

4. MAPPING AND ANALYSIS OF SPECIFIC MINERAL VALUE CHAINS

4.1. Energy and Production Minerals

4.1.1. Coal

South Africa has approximately 33.8 billion tonnes of coal reserves, primarily located in the Witbank, Highveld, and Waterberg coalfields, which collectively represent more than 70% of these reserves (Department of Mineral Resources and Energy, 2021). As of June 2023, the coal reserves are estimated at approximately 5 106Mt from mines that are currently operating (PwC, 2023). The Mpumalanga province accounts for most of the coal production output in the country as most of the coal mining companies are in the province including Exxaro, Thungela, and Seriti Resources. The Witbank Coalfield is close to depletion, leading to a transition to the Waterberg Coalfield in Limpopo, seen as the future of South African coal mining and is estimated to hold 40% to 50% of the remaining coal reserves (Exxaro Resources, 2022).

Current production from operating mines is approximately 126 Mtpa (PwC, 2023). Approximately 75% of coal production is sourced from Mpumalanga with only 24% sourced from a single operating mine owned by Exxaro in Limpopo. Based on these current depletion rates, there is an estimate of approximately 41 years left of mining. Mpumalanga has approximately 27 operating collieries with estimated reserves of 2 485Mt giving an estimated average of 27 years left of mining (PwC, 2023). There are currently four development projects in Limpopo and of the 2 585Mt reserves in the province, 99% of it is attributed to a single mine giving approximately 86 years left of mining at the current annual depletion rates (PwC, 2023).

Coal Value Chain

The coal value chain plays an important role in the country's economy, particularly in energy production and industrial use. The coal value chain comprises of four stages including, extraction, transportation, beneficiation, and end-user applications such as domestic power generation and export markets. The explanation of each stage is discussed below.

Coal Mining: Coal mining represents the initial phase of the value chain, mainly focused on the Mpumalanga and Limpopo provinces, home to significant coalfields such as Witbank, Highveld, and Waterberg. The extraction method utilises surface truck and shovel operation and underground mining techniques such as bord and pillar and longwall mining, depending on the depth and quality of the coal seams.

Transportation: After extraction, coal is moved to different locations, such as power stations and export terminals. Modes of transportation consist of railroads and trucking. The effectiveness of this phase is crucial. for example, Richards Bay Coal Terminal can ship as much as 9 Mtpa, yet logistical issues frequently restrict the real output (ESI-Africa, 2023).

Beneficiation: Beneficiation is an essential process that improves coal quality by minimizing impurities through methods like crushing, washing, and drying. This method enhances the calorific value of coal and readies it for multiple uses. Specialised machinery such as crushers, screens, and washing facilities are utilized to attain these enhancements (Trade and Industrial Policy Strategies, 2020). The beneficiation procedure utilises specialized machinery like, dense medium separators; spiral concentrators; thickening; dense medium drums; and jigs. The main approaches consist of:

Crushing and Screening: Breaks coal down to usable sizes. Primary crushing normally takes place underground when coal is fed into the feeder breaker and coal is sent to the secondary and tertiary crushing at the plant.

Gravity Separation: The coal is then classified into different sizes fractions, which include coarse, intermediate and fines. Coarse materials are treated using dense medium separators and fine material are treated with spirals and thickeners while ultra fine are treated with froth flotation.

Drying and Dispatch: Water is removed to improve combustion efficiency and made ready for dispatch. Centrifuges are used for coarse material and cyclones are used for fine material.

The produced items comprise premium thermal coal for power generation and metallurgical coal for industrial applications. The last phase includes utilising the treated coal for different purposes:

- Electricity Production: Roughly 95% of the electricity in South Africa is produced by coal-fired plants run by Eskom (Sasol, 2023).

- Petrochemicals: Firms such as Sasol make use of coal to transform it into synthetic fuels and chemicals.
- Exports: Approximately 40% of the coal produced is sent to global markets (Western Cape Government, 2020)

In 2022, seventy-five percent of South Africa's coal production was processed into electricity and liquid fuels. Figure 7 depicts the coal value chain from mining to end-user applications whereas figure 8 shows detailed flow of ROM coal.

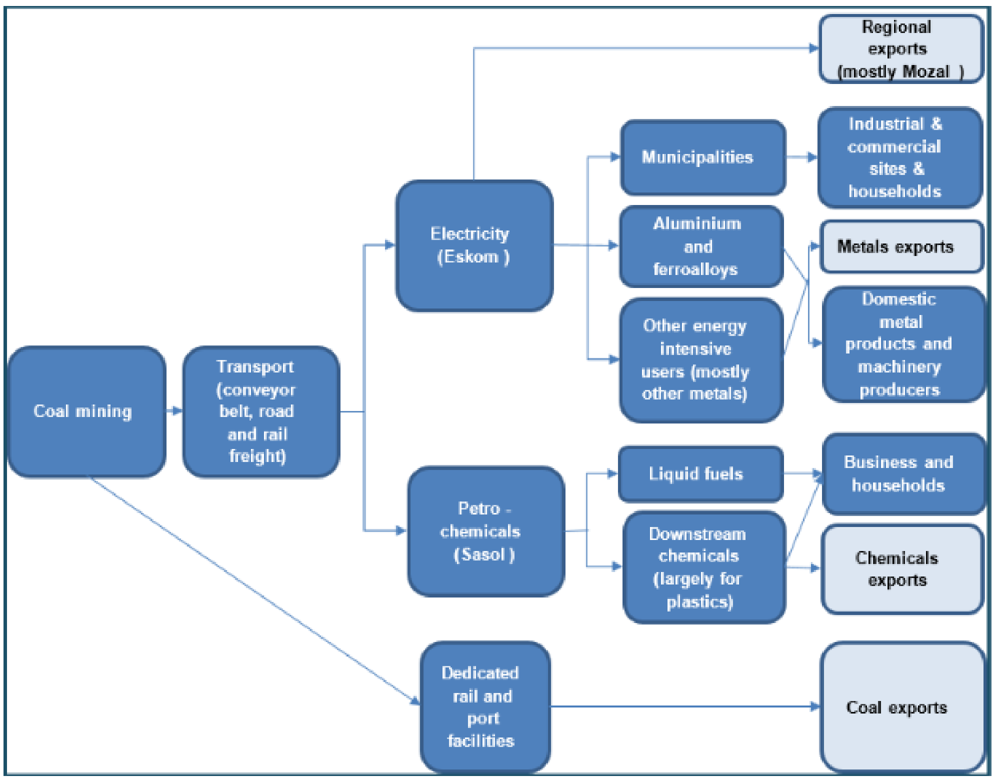


Figure 7: Coal Value Chain

(Source: Makgetla & Patel, 2021)

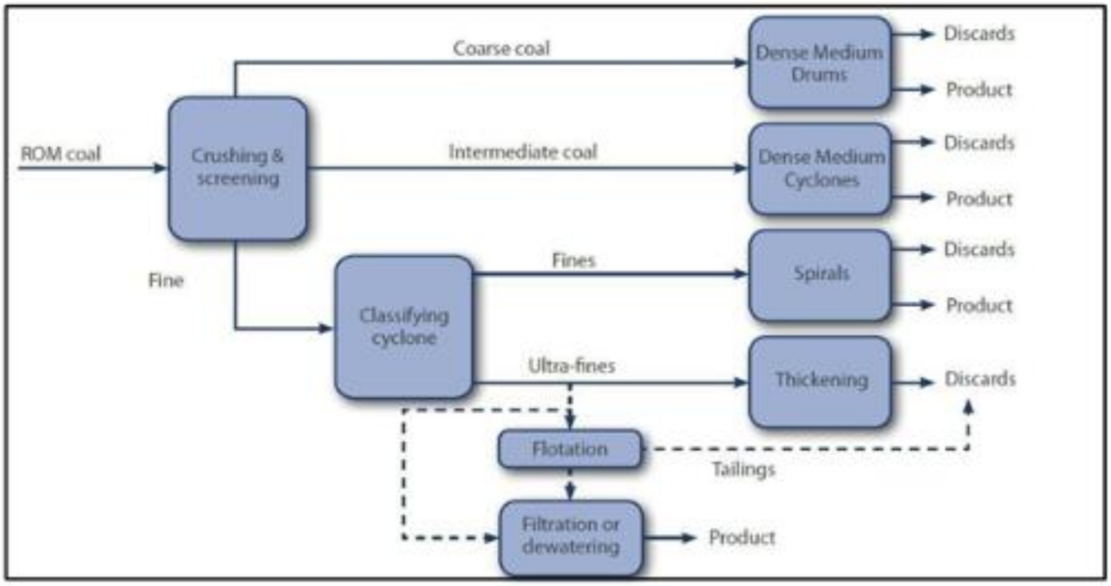


Figure 8: Water based coal preparation

(Source: SACRM, 2011)

Coal Products

Four coal products can be classified - metallurgical coal, synthetic fuel coal, thermal coal, and export coal are typically classified into grades A, B, C, and D respectively (SACRM, 2011). Every application demands coal of a certain quality based on its distinct characteristics including calorific value, ash content, volatile substances, sulphur content, and moisture level. Table 6 presents the usual features of South African run of mine (ROM) coal and its products.

Table 6: Characteristics of SA coal products

Coal product	ROM coal	Grade A	Grade B	Grade C	Grade D
Ash value (%)	20 - 40	5.5 - 13	< 15	20 - 35	30 - 35
Sulphur content (%)	< 2	0.15 - 1.2	0.6 - 0.7	1 - 2	0.7 - 2
Calorific value MJ/kg	16 - 21	27 - 28.5	25 - 27	± 21	19 - 23

(Source: South Africa Coal Road Map, 2011)

Companies involved in coal beneficiation

In 2015, South Africa had approximately 60 coal preparation facilities, the majority of which are found in the Witbank region (De Korte, 2015). Numerous of these facilities generate thermal coal for export, which is shipped through RBCT currently totalling around 90 Mtpa. Table 7 mentions a few of the companies involved in coal washing and their respective plants.

Table 7: Coal processing plants in South Africa

Company	Beneficiation Plant
Sasol	Secunda Operations (coal-to-liquid processing)
	Rietvlei plant
	Ntimeni plant
	Mzimkhulu Plant
	Mgayo Plant
	Gugulethu Colliery Coal Plant
	Emoyeni Plant
Exxaro Resources	Grootegeluk mine plant
	Thabametsi Mine plant
Seriti and Thungela	Phola plant
Ingwenya	Umlalazi processing plant
	Phalanndwa plant
	Khanye colliery plant
BHP Billiton Energy Coal	Douglas Middleburg coal plant

4.1.2. Uranium and Thorium

There are eight known uranium deposits in South Africa, which are: quartz-pebble conglomerate-hosted deposit in the Witwatersrand Basin, sandstone-hosted deposit in the Karoo Uranium Province, carbonaceous shale- and coal-hosted deposit in the Springbok Flats Basin, surficial deposit in the Namaqualand region, intrusive-hosted deposit in the Phalaborwa, granite-related deposit in the Namaqualand region, and phosphorite deposits within the marine areas (Kenan & Chirenje, 2014).

The Witwatersrand Basin is currently the only active uranium mining area in South Africa, where uranium is produced as a by-product of gold mining. This involves both underground mining and processing material from tailings dams. There are about 400 dams and dumps arising from gold mining in the Witwatersrand area of Gauteng province, and much of the available uranium today is in these (World Nuclear Association, n.d.). Uranium is extracted from operations in the Vaal River region, specifically from Moab Khotsong, Great Noligwa, and Kopanang mines which are owned by Village Main Reef (VMR). The extraction takes place in the Noligwa gold plant and South Uranium plant using a reverse leach process. The Great Noligwa gold mine is considered mined out and not actively producing. Uranium is mainly used to fuel commercial nuclear power plants. South Africa is currently exporting uranium in its oxide form (U_3O_8), the first stage of beneficiation and imports the enriched uranium from the northern hemisphere for power generation purpose (Department of Mineral Resources, 2011).

South Africa's uranium production began in 1952 and peaked in the early 1980s, with annual production exceeding 6,000 tons. However, by 2013, this had declined significantly to under 500 tons per year. Despite this drop, future production is expected to increase, driven by planned projects in the Karoo Uranium Province and the Namaqualand region (Kenan & Chirenje, 2014).

Uranium Value Chain

In South Africa uranium is associated with gold production from the Witwatersrand basin and it's generally associated with the following (Dworzanowski, 2013):

- Uranium can be extracted either before or after gold extraction, depending on the flowsheet preference because 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.

Figure 9 shows the unit process steps, from ore produced by an open-pit or underground mine through to yellowcake production whereas Figure 10 shows metallurgical flowsheet.

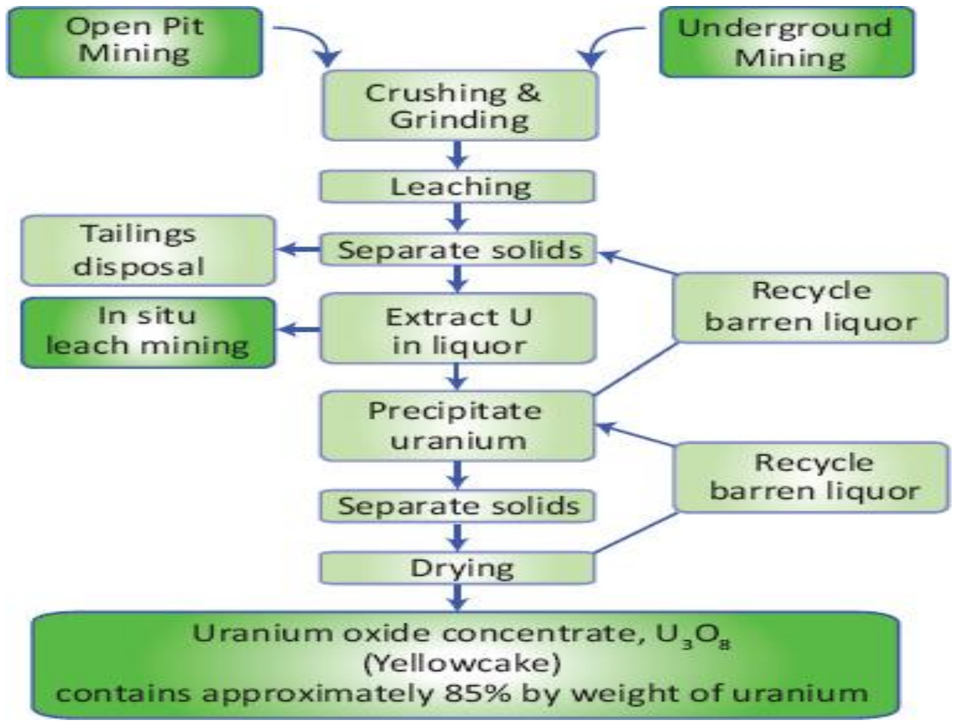


Figure 9:Yellowcake production from uranium

(Source: Committee on Uranium Mining in Virginia, 2011)

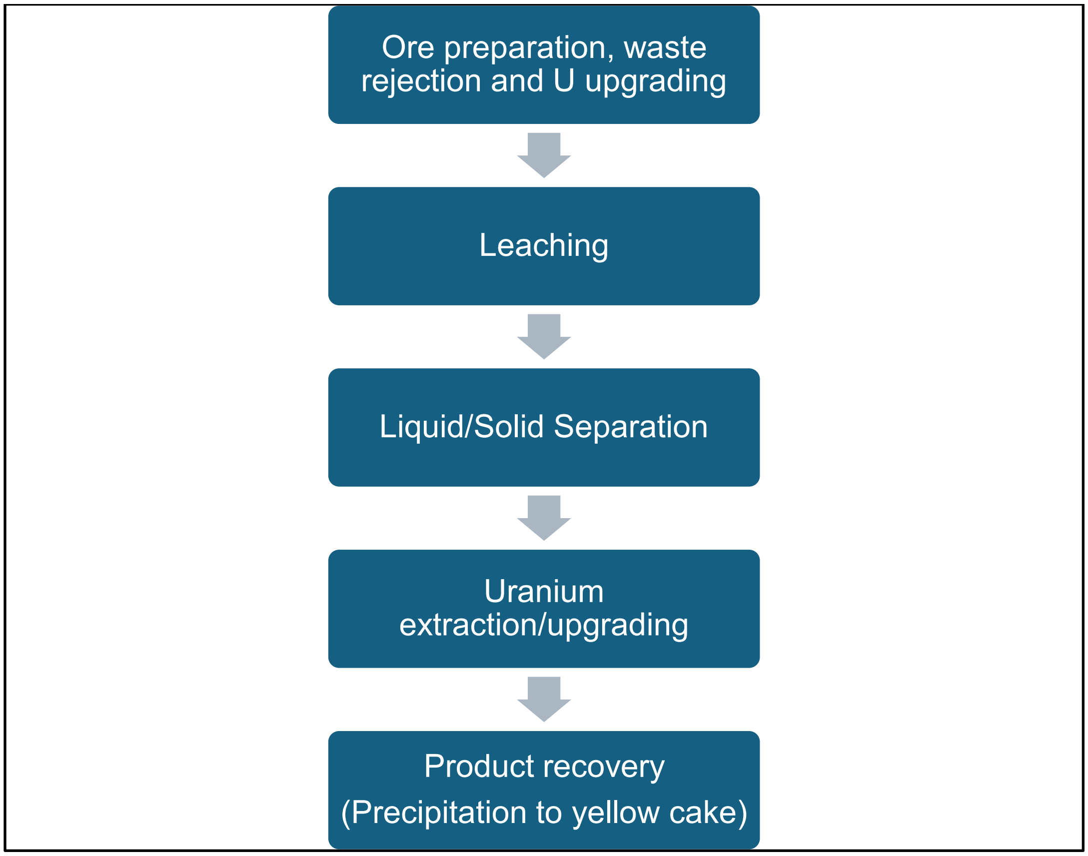


Figure 10: Typical metallurgical flowsheet of uranium

(Source: King, 2014)

It should be noted that uranium is not currently mined as the main product in South Africa. However, uranium is as a byproduct of gold and copper mining, given the reserves of gold remaining in the Witwatersrand basin, the country can be said to have significant amounts of uranium. The complete cycle of the uranium production and processing steps:

Drilling and Blasting: Drill, blast, load, and haul uranium ore from the mine. Use radiometric scanners to measure radioactivity and decide whether material goes to primary crushers or waste storage.

Crushing: Transport ore to primary crushers, crush and screen it until particles are smaller than 19mm, and store fine ore.

Grinding: Wet-grind crushed ore into slurry using steel rods. Operate mills to process material in parallel.

Leaching: Oxidize uranium content in slurry with ferric sulfate and dissolve it in sulfuric acid inside large tanks.

Slime Separation: Separate sand and slime from the leaching product. Wash slime to remove traces of uranium-bearing solution and transport sand to the tailings storage facility.

Thickening: Use counter-current decantation thickeners to wash slimes further. Uranium-bearing solution ("pregnant solution") overflows, while washed slime is mixed with sands for tailings.

Continuous Ion Exchange: Pass pregnant solution through resin beads to adsorb uranium ions. Periodically elute uranium from beads for further purification.

Solvent Extraction: Mix ion exchange eluate with organic solvent to extract uranium. Remove impurities and prepare uranium-rich "OK liquor."

Precipitation: Add gaseous ammonia to OK liquor, raising pH and precipitating ammonium diuranate. Produce thick yellow slurry.

Filtration: Recover ammonium diuranate as yellow cake using drum filters.

Drying and Roasting: Remove ammonia through roasting to produce uranium oxide. Deposit the final product in drums.

Loading and Dispatch: Export uranium oxide drums overseas for further processing. Full capacity output is 4 500 tonnes annually.

Conversion: Convert uranium oxide to uranium hexafluoride crystals at commercial plants.

Enrichment: Increase uranium-235 concentration from 0.7% to around 3% for nuclear reactor fuel.

Fabrication: Convert enriched uranium into uranium dioxide, forming cylindrical pellets. Seal pellets in fuel rods and bundle into fuel assemblies.

Power Generation: Load fuel assemblies into nuclear reactors. Uranium-235 fission generates heat and steam to produce electricity.

This cycle describes the complete process from uranium mining to electricity generation. Some of the uranium output products are as follow:

- **Yellowcake (Uranium Oxide, U_3O_8)**: A concentrated uranium oxide used as feedstock for the nuclear fuel cycle.
- **Uranium Hexafluoride (UF_6)**: A chemical form used in the enrichment process.
- **Enriched Uranium**: High-purity uranium used for nuclear fuel.
- **Nuclear Fuel Rods**: Final product fabricated for use in nuclear reactors

Table 8 shows the name of the companies that are involved in the beneficiation of uranium together with the beneficiation plants.

Table 8: Companies involved in the beneficiation of uranium

Company	**Plant**
Harmony Gold	Noligwa Gold Plant South Uranium Plant
Village Main Reef (VMR)	Kopanang Plant
Sibanye Stillwater	Cooke Plant Ezulwini Plant

Thorium

South Africa has approximately 148,000 tons thorium resources, which is around 1 to 2% of world's thorium reserves and are frequently located together with rare earth elements (REEs) and heavy mineral sands (Kemp, 2017). Most of the deposits are found in the Western Cape and coastal areas such as Steenkampskraal and Richards Bay, where monazite, a mineral containing thorium, is obtained during heavy mineral mining (Selby, 2010). Thorium is more abundant than uranium and its abundance and efficiency make it a promising nuclear fuel for thorium-based reactors in comparison to uranium (Barthel & Tulsidas, 2014). Thorium production levels are currently very low because it is not mined directly but is instead a byproduct of mining activities targeting titanium, zirconium, and REEs. The economic feasibility of thorium as a nuclear fuel is contingent on its connection to rare earth elements.

Value chain

The thorium value chain involves several stages from the physical separation of monazite from other mineral sands to fabrication and end-use including nuclear power and industrial use. Figure 11 shows the thorium value chain from thorium-bearing monazite ore.

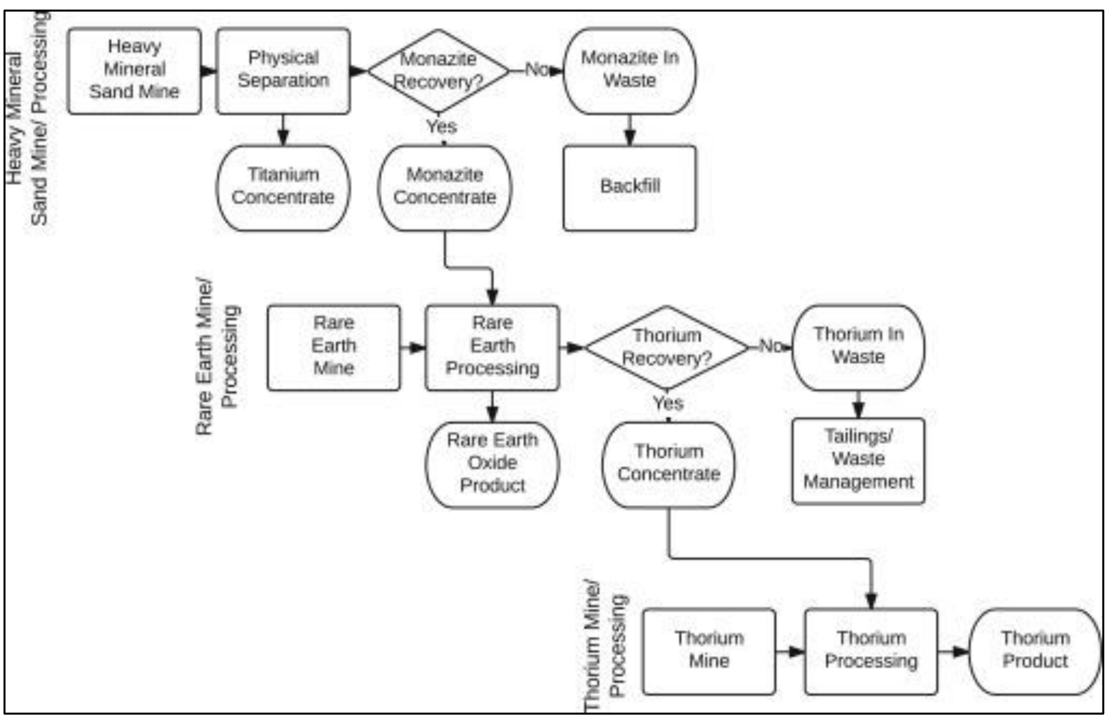


Figure 11: Generic process flow of Thorium

(Source: Jordan et al., 2015)

Monazite Beneficiation

The traditional conventional methods and substances employed for the treatment of monazite are difficult and costly and a new method to beneficiate monazite is currently under investigation (Kemp, 2017). South Africa seeks to add value to tackle this issue with monazite included in its mineral beneficiation plan. Figure 12 shows monazite process flow and Figure 13 shows the simplified version of Thorium and rare earth recovery from monazite.

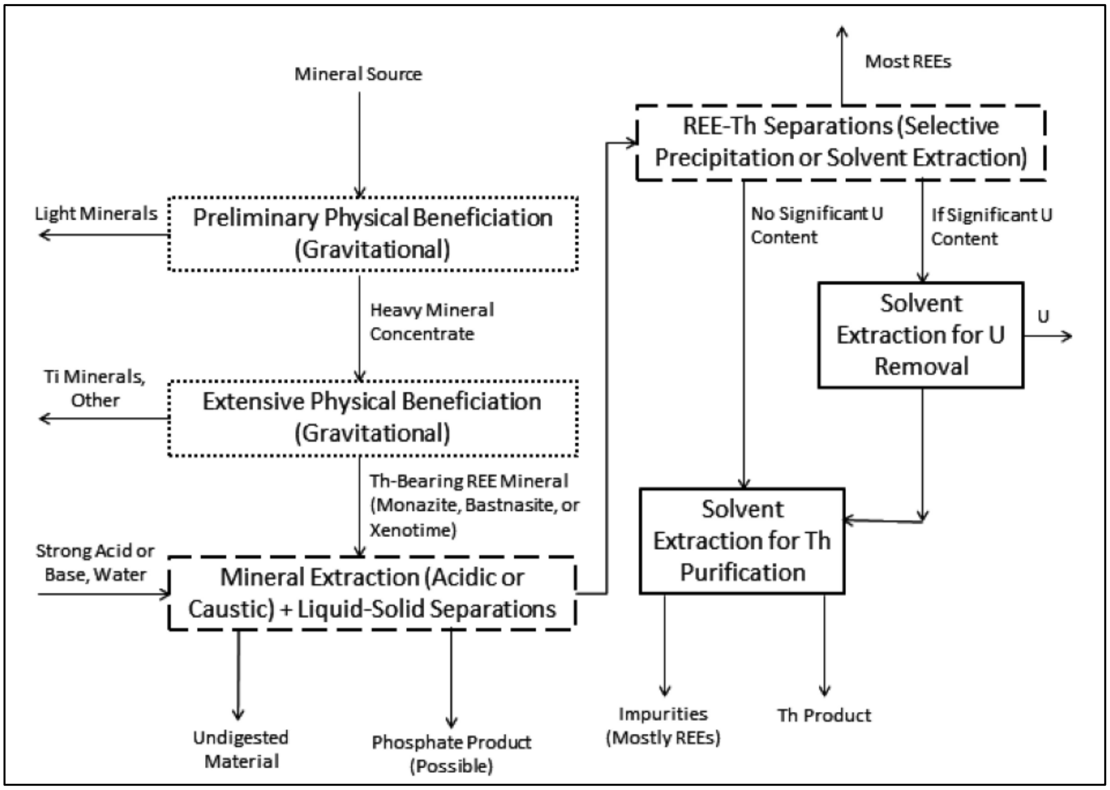


Figure 12: Monazite concentrate flow diagram

(Source: Ault et al., 2016)

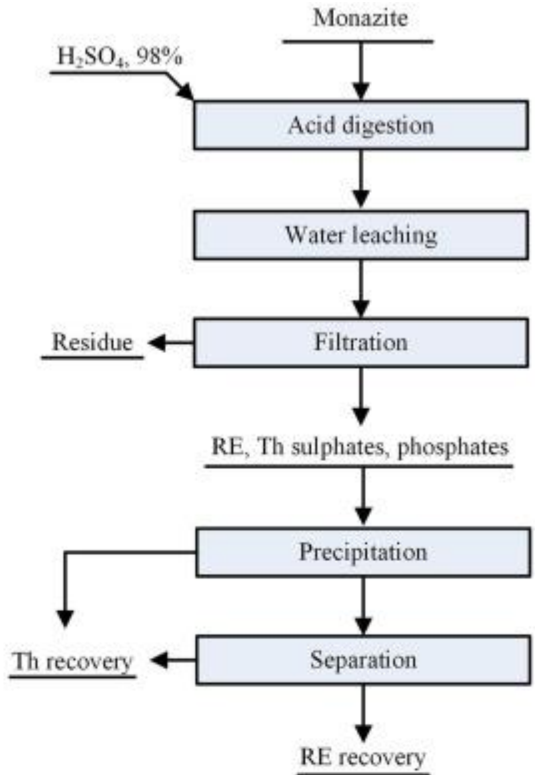


Figure 13: Thorium recovery from Monazite

(Source: Cheng et al., 2024)

Processes along the Value Chain

Physical Separation Methods: Thorium minerals are separated through processes such as gravity separation, flotation, and magnetic separation using equipment like spiral concentrators and magnetic separators. The product is concentrated monazite sand.

Chemical Treatment: Monazite undergoes a process using acid leaching by 98% concentrated sulfuric acid at elevated temperatures to disintegrate the structure.

Solvent extraction is used to isolate thorium. Using plasma reactors in recent advancements helps boost monazite's chemical reactivity, leading to a potential 17% improvement in thorium recovery efficiency and decreased environmental effects when compared to conventional techniques (Kemp, 2017). Thorium nitrate or thorium oxide (ThO_2) is produced. Table 9 shows the companies and/or entities involved in extraction and beneficiation of thorium.

Table 9: Companies involved in the extraction and/or beneficiation of thorium

Company	**Involvement**
Richard Bay Minerals	Producing monazite as a by-product
Steenkampskraal Monazite Mine	REE production with potential thorium output
South African Nuclear Energy Corporation (NECSA)	Research in nuclear applications, crucial for downstream beneficiation

The state of thorium can be summarised as follow:

- Thorium is found in greater quantities in the Earth's crust compared to uranium, which makes it an appealing option for sustainable energy generation in the long run (Kemp, 2017). Thorium is the most common radioactive element found in the monazite ore at Steenkampskraal. One of the main benefits of using thorium-based nuclear fuel is its enhanced safety features.
- Even though it shows potential, thorium-based nuclear energy is currently in the stage of research and development. There are still important obstacles to overcome, such as the advancement of appropriate reactor technologies, fuel fabrication methods, and regulatory structures. Ongoing research is being conducted to tackle these challenges and prove the viability of thorium-based nuclear energy on a large scale.
- Many nations including India, China, and the United States, are currently investigating the use of thorium-based nuclear energy in their future energy plans (Jyothi et al., 2023).

4.2. Iron and Steel

4.2.1. Iron Ore

South Africa is one of the world's leading iron ore producers, holding significant reserves primarily located in the Northern Cape Province, particularly around the Sishen and Kolomela mines owned by Anglo American. As of 2023, the country ranks as the seventh-largest producer globally, contributing approximately 3% to world production (Mining Technology, 2023). As of June 2023, there are seven iron ore mines operated by three different companies and South Africa has approximately 700 million tonnes of iron ore reserves, which are expected to sustain production for about 13 years at current extraction rates (PwC, 2023). In 2023, mine production of iron ore in South Africa amounted to an estimated 61 million metric tons (Jaganmohan, 2024), Sishen alone producing around 26 million tonnes per annum (GlobalData, 2023).

Iron and steel value chain

The value chain of iron ore in South Africa comprises of four key stages, each contributing to the overall production and distribution of iron ore products. Figure 14 shows the value chain of iron ore.

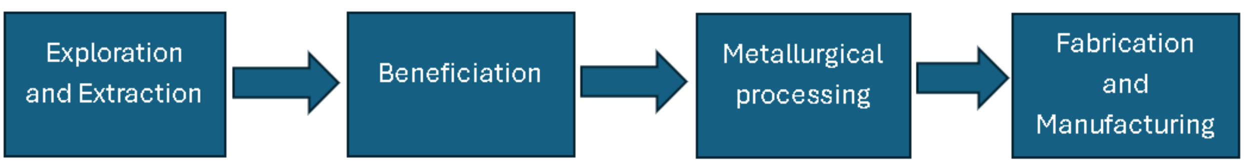


Figure 14: Iron ore value chain

Stage 1 (Exploration and extraction): This initial phase involves the identification and extraction of iron ore deposits, primarily through open-pit mining methods. The main players include Kumba Iron Ore, Assmang, Ironveld and smaller junior mining companies. The extracted ore is often referred to as run-of-mine (ROM) ore. The ROM ore undergoes beneficiation processes to increase its quality and value. This typically involves crushing, screening, and separation techniques such as Dense Media Separation (DMS) or jigging. The output includes lump iron ore and fines, which are essential for steel production.

Normally iron ore is beneficiated in two processes:

- Dense Medium Separation (DMS) – drums and cyclones
- JIG gravity separation – Coarse, medium and fine jigs

The DMS is for high-grade iron ore and the JIG separation is for low-grade iron ore. Figure 15 and Figure 16 show the DMS and the jig plant flow diagrams, respectively.

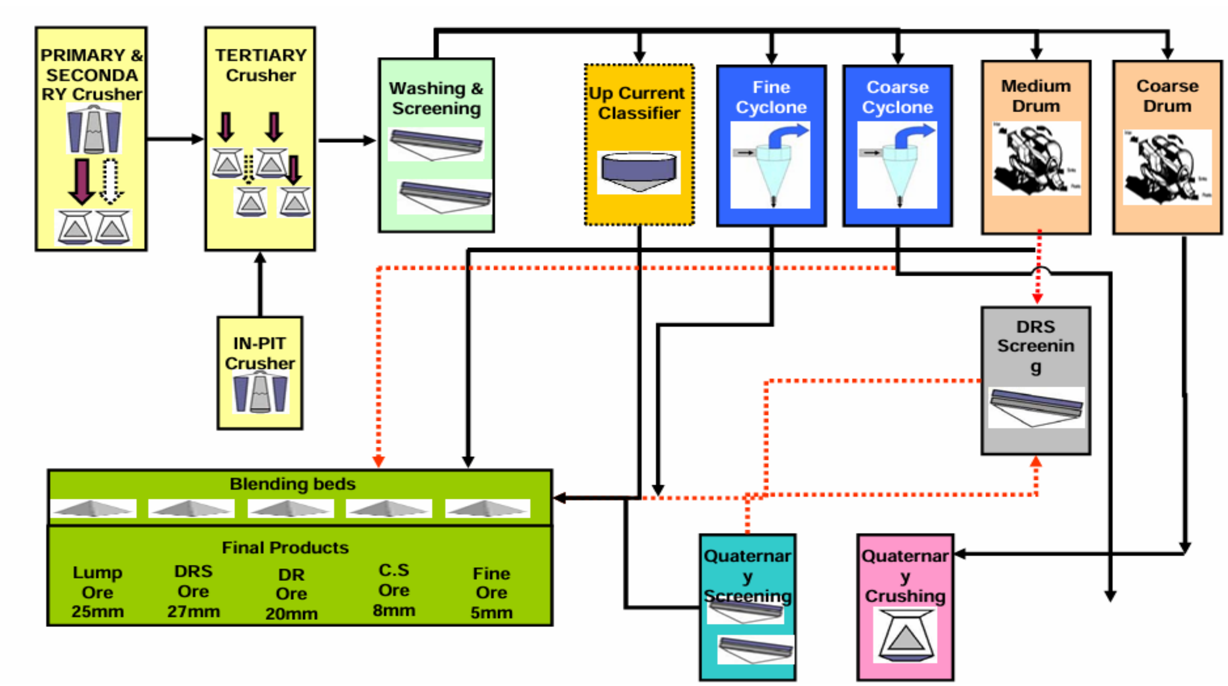


Figure 15: DMS plant flow diagram

(Source: Kumba Iron Ore, 2010)

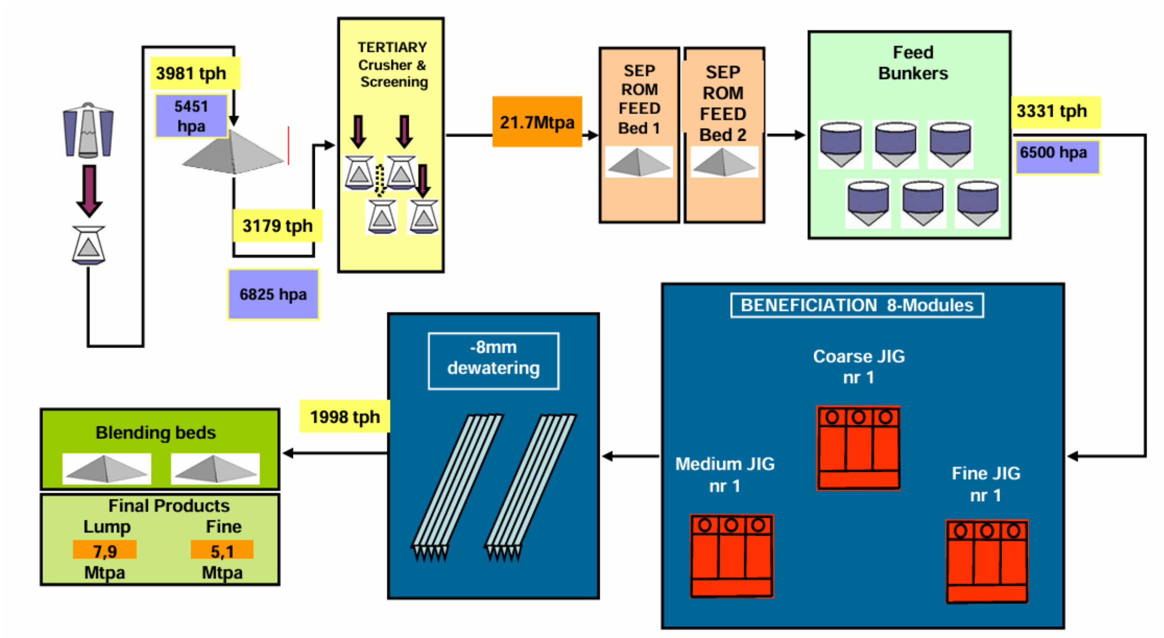


Figure 16: Jig plant flow diagram

(Source: Kumba iron ore, 2010)

The final products from both processes shown in Figures 15 and Figure 16 are lumps and fines. The Jig plant produces a product of approximately 63-64% Fe and the DMS produces approximately 64-65% Fe from ROMs of 53-56%Fe and >59%Fe, respectively.

Stage 2: The beneficiated iron ore is then processed in steel manufacturing facilities where it is smelted to produce pig iron using blast furnaces. This stage may also involve refining processes to convert pig iron into various steel products.

Stage 3: The processed steel is shaped into semi-finished products like hot-rolled coils, which are used as intermediary products in various industries, including construction, automotive, and manufacturing.

Stage 4: Intermediate iron and steel products are converted into complex intermediary (e.g., engine block) artefacts such as components or final consumer products (e.g., stain and steel handrails).

Some of the specialised equipment required in iron and steelmaking include jaw crushers, jigs, dense medium separators units, cone crushers, drums, blast furnaces oxygen furnaces, rolling mills, and electric arc furnaces. All these and other inputs such as EPCM, supply of consumables, utilities and equipment and infrastructure service and maintenance form the important backward linkage envelope to support the manganese value chain.

Companies involved in iron ore beneficiation

Table 10 shows the companies taking part in extraction and beneficiation of iron ore with Kumba Iron ore being the top producer of iron ore in South Africa.

Table 10: Companies involved in the beneficiation of iron ore

Company	Mines	Beneficiation plant
Kumba Iron Ore	Sishen and Kolomela	• Sishen plant • Kolomela plant
Assmang	Khumani and Beeshoek	• Khumani plant • Beeshoek plant
Ironveld	-	• Ferrochrome Furnaces (Smelter in Rustenburg)

4.2.2. Chrome

South Africa is home to over 70% of the world's chrome reserves, primarily located in the Bushveld Igneous Complex, which is crucial for global chromium supply. Chromium is an element which is generally found and subsequently mined from chrome. In 2023, the country produced approximately 18 million tonnes of chromium, a slight decrease from 19.1 million tonnes in 2022 due to energy constraints affecting production capabilities (Statista, 2024). The chrome industry is vital for South Africa's economy, contributing significantly to employment and export revenues, with chrome ore being predominantly used in stainless steel production. Key players in South Africa's chrome industry include Samancor, Glencore, and Tharisa, which operate several mines and smelters. Samancor's operations, including the Western and Eastern Chrome Mines, are vital for ferrochrome production, while Glencore's Bushveld Complex significantly contributes to the national output. Primarily, chrome is essential in the production of stainless steel, where it enhances corrosion resistance and strength, making it indispensable for kitchen appliances, automotive components, and construction materials. Chrome alloys are used in stainless and special steel.

Chrome value chain

The chrome value chain in South Africa consists of several key processes: mining, beneficiation, smelting and refining as shown in Figure 17. The beneficiation process is crucial for converting raw chrome ore into ferrochrome, which is primarily used in stainless steel production. This process typically begins with crushing and milling the ore, followed by gravity separation and magnetic separation to concentrate the chrome content. Advanced technologies such as electrical arc furnaces are then employed to smelt the concentrated ore into ferrochrome. The output products include metallurgical-grade ferrochrome and charge chrome, which are essential for various industrial applications.

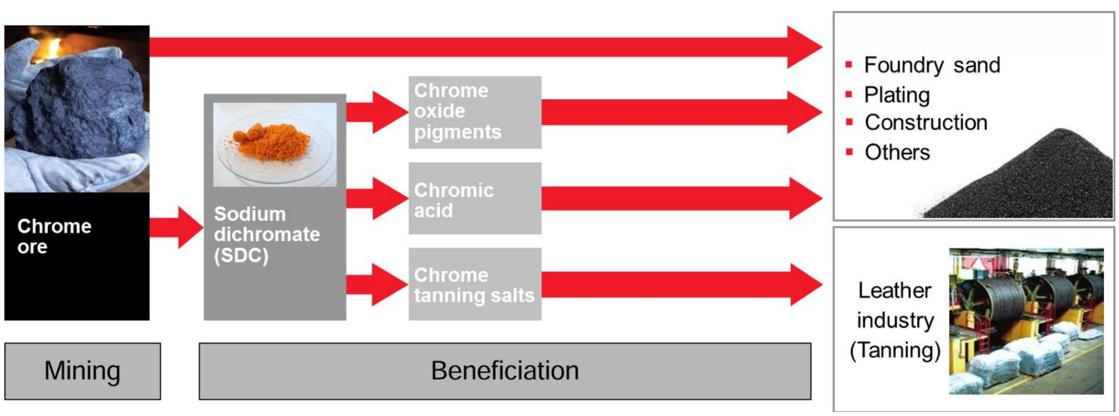


Figure 17: Chrome value chain

(Source: Gassen, 2013)

Samancor Chrome is the main company in South Africa involved in the extraction and processing of chrome. Samancor Chrome's beneficiation starts with dense-medium separation technology, separating valuable chromite from waste. Following initial processing, chromite fines are pelletized and sintered. Using Outokumpu technology, chromite fines and coke are milled, filtered, and processed in sintering furnaces, producing high-grade pellets. This pelletized chromite is then directed to the alloy plants for smelting. Samancor's process description is as follows:

- **Pelletising and Sintering**: After milling, chromite fines are mixed with binders and formed into pellets in a drum before sintering in furnaces, achieving high chromite recovery. The sintered pellets are cooled, screened, and stored, ready for smelting. Figure 18 shows the pelletizing and Sintering process flow.

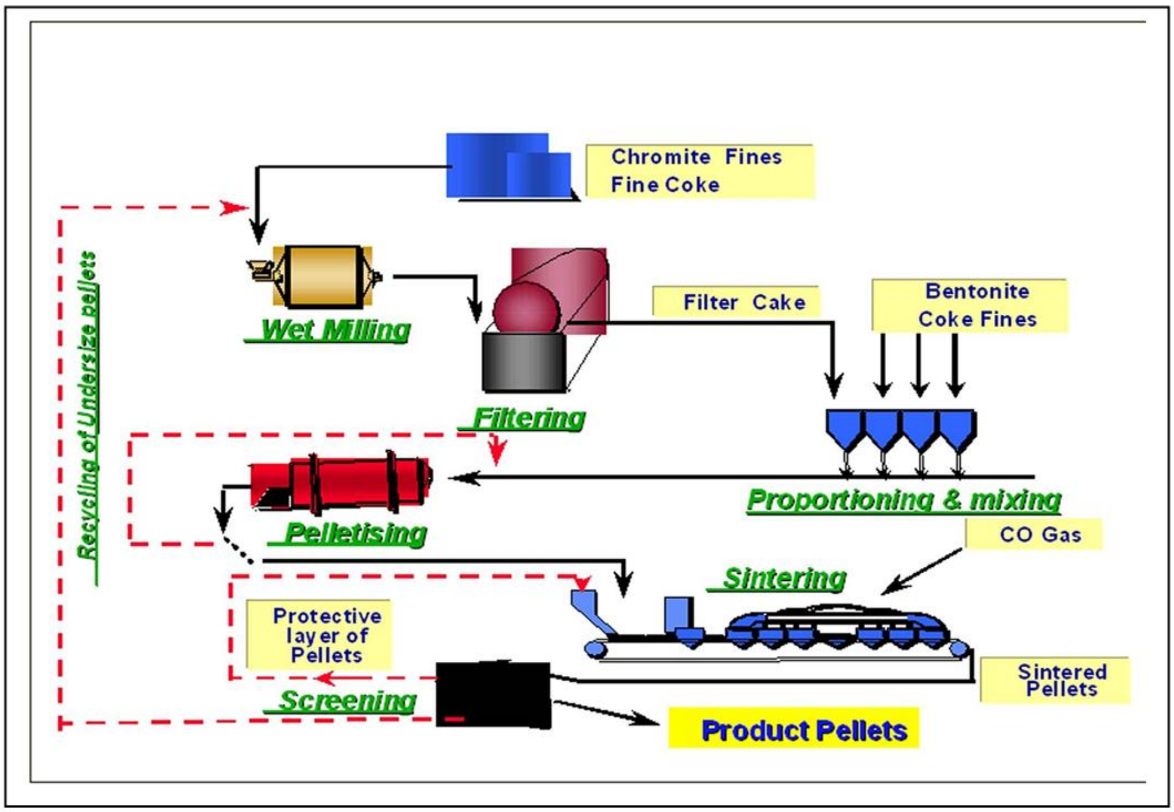


Figure 18: Pelletizing and sintering process flow

(Source: Visser, 2006)

- **Smelting**: Charge chrome production occurs in submerged arc furnaces using carbon electrodes. These high-energy processes use raw ore, fluxes, and reductants. The process includes closed and open furnaces, with CO gas from closed furnaces captured and reused, enhancing energy efficiency. The smelting process employs 63 MVA furnaces, such as those at Ferrometals and Middelburg, capable of producing various ferrochrome grades. Specialised equipment includes ball mills, pelletizing drums, sintering furnaces, and closed-arc furnaces for refining. It is imperative to localise the manufacturing of specialised input equipment and consumables, that is, the densification of the value chain for its sustainability.

Charge chrome

Charge chrome makes up the bulk of the Samancor's chrome alloy production. It is an alloy of iron and chromium, consisting of between 50% and 55% chromium, with carbon at around 7% and silicon at around 4% as other main constituents (Visser, 2006). It is produced in both open and closed submerged arc furnaces, as well as in a DC plasma arc furnace. Charge chrome is extensively used in stainless steel production for the manufacturing of a huge range of stainless-steel products.

Intermediate-carbon ferrochrome

Intermediate-carbon ferrochrome is a product of further refining of charge chrome. Figure 19 shows the production process of intermediate-carbon ferrochrome.

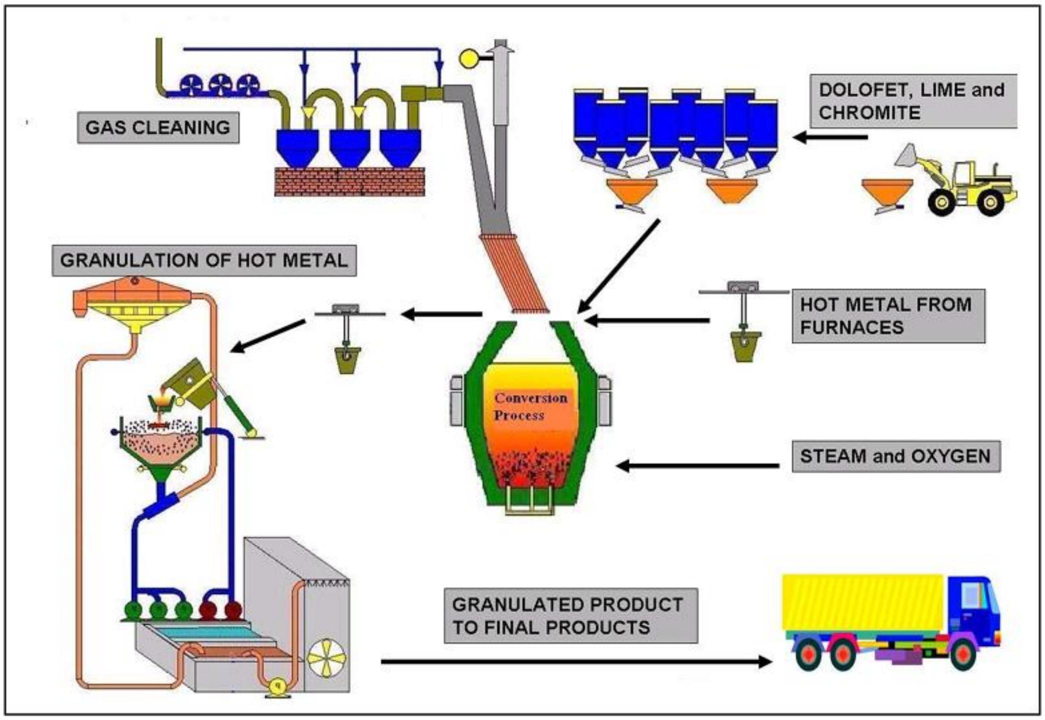


Figure 19: Intermediate-carbon ferrochrome production process

(Source: Visser, 2006)

Low-carbon ferrochrome

Low-carbon ferrochrome is produced by mixing ferrosilicon-chromium (FeSiCr) with a lime/chrome ore melt. Figure 20 shows the production process of low-carbon ferrochrome.

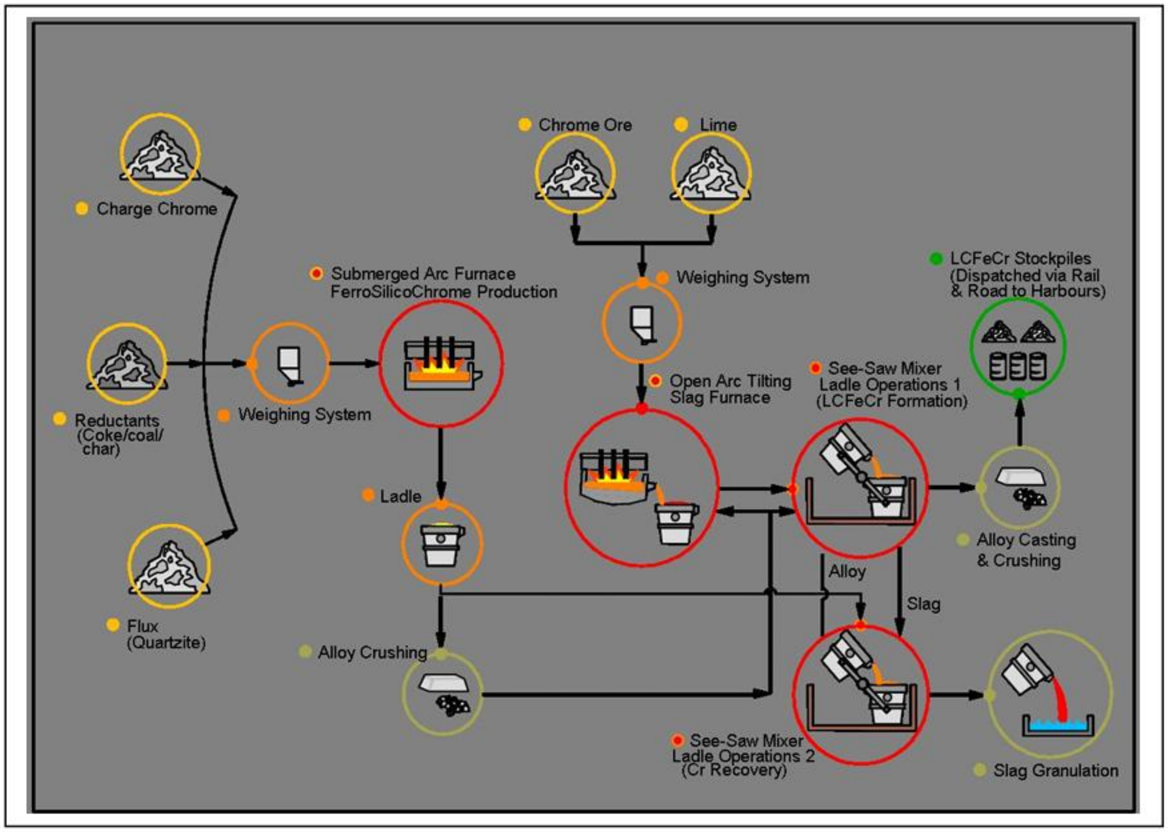


Figure 20: Low-carbon ferrochrome production process

(Source: Visser, 2006).

Companies involved in chrome beneficiation

Table 11 shows the companies taking part in the extraction and beneficiation of chrome in South Africa.

Table 11: Companies involved in the beneficiation of chrome

Company	Smelters	Downstream Processing
Samancor chrome	• Middleburg Ferrochrome (MFC) • Ferrometals • Tubatse Ferrochrome (TFC) • TC Smelter (TCS) • Tubatse Alloy (TAS) • Dikwena Chrome (DCR)	
Glencore-Merafe Chrome venture		• Rustenburg Ferrochrome • Tswelopele Pelletising and Sintering • Lion Ferrochrome • Lydenburg Ferrochrome
Clover alloys		• Rietfontein • Benoni

4.2.3. Manganese

South Africa is the world's leading producer of manganese, accounting for 36% of global output with an estimated 600 million metric tons of reserves, representing nearly 38% of the world's total manganese reserves (Investing News Network, 2024). The primary mining regions are in the Kalahari Basin, particularly around the Northern Cape, where major companies such as South32, Assmang, and Tshipi e Ntle operate significant mines like the Mamatwan and Tshipi Borwa mines. Additionally, the Manganese Metal Company (MMC) located in Mbombela South Africa is the producer of high-grade electrolytic manganese metal (EMM). These operations have long life spans, with many expected to remain viable for decades, bolstered by increasing demand for manganese in steel production and battery manufacturing (Prager, 2024). Despite its vast resources, only about 2% of manganese produced in South Africa is processed locally, indicating a significant opportunity for growth in value-added products such as high-purity manganese sulfate for lithium-ion batteries (Prager, 2024).

Manganese value chain

- **Stage 1**: This involves the extraction of manganese ore, primarily from the Kalahari Manganese Field, which holds a significant portion of global reserves as well as the processing of manganese ore to improve its quality and prepare it for further use, including the production of manganese alloys. Figure 21 shows the manganese refining process with a product of 99.9% pure manganese.

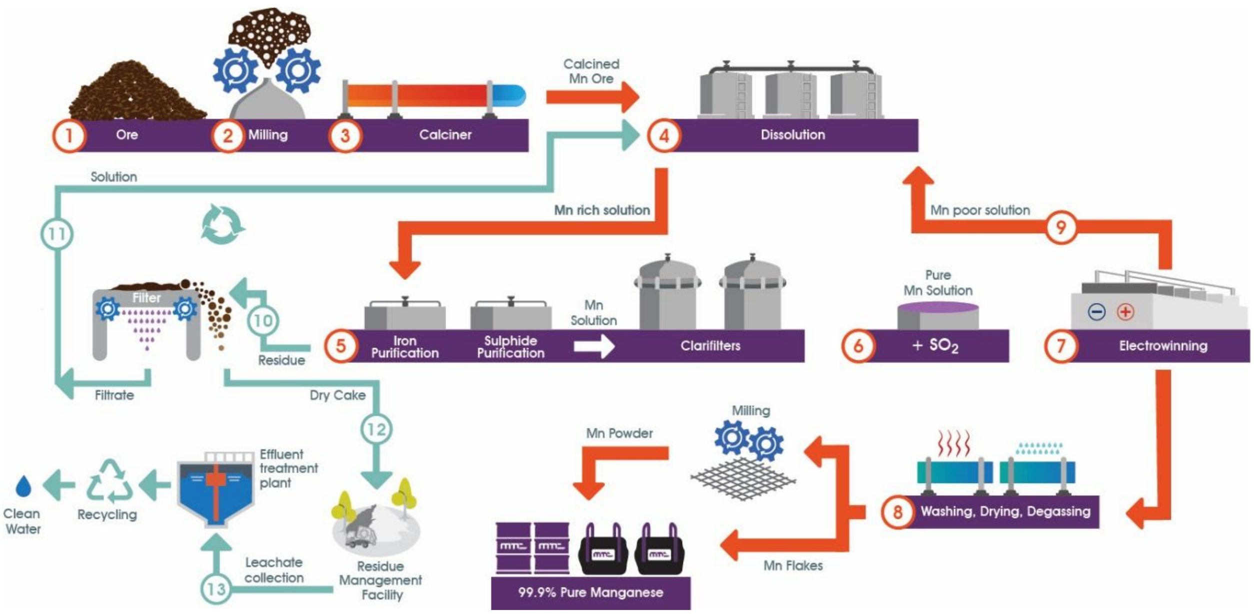


Figure 21: Manganese refining

(Source: MMC, 2024)

The refining process follows 13 steps as depicted in Figure 20 (MMC, 2024):

- *Step 1*: The refining process begins with high-grade ore, mined in the Kalahari.
- *Step 2*: The ore is milled to a powder.
- *Step 3*: Then it undergoes calcining in rotary kilns, to be reduced to a soluble form.
- *Step 4*: The reduced ore is dissolved in an acid solution.
- *Step 5*: Solution purification - precipitation of impurities in 2 thickener stages, followed by filtration in clarifilters (devices which combine clarification and filtration to remove suspended solids and impurities).
- *Step 6*: Sulphur dioxide, and not selenium dioxide, is added to the purified solution before electrolysis can take place. Both, Sulphur dioxide and selenium dioxide can act as depolariser, but selenium dioxide is not used because of its potential toxicity.
- *Step 7*: The solution is then fed into the electrolytic cells, where electric current causes the pure manganese to plate on the cathodes.

- *Step 8*: The plated manganese is stripped from the cathodes, washed, dried and degassed. This metal is manganese in its purest, cleanest form. Depending on the individual customer requirements, the metal is then processed further (e.g. milled to powder) and packaged for shipment.
- *Step 9*: Sulphuric acid, formed at the anodes, is re-cycled back to the dissolution process.
- *Step 10*: The solid residue remaining after dissolving the manganese is filtered to recover manganese- and ammonium sulphates to obtain a dry cake for disposal.
- *Step 11*: The recovered solution is returned to the dissolution.
- *Step 12*: The dry cake is transported to Kingston Vale located in London, England. MMC holds permits to operate a hazardous landfill facility here. The Kingston Vale landfill design includes liners with leakage detection and trenches to collect all run-off and leachate.
- *Step 13*: After collection, the liquid is returned to MMC's plant and passed through the effluent treatment plant. All other liquid effluents from anywhere on the MMC site, including contaminated runoff from rainwater, are also cleaned in the effluent treatment plant. Here dissolved metals are precipitated and filtered out, followed by pH correction and ammonia stripping, to ensure that no contaminated water leaves the MMC site.

- **Stage 2**: Smelting processes to create high-carbon ferromanganese, essential for steel production.
- **Stage 3**: Approximately 90% of mined manganese ores and their corresponding alloys are utilized in steel production. Ferromanganese is primarily employed to enhance the hardness and wear resistance of steel, while silicomanganese contributes to the strength and functionality of the material. Additionally, manganese plays a crucial role in eliminating sulphur and oxygen from steel. Figure 22, which illustrates the manganese value chain, shows the different applications of manganese.

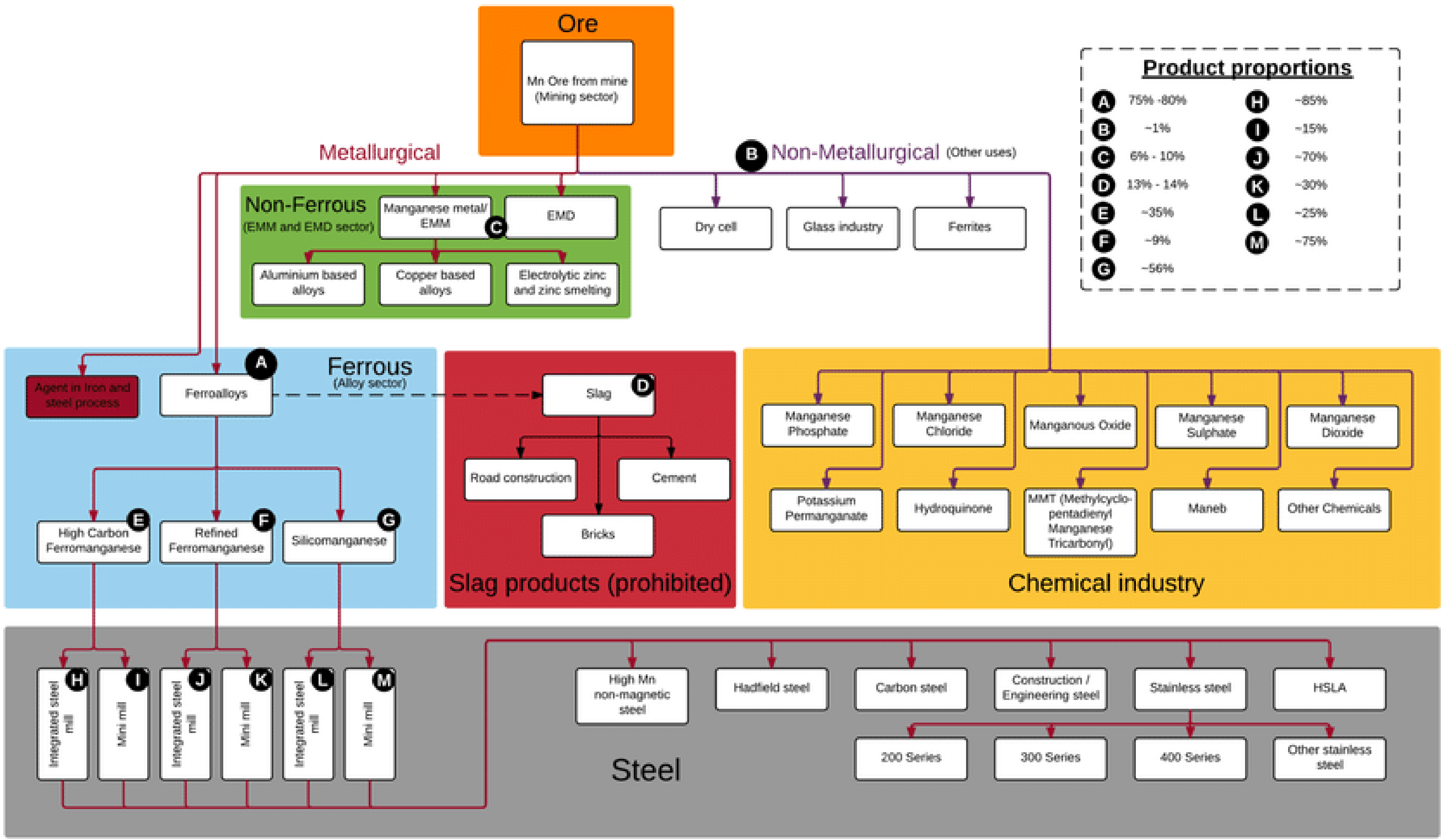


Figure 22: Manganese value chain

(Source: Van Zyl et al., 2016)

Equipment required in the beneficiation of manganese includes ball mills, crushers, DMS units, jigs, arc furnaces, rotary kilns, acid dissolution tanks, thickeners and clarifiers, filtration units and sulfuric acid recycling units. All these and other inputs such as EPCM, supply of consumables, utilities (EWG), and equipment and infrastructure service and maintenance form the important backward linkage envelope to support the manganese value chain. The localisation of this envelope is imperative. Table 12 shows the companies involved in beneficiation of manganese.

Table 12: Companies involved in manganese beneficiation

Company	Smelters	Beneficiation Plants	Refinery
Assmang	• Cato Ridge Works • Cato Ridge Alloys		
Manganese Metal Company (MMC)			• MMC
Transalloys	• Transalloys		
Kalagadi Manganese		• Kalagadi Manganese	

4.2.4. Nickel

South Africa is the 13th largest producer of nickel globally, with significant reserves primarily located in the Limpopo and North West provinces. The country has an estimated 3.5 million tonnes of nickel reserves, most of which occur as byproducts of PGMs, with major mines such as Mogalakwena and Impala Rustenburg contributing to the overall production output of nickel. The Mogalakwena Mine, owned by Anglo American Platinum, is the largest nickel producer, yielding approximately 14,530 tonnes of nickel in 2023 and projected to operate until 2040 (GlobalData, 2023). The life of mines varies, with some like the Mogalakwena Mine expected to operate until 2040, while others like the Impala Rustenburg may continue until 2051 (Mining Technology, 2023).

The combination of substantial resources and ongoing production indicates a promising future for nickel mining in South Africa, particularly as global demand for battery-grade nickel continues to rise due to its critical role in electric vehicle batteries and renewable energy technologies (Fitch Solutions, 2021).

Nickel value chain

The primary nickel ores in South Africa are typically found in two forms: sulphide and lateritic ores. The nickel value chain includes several stages: mining, beneficiation, refining, and marketing. Beneficiation is a critical process that enhances the quality of nickel ore through various methods such as crushing, milling, flotation, and smelting. Figure 23 shows the typical value chain of nickel in South Africa.

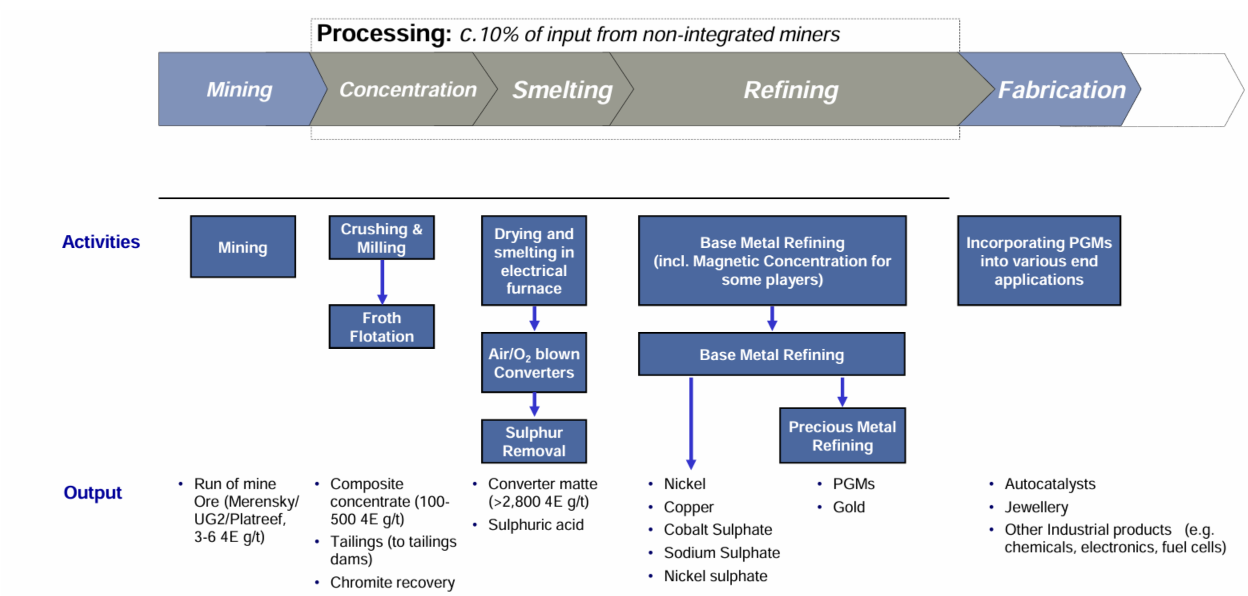


Figure 23: Simplified PGM value chain

(Source: Ndlovu, 2021)

Specialized equipment used in these processes includes jaw crushers, ball mills, flotation cells, and electric arc furnaces. Companies involved in nickel beneficiation include Anglo American Platinum, Impala Platinum Holdings, which operates Impala Rustenburg and its associated processing facilities, and Sibanye Stillwater, which runs the Rustenburg Complex (Mining Technology, 2023).

Most of the nickel produced in South Africa is derived from the base metals refineries of the major platinum producers. The nickel is produced in the form of nickel sulphate or nickel metal (cathode or briquettes). Most of the nickel metal is used as the nickel component in the alloying process for stainless steel production (Dworzanowski, 2013). Figures 24 illustrate PGM value chains where nickel is derived from refining while Figure 25 shows the nickel processing process flow. For local value-add and job creation, all inputs such as EPCM, supply of consumables, utilities, and equipment and infrastructure service and maintenance in the backward linkage envelope must be localised in South Africa.

.

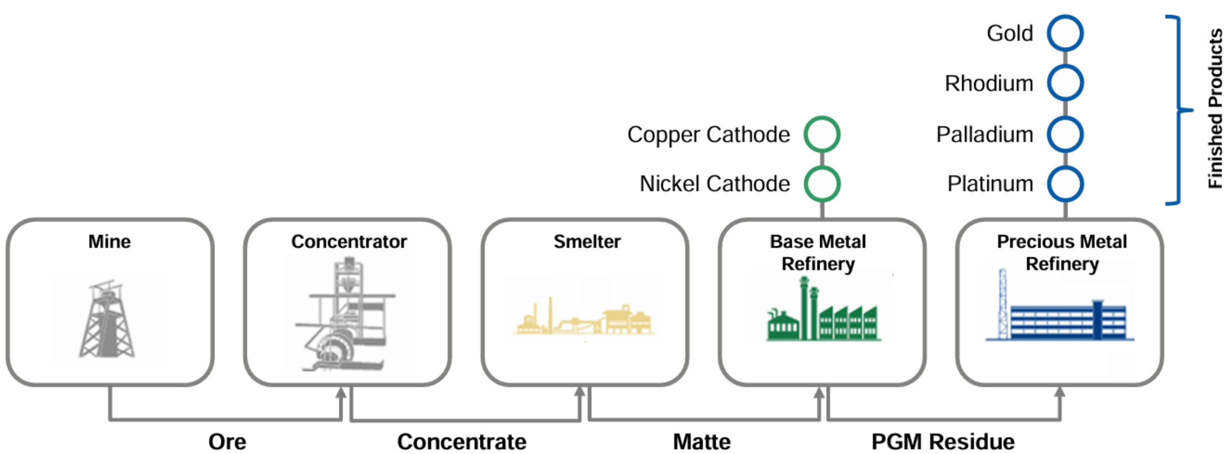


Figure 24: Nickel as part of base metals from PGMs value chain

(Source: Gerick, 2016)

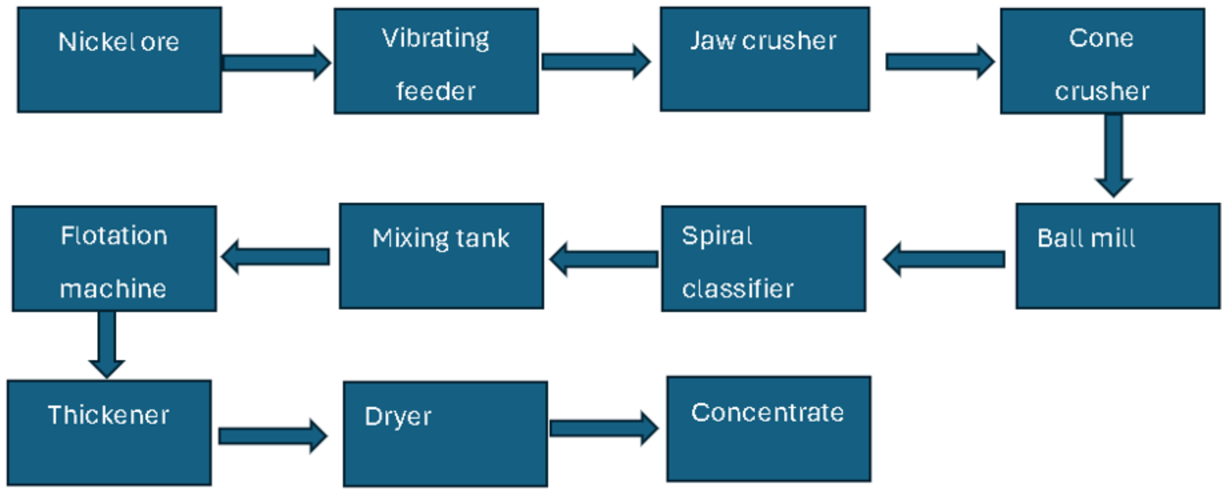


Figure 25: Nickel concentrate production process

(Source: Adapted from Machinery, 2024)

Output products from nickel beneficiation

- **Nickel Concentrate**: Intermediate product produced after flotation and concentration, used for further processing in smelting and refining.
- **Nickel Matte**: Semi-refined product from smelting, containing high concentrations of nickel and other metals like copper and cobalt.
- **Nickel Sulphate**: A key product used in battery production, especially for electric vehicles.
- **Nickel Metal**: Final refined product, produced as:

  Nickel Cathodes: High-purity nickel plates used in industrial applications.

  Nickel Briquettes: Compressed nickel blocks for ease of transport and use in alloy production.

Companies involved in the beneficiation of Nickel

Table 13 shows the companies involved in the beneficiation of Nickel

Table 13: Companies involved in nickel beneficiation

Company	Processing Plant	Refinery
Anglo American Platinum		• Base metal
Impala		• Base metal
Sibanye Stillwater	• Marikana Smelter	• Base Metals
ARM and Norilsk Nickel	• Nkomati	
Thakadu Group		• Thakadu Nickel Sulphate

4.2.5. Vanadium

South Africa has substantial vanadium deposits, mainly found in the Bushveld Igneous Complex, the largest vanadium source globally. The country is the third largest global producer of Vanadium and is a host to 18% of the world's Vanadium resources (Quiroz et al., 2024). Vanadium is mainly derived from titaniferous magnetite ores, which are the main deposits in the country. Key companies include Steelpoortdrift Vanadium Project, Tweefontein in Mokopane, Bushveld Minerals and Glencore Rhovan mine. According to Mining Technology (n.d), the Steelpoortdrift Vanadium Project is among the biggest untapped vanadium reserves worldwide. It is thought that the Steelpoortdrift vanadium project holds around 76.86 million tonnes of proven and probable reserves with a grade of 0.72% V_2O_5. The extensive reserves and continuous exploration activities are enhancing the longevity of South Africa's vanadium operations.

One of the uses of vanadium in the Vanadium Redox Flow batteries which are known for their capacity to store significant energy quantities. The Vanadium Redox Flow batteries are key in the fulfilment of South Africa's vision of enhancing energy security and shifting towards more environmentally friendly energy systems

Vanadium value chain

The Vanadium value chain involves key stages from the mining of magnetite ore to the end-use applications including batteries and steel production. Figure 26 shows the simplified process of vanadium extraction and Figure 27 shows the flow sheet of vanadium.

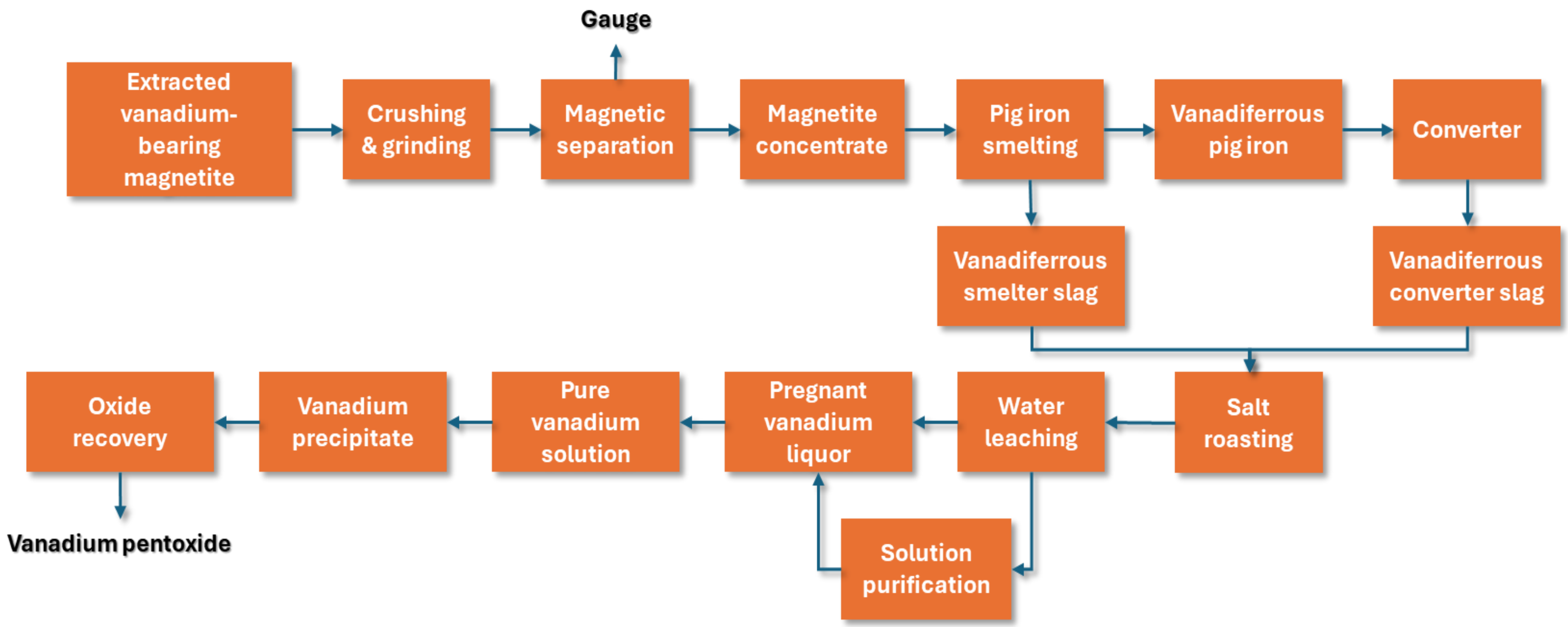


Figure 26: Extraction of Vanadium

(Source: DMRE, 2008)

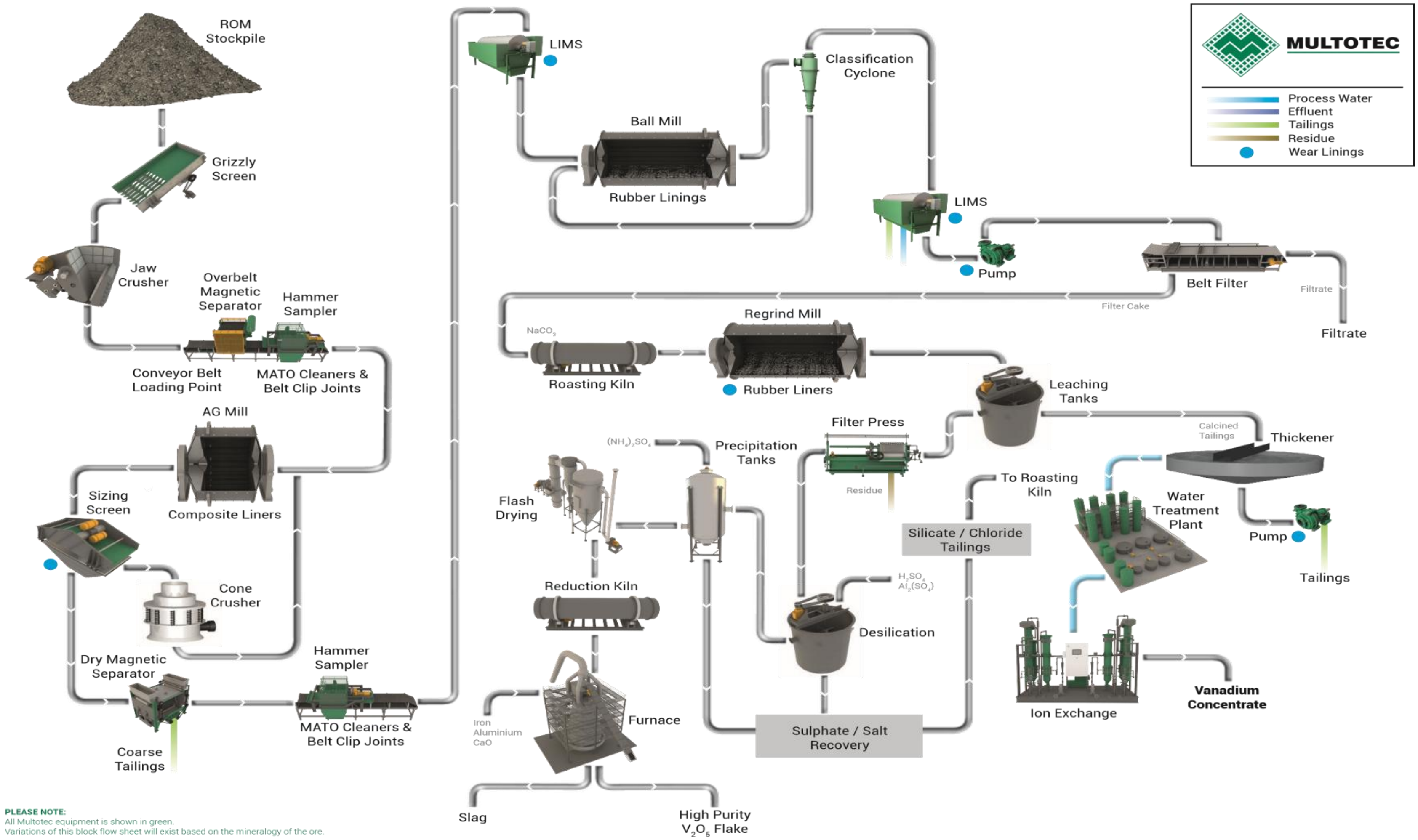


Figure 27: Vanadium beneficiation flow sheet

(Source: Multotec, 2021)

Summary of processes along the Vanadium beneficiation process (Dworzanowski, 2013) and (Bushveld Minerals, n.d):

- **Extraction**: Vanadium is extracted as a by-product from iron ore mining found in vanadium bearing magnetite.
- **Crushing and grinding**: The ore is crushed and milled by ball mills to release the valuable minerals.
- **Magnetic Separation**: Magnetic separation techniques such as wet magnetic separation are used to produce magnetite concentrate with 2% V_2O_5 in-magnetite.
- **Salt Roasting and Leaching**: The magnetite concentrate is roasted with sodium carbonate in kiln at ±1,150°C and then leaching to obtain vanadium pentoxide (V_2O_5).
- **Refining and Purification**: The leachate, which is the roasted concentrate, undergoes purification through the precipitation of ammonium sulphate and is then dried to produce Modified Vanadium Oxide (MVO) and Ammonium Metavanadate (AMV).
- **Final Product Production**: Vanadium pentoxide is transformed into ferrovanadium alloys or chemical-grade vanadium products using aluminium in the presence of iron for use in steel production, catalysts, and energy storage technologies such as vanadium redox flow batteries.

South Africa exports most of the vanadium as vanadium pentoxide slag and as ferrovanadium (DMRE, 2008)**.** South Africa's main exports can be classified as processed forms, such as vanadium pentoxide (V_2O_5) flakes and ferrovanadium. Bushveld Minerals and Vanadium Resources are important players in this sector. They manage state of the art facilities that can process vanadium-bearing magnetite ore into pure products of high quality. For instance, Bushveld Minerals manufactures a range of vanadium products like ferrovanadium and vanadium oxides, which are commonly utilised in the steel and energy industries. Unfortunately, Bushveld Minerals was under business rescue in 2024.

According to Mining Technology (n.d), Vanadium Resources' Steelpoortdrift project, one of the biggest vanadium deposits worldwide, has commenced the production of V_2O_5 concentrate and aims to grow into 98% high-purity V_2O_5 flakes to satisfy market needs. These refined goods serve sectors like steel manufacturing and the storage of renewable energy, such as vanadium redox flow batteries. Table 14 shows companies involved in the beneficiation of vanadium in South Africa

Table 14: Companies involved in the beneficiation of vanadium

Company	Processing Plant
Bushveld Minerals	• Vametco Mine and Processing Facility • Vanchem Processing Facility
Glencore	• Rhovan mine plant
Evraz Highveld Steel and Vanadium	• Evraz Highveld Steel and Vanadium plant (under business rescue)
Vanadium Resources	• Salt Roast Leach Plant

Vanadium Products and Uses

Vanadium products are tabulated in Table 15.

Table 15: Vanadium products

Product	Uses	Visual
Vanadium Pentoxide Flake (V_2O_5)	Used in the making of Ferrovanadium	
Vanadium Trioxide	Is a vanadium powder catalyst used in the production of sulphuric acid	
Ferrovanadium	Used as steel strengthening product such as reinforcing bars and sheets	
Nitro-Vanadium	Used as steel strengthening product	
Sodium Ammonium Vanadate	Chemical catalyst used in sulphur removal in scrubbers	
Vanadium Oxolate Liquid	Used as a catalyst in diesel engines	
Ammonium Metavanadate Powder	Used in fluorescent tubes and pigments ceramics. Also used to make ferrovanadium	

Sodium Metavanadate Powder	Used in pharmaceutical industry	
Potassium Metavanadate	Used in blue ceramics and paints. Also used in petrochemical industry for corrosion inhibitor	

(Source: Bushveld Minerals, n.d)

Vanadium is primarily used for steel production due to its high corrosion resistance. Vanadium is also used in Vanadium Redox Flow Batteries (VRFB) energy grid storage (Bushveld Minerals, n.d). Figure 28 shows the VRFB flow chain visualising the role of vanadium and other minerals such as nickel, manganese, cobalt and copper. Beneficiation skills require understanding possible industrial products and/or uses of minerals as well as processes and equipment required to produce these products.

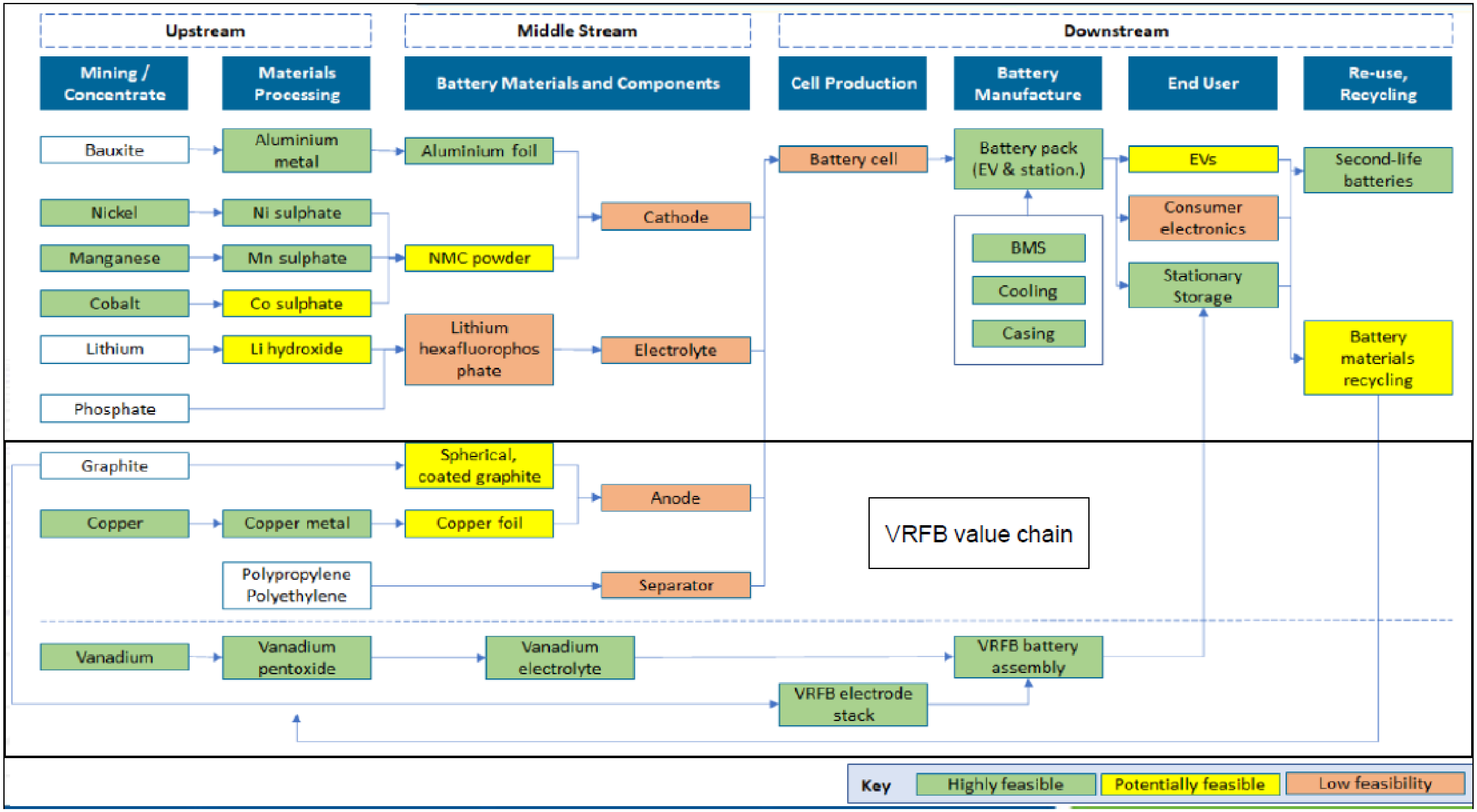


Figure 28: Value chains for vanadium redox flow battery

(Source: World Bank, 2023)

4.3. Pigment and titanium metal production

Titanium is used across different industries including aerospace, automotive, chemical processing and biomedical due to its unique properties such as light weight and high strength (Veiga et al., 2012). South Africa has about 82 million tonnes of titanium reserves and plays a major role in the production of titanium raw mineral production (De Bruyne, et al., 2023; Subasinghe & Ratnayake, 2022). However, the country does not create higher value from titanium as there is limited downstream beneficiation of titanium (De Bruyne, et al., 2023).

Kale and Bisaka (2011) classify the titanium value chain into three broad categories namely, mineral separation and beneficiation of titanium feedstocks; manufacturing of TiO_2 slag; and manufacturing of titanium metal and its downstream applications. Titanium value chain has eight stages mining to manufacturing final products. Beneficiating titanium ores increase titanium content and consequently the price. Figure 29 shows the value chain of titanium including prices and table 16 shows visual illustration of products from each stage.

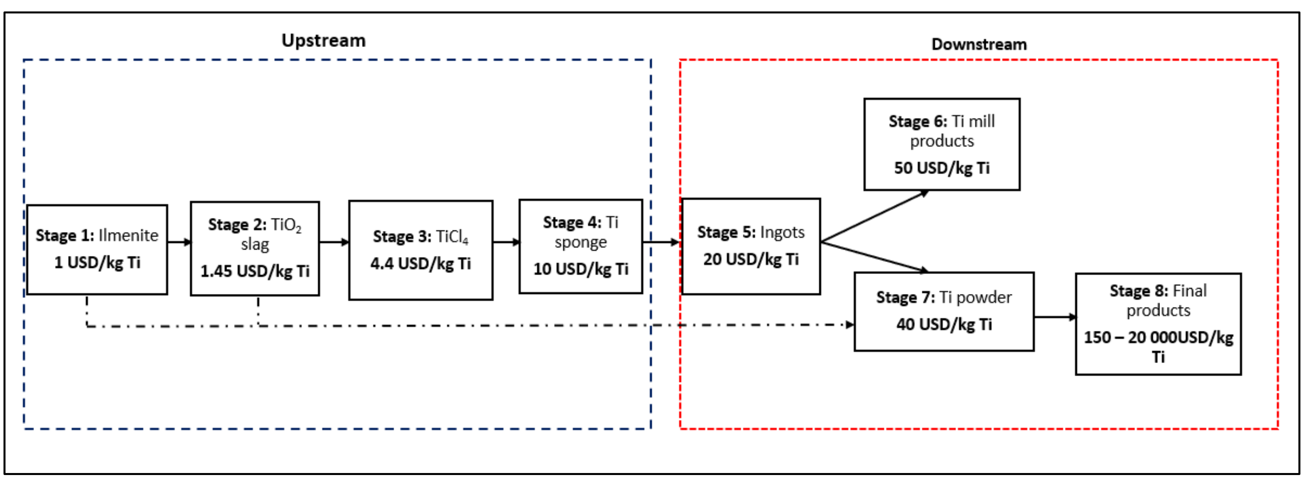
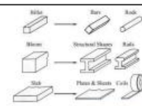
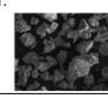
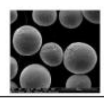


Figure 29: Titanium value chain and prices

(Source: Adapted from du Preez, 2014; Roux et al., 2019)

Table 16: Illustration of the products from each stage of the titanium metal value chain

Stage	Name	Visual
1	Titanium mineral (reserves)	 
2	Titanium slag	 
3	$TiCl_4$	 
4	Titanium sponge	 
5	Melted products	 
6	Mill products	 
7	Titanium metal powder	Angular:  Spherical: 
8	Powder products	 

(Source: Roux, 2020)

Stage 1 - Discovery and Mining: According to Bykhovskii and Tigunov (2011), titanium deposits occur in three categories, namely, primary ore, placer deposits (heavy minerals concentrates) and weathered carbonatite complexes. The authors further argued that while most titanium deposits are in primary ores, but heavy minerals are more economically feasible to mine. Ilmenite ($FeTiO_3$) is the most abundant titanium primary mineral whereas rutile (TiO_2) is the higher grade but less abundant titanium mineral. From this stage, raw titanium ores (ilmenite and rutile) are extracted using appropriate mining methods and transported for processing.

According to Roux (2020), Rio Tinto's Richard's Bay Minerals (RBM), Exxaro's Hillendale mine and Tronox' Namaqua Sand mine are leading companies in mining and upgrading titanium. Stage 1 requires a good geological understanding of the ore(s) as well as well as expertise in economic and safe mine design and planning. Some of the key skills and/or careers required for stage 1 include but not limited to basic and intermediate rigging; forklift and RBM dune licenses (RBM,2020). According to Roux (2020: 99) "titanium mining and beneficiation has been conducted in South Africa for a long time and employs several skilled and unskilled employees." However, RBM (2020 -2024) further identified Diesel Electric, Fitter, Artisan, Millwright Artisan and Rigging among the hard to fill vacancies due to scarcity of trade test(s) and mining specific skills. While these hard to fill vacancies are noted here, detailed study on the artisans required for stage 1 is beyond the scope of this research.

Stage 2 - Processing (Beneficiation): During this stage contaminants in ilmenite are removed to produce a titanium rich slag (80 – 90% TiO_2). This slag, also referred to as synthetic rutile can be processed further, however, it is also ready for use mainly in the paint, paper and fertiliser industry (Roux et al., 2019). The main processes which can be applied to produce synthetic rutile from ilmenite are smelting processes; reduction of ilmenite to partially convert ferric iron to ferrous iron; reduction of iron to metallic iron; the MURSO process; and the Enhanced Roasting and Magnetic Separation (ERMS) process (Mehdilo and Irannajad, 2011).

In South Africa, major producers of titanium slag are Namakwa Sands and RBM. According to Tronox (2024), mined ore is processed at the primary and secondary concentration plants to produce mineral concentrate and magnetic/non-magnetic stream, respectively. Moreover, these concentrates are separated in Mineral Separation Plant to produce zircon, rutile and ilmenite, and in the furnaces, ilmenite is processed producing titanium dioxide slag (Tronox, 2024). Notwithstanding some hard to fill vacancies which may be experienced by companies during this stage as well as possibility of relying on imported skills, South Africa is exporting upgraded titanium slag and rutile, thus, the country has access to skill set for this stage. It is however important to determine the source(s) of skills used by the two major companies engaged in this stage.

Stage 3 - Titanium tetrachloride ($TiCl_4$): Fluidised bed chlorination is the main process used to produce $TiCl_4$ from rutile and upgraded titanium slag (Roux et al., 2019). A chlorination pilot plant commissioned at Mintek to produce $TiCl_4$ faced low efficiency due to technical challenges and the size of the plant (Kale and Bisaka, 2011). Roux (2020) notes that research is ongoing, but no commercial plant has been established in South Africa to produce, titanium tetrachloride. The pilot plant trials done at Mintek form a good basis to understand and document skills required to commission and operate a chlorination plant.

Stage 4 - Titanium sponge production: The Kroll process is the main process used to produce a porous form (sponge) of titanium which is up to 98% pure from $TiCl_4$. Notable efforts to develop the country's capacity to refine titanium metal include the collaborative establishment of the Titanium Centre of Competence (TiCoC) (du Preez, 2014). The aim of the TiCoC is to produce titanium metal powder by developing and commercialising an innovative, cost-effective and competitive process (du Preez, 2014; Oosthuizen & Swanepoel, 2018). Figure 30 shows the industrialisation plan to produce pure titanium as well as titanium alloy.

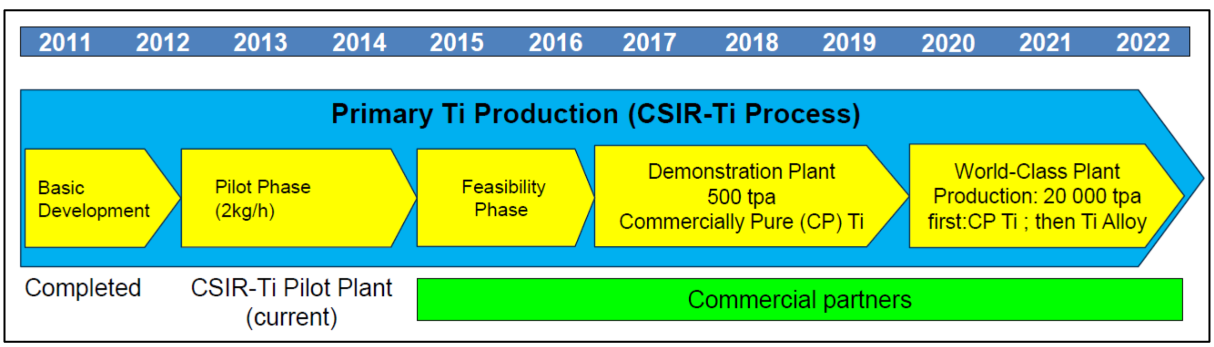


Figure 30: Primary titanium industrialisation plan

(Source: du Preez, 2014)

Oosthuizen & Swanepoel (2018) noted the following impacts of a local low-cost titanium industry:

- Generation of about R3 billion to R5 billion per year which may increase to R10 billion to R30 billion per year after establishing a downstream industry.

- Ability to employ about 450 and 2000 workers (engineers and technicians) in the upstream and downstream components, respectively.
- Spillover of technologies and skills into other industries through procurement of goods and services.

While Roux (2020) noted that there has been research on the Kroll process, South Africa does not produce titanium sponge. It is important to profile skills required in the CSIR-Ti pilot plant to estimate skills which will be required for commercial production of pure titanium and titanium alloy.

Stage 5 - Refining and alloying: Titanium sponge is melted by electron-beam remelting (EBR) or vacuum arc melting and remelting (VAR) or plasma or remelting (PAR or electro-slag remelting (ESR) to produce high purity titanium ingots and billets (Roux et al., 2019). To enhance properties of titanium, other elements such as aluminium, vanadium or molybdenum are added to titanium (Veiga et. al., 2012). South Africa has limited melting capabilities and imports limited melted products (Roux, 2020). As shown in figure 30, the CSIR-Ti production process is envisaged to produce about 20 000 tonnes of pure titanium as well as titanium alloy. Refining and alloying titanium require various skills that include metallurgical knowledge to understand titanium and its alloys, process engineering expertise to manage extraction and refining processes like the Kroll process.

Stage 6 - Metal forming and fabrication: Titanium ingots and billets are converted into finished or semi-finished titanium products such as sheets and pipes through processes including casting, forging and rolling (Dutta and Froes, 2017). There are some companies in South Africa involved in machining imported ingots and sell final products to both, local and international markets (Roux, 2020). This means that these companies have access to skills for this stage of the titanium value chain. It is also noted that there is active research and development of this stage in South Africa.

Stage 7 - Titanium metal powder production: This which involves the techniques from two mainstream processes namely, powder from sponge and powder form direct electrochemical reduction (Roux et al., 2019). While the powder from sponge dominates the powder supplies, some countries including South Africa are developing methods with respect to producing powder form direct electrochemical reduction. Access to skills for titanium metal powder production in South Africa is facilitated through institutions like CSIR which has a Titanium Centre of Competence (TiCoC) (CSIR, n.d.).

Stage 8 - This stage focuses on converting titanium metal into fine powders for various high-value applications, including aerospace, medical implants, and additive manufacturing (3D printing) (Zhang et al., 2019). Zhang et al., (2019) further state that the stage typically involves atomization, where molten titanium is rapidly cooled to form fine particles and subsequently classification is performed to achieve desired powder size and shape. This stage is essential for producing materials with specific properties required for advanced engineering applications, enhancing the versatility and utility of titanium in modern technology (Froes, 2020; Zhang et al., 2019). In addition to metallurgical and process engineering, knowledge of selective laser smelting and electron beam melting is also required. Through industry collaboration, CSIR's TiCoC is expected to offer specialised training in selective laser smelting and electron beam melting because the goal of this centre is to pilot the entire value titanium value chain.

4.4. Autocatalytic converters and diesel particulate filters

Autocatalytic converters use Platinum Group Metals (PGMs) to convert harmful emissions into less harmful substances, while diesel particulate filters capture and periodically burn off soot to reduce particulate matter emissions from diesel engines. The Bushveld Complex (BC) in South Africa hosts approximately 450 known minerals, including PGMs. The BC hosts the world's largest PGM resources and is divided into three geographical zones or limbs: the Eastern Limb, the Western Limb, and the Northern Limb. The BC is estimated to contain around 1.96 billion ounces of PGM from known resources. There are approximately 39 mines in the BC with active, developing, and care and maintenance statuses. Some of the mining companies operating in the BC are Anglo American Platinum, African Rainbow Minerals, Impala Platinum Holdings, Northam Platinum Holdings, Royal Bafokeng Platinum, Sibanye Stillwater, and Siyanda Resources.

PGM Value chains

The PGMs value chain in South Africa involves a range of interlinked stages that convert raw PGM minerals into valuable products. This process involves mining, concentration, smelting, purifying, and refining, ultimately resulting in different end-use applications. Figure 31 shows the PGM value chain from mining to end-use applications and Figure 32 shows the detailed process of PGM beneficiation.

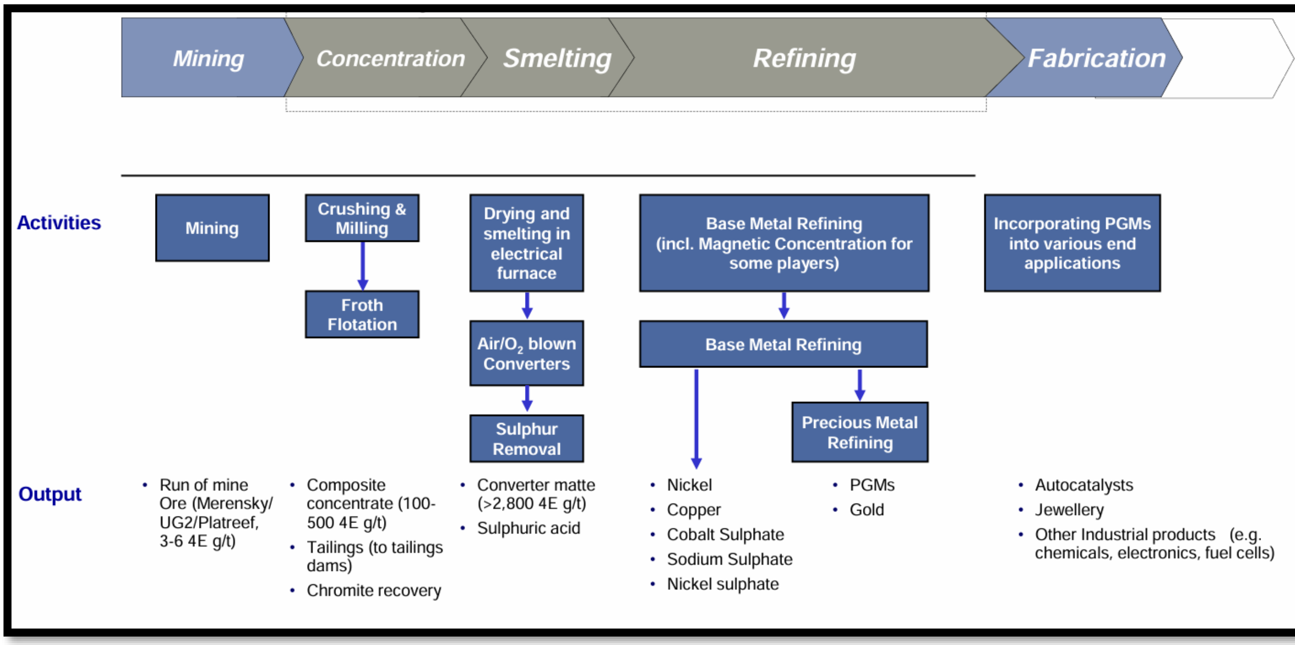


Figure 31: PGM Value Chain

(Source: Ndlovu, 2021)

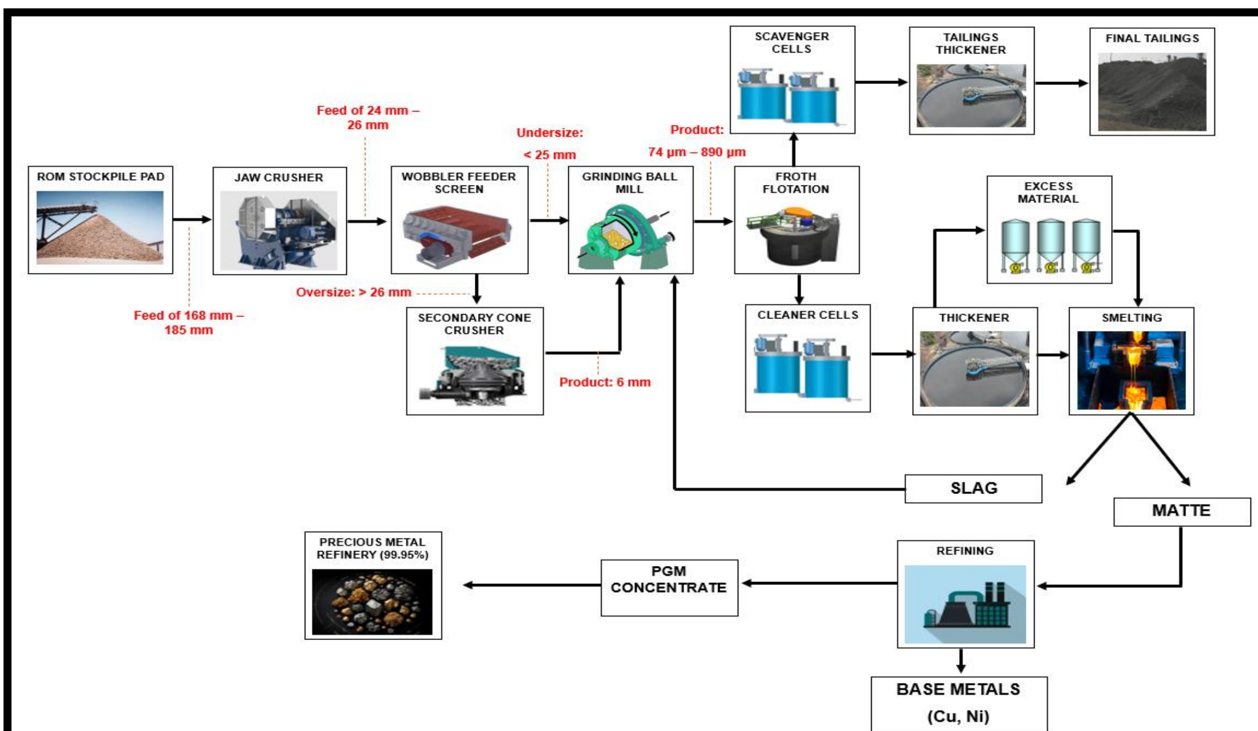


Figure 32: PGM Beneficiation Flow

(Source: Ndlovu, 2021)

Processes Along the Value Chain

Mining: The mining of PGM primarily takes place in the Bushveld Complex, using both opencast and underground mining methods. The primary reefs containing minerals are the Merensky Reef which is famous for its high gold and platinum content, the UG2 Reef, which is chromite-rich and more consistent, and the Platreef which is wider, but with decreased quality in PGMs (Skinner, 2019). The ROM ore typically contains 4 to 6 g/t 4E (Ndlovu, 2021).

Concentration: Following mining, the ore is typically crushed in a three-stage crushing circuit using a combination of jaw and cone crushers and milled by ball and rod mills before being subjected to froth flotation to separate precious group metals from unwanted material. The result is a blend concentrate with a PGM content ranging from 100 to 500 g/t (Moller, 2020).

Smelting: After flotation, the concentrate is dried and smelted in a rectangular six-in-line or circular three-electrode electric furnaces, resulting in a converter matte with more than 2,800 g/t of platinum group metals (PGMs). This process also retrieves additional substances like nickel and copper (Möller, 2020).

Converting: Following the smelting process, the furnace matte undergoes treatment in either Pierce-Smith converters or the Ausmelt process, during which iron sulphide is oxidized to ferrous oxide and sulphur is oxidized to sulphur dioxide (Cramer, 2008). Sulphur dioxide is eliminated, while iron oxide is eliminated as a fayalitic slag. The converter's slag phase holds a large quantity of trapped PGM and is sent back to the smelting furnace for recovering the trapped PGM. The converter matte undergoes cooling, milling, and processing at the base metals' refinery (Safarzadeh et al., 2018).

Base Metals Refining: Refining is the process of isolating precious metals from the converter matte to create metals of high purity using solvent extraction or pressure oxidation leach. In the Base Metals refinery, the base metals are leached, but the PGMs are retained in the residue and copper, nickel and sometimes cobalt are recovered. The residue containing PGMs is sent to the precious metals refinery (Safarzadeh et al., 2018). Residual sulphur is eliminated in this stage and sent to the production of sulphuric acid (Ndlovu, 2021)

Precious Metal Refinery: The slag from the base metals refinery containing PGMs is sent to the PGM refinery to recover PGM metals at 99.99% purity (Ndlovu, 2021).

Specialized Equipment Used: These include jaw, gyratory, and cone crushers; gravity separators; ball and rod mills; electric furnaces; froth flotation cells; and air blown converters.

Options available in the PGM Beneficiation

There are options available to sell PGMs. Figure 33 depicts the options that are available to sell PGMs throughout the value chain.

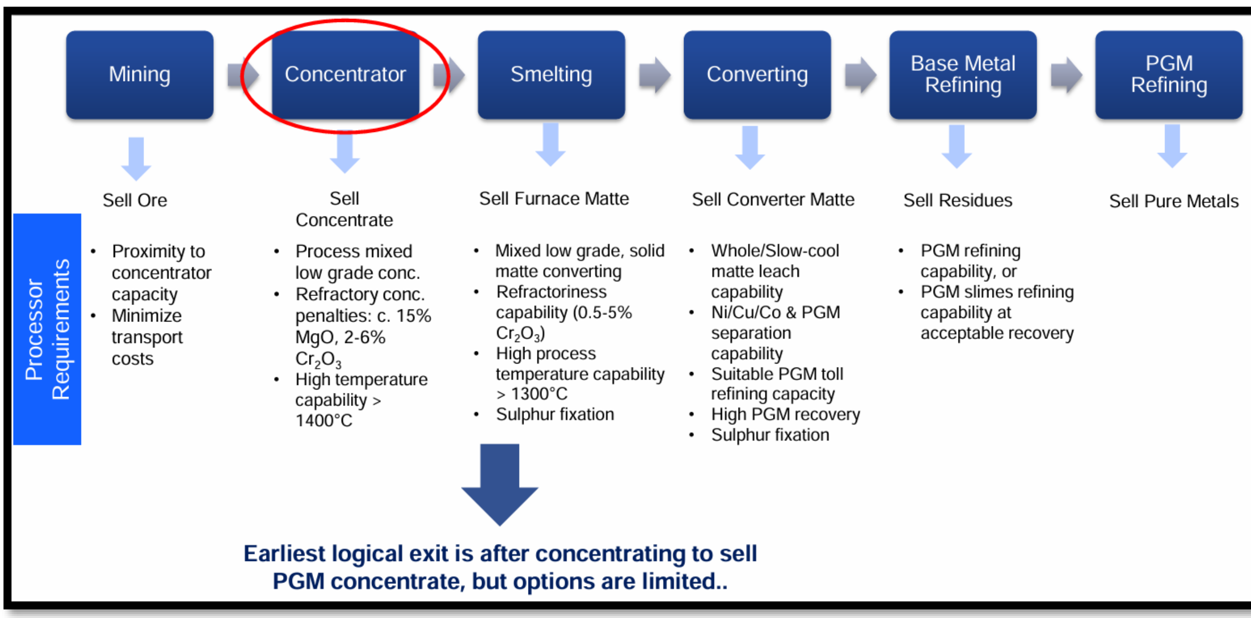


Figure 33: Options Available in the PGM Processing Value Chain

(Source: Ndlovu, 2021)

Companies Involved in the Beneficiation

Several companies are involved in the processing, smelting, and refining of PGMs. Table 17 shows the list of companies involved and their respective smelters and refineries.

Table 17: A list of PGM smelters and refineries in the Bushveld Complex

Refineries		Smelters	
Name	**Owner**	**Name**	**Owner**
Rustenburg Refinery	Anglo American Platinum Ltd.	Mortimer Smelter	Anglo American Platinum Ltd.
Barplats Refinery	Eastern Platinum Ltd.	Polokwane Smelter	Anglo American Platinum Ltd.
Impala Refinery	Impala Platinum Holdings Ltd.	Waterval Smelter	Anglo American Platinum Ltd.
Brakpan Refinery	Sibanye Stillwater Ltd., Incwala Resources (Pty) Ltd.	Impala Smelter	Impala Platinum Holdings Ltd.
Western Platinum Refinery	Western Platinum Refinery Ltd	Randburg (Demonstration) Smelter	Mintek
		Northam Smelter	Northam Platinum Holdings Ltd.
		Marikana Smelter	Sibanye Stillwater Ltd., Incwala Resources (Pty) Ltd.
		Middelburg ConRoast Smelter	Siyanda Resources Pty Ltd.

(Source: S&P Capital IQ, 2023)

PGM Products

PGMs play a vital role in a range of uses like automotive catalysts to lower emissions, luxury Jewellery for their strength, electronics for conducting electricity, and fuel cells for converting energy. They are additionally utilised in chemical reactions to increase effectiveness and in medical equipment because of their compatibility with living tissue. As the need for sustainable green technologies rises, the significance of PGMs in various industries is increasing, emphasizing the importance of efficient resource management in producer nations such as South Africa (Grilli et al., 2023).

Challenges in exporting PGMs as final products from South Africa

Although South Africa is the global leader in the production of PGMs, it encounters major difficulties in exporting these metals as finished products such as jewellery, autocatalysts, and other industrial uses including automotive. One major problem has been the country's lack of historical beneficiation and value addition. Even though South Africa has around 90% of the world's PGM reserves, and produces 70% of global supply, a large portion of the production is exported in partially processed forms instead of final products (Moller, 2021). This problem is made worse by the control of multinational corporations in the PGM industry downstream, as they typically focus on cost-effectiveness and worldwide supply chains at the expense of local manufacturing. As a result, South Africa's geographic location is far from automotive manufacturing hubs, and this limits its potential to attract investment and funding for domestic processing plants capable of manufacturing finished products (Skinner, 2018).

Furthermore, the South African PGM industry heavily depends on specific uses, specifically in the automotive sector, where PGMs are mainly utilised in catalytic converters. Nevertheless, the ability of the local market to convert these metals into finished goods is limited due to economic factors and competition from global companies (Pheto, 2023). Nevertheless, despite South Africa's significant contribution to global PGM demand, it faces challenges in fully exploiting its resources to create more valuable end products that could boost the country's economic gains (African Export-Import Bank, 2024).

4.5. Jewellery and Fabrication

4.5.1 Gold

The world's largest reserves of gold are in the South African Witwatersrand basin which significantly contributes to the global production of gold and national economy. Geographically, the basin covers four provinces namely, Gauteng, Free State, Mpumalanga and North West. In 2022, South Africa produced around 110 tonnes of gold, positioning it among the top producers worldwide. Approximately 2.56Moz of gold which is equivalent 62% of total gold output from South Africa is sourced from Gauteng, 22% from Free State, and the remainder sourced from North West and Mpumalanga provinces (PwC, 2023). Note that there has been a considerable drop in output compared to earlier decades due to issues like diminishing ore quality and rising operational costs (World Gold Council, 2023). There is one mine in Gauteng that hosts 55% of the total 56.88Moz gold reserves and excluding this mine, there would be approximately 21 years left of mining at the current depletion rates from remaining operations (PwC, 2023).

The gold mining value chain includes multiple phases, starting with exploration and the discovery of the gold reserves to the production and final application of gold items such as gold bullions and jewellery. Figure 34 displays the value chain of gold mining and Figure 35 shows the gold processing flow sheet

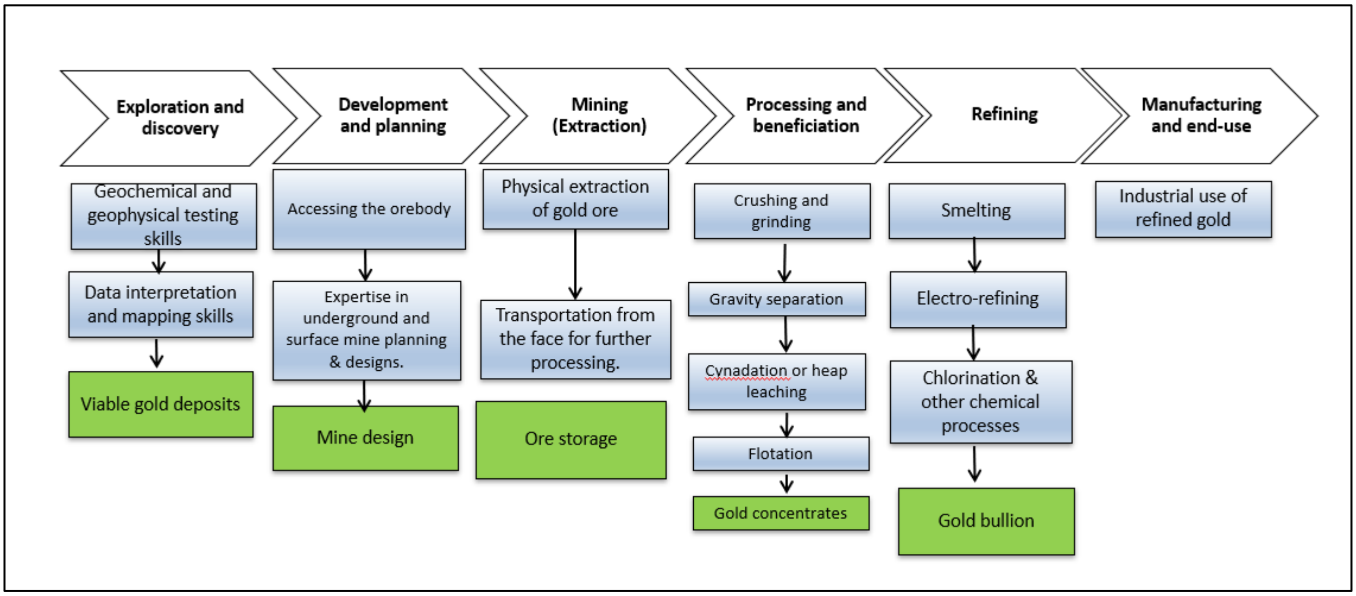


Figure 34: Generic gold mining value chain

(Source: Adapted from Bester et al., 2016; Scott & Matchett, 2004; Vorster, 2001)

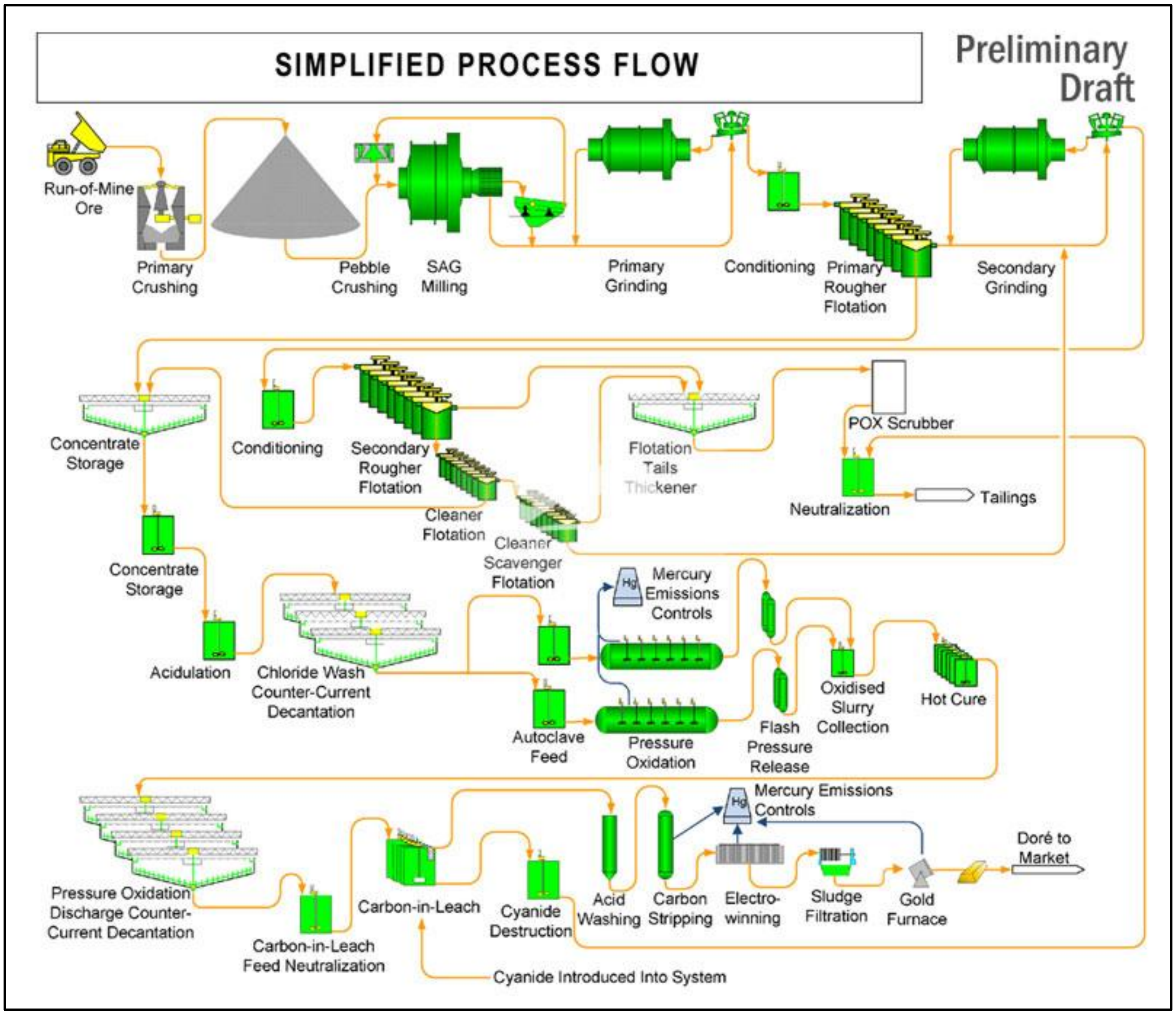


Figure 35: Gold processing flow sheet

(Source: Raymond Mills, n.d)

Beneficiation of gold in South Africa includes various essential processes namely, crushing and grinding, gravity separation, flotation, cyanidation and leaching, carbon-in-pulp & electrowinning, smelting, and refining. The extracted ore is crushed with jaw crushers and subsequently ground into a fine powder using ball mills and semi-autogenous grinding (SAG) to separate gold from other minerals before applying gravity separation devices to produce a slurry bearing gold (Misra, 2000). Fleming (2022) states that flotation methods are used to concentrate gold found in sulfide minerals producing gold concentrates with between 60-70% purity. The concentrated gold ore goes through cyanidation whereby cyanide is applied to extract gold from the ore in tanks or heap leaching piles and oxygen is introduced producing a leach solution contains up tom 70-90% purity (Marsden & House, 2006).

Carbon is utilized to adsorb gold which is referred to as the 'carbon-in-leach' method and consists of three stages namely, adsorption, elution and electrowinning (Anglo American, 2008). The concentrated gold is subsequently subjected to high temperatures in an electric furnace to eliminate impurities, producing dore bars that contain a blend of metals with 99% purity (International Cyanide Management Code, 2021). Flux is introduced, and the gold is heated in a furnace to isolate the gold from the impurities. The flow will oxidise the impurities, which will rise to the surface of the liquid gold that can be extracted. Additional purification via methods like electrolysis or chemical refining using induction furnaces and chlorine gas injection systems produces high-purity gold (typically 99.99%) appropriate for market sale (Rand Refinery, 2023).

Companies Involved in Beneficiation

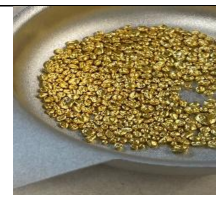
Numerous leading firms participate in the gold beneficiation process in South Africa and the companies, and the plants are given in Table 18. Rand Refinery is one of just five companies in the world recognized as Good Delivery Referees by the London Bullion Market Association (LBMA), guaranteeing that its refined gold complies with the industry's top standards (Rand Refinery, 2023). Gold products at some of the processing stages are illustrated in Table 19.

Table 18: Gold processing companies and plants

Company	Beneficiation Plant	Location
GoldFields Limited	South Deep Gold Plant	Gauteng
Sibanye Stillwater	Kloof Gold Mine Plant	Gauteng
	Driefontein Gold Mine	Gauteng
	Cooke Plant	West Wits Line, Randfontein
Harmony Gold	Mponeng Mine Plant	Gauteng
	Tshepong Mine Plant	Free State

DRDGOLD	Ergo Plant	Brakpan, Gauteng
Rand Refinery	Rand Refinery Plants	Germiston, Gauteng

Table 19: Gold products (Google images)

Stage	Product	Visual
Mining	Raw gold ore	
Crushing	Crushed gold	
Flotation	Gold concentrate	
Cyanidation and Leaching	Gold-rich slurry	
Electrowinning and precipitation	Dore bars	
Refining	Gold bars, coins, jewellery, gold powder, and gold granules	Gold bar  Gold coins  Jewelry  Granules 

4.5.2. Diamond

As of 2023, South Africa holds a vital role in the global diamond market, standing as the fifth largest diamond producer and accounting for nearly 10% of worldwide output averaging 7 million carats annually (GlobalData, 2023). The diamond resources of the country are predominantly situated in the Northern Cape, with significant deposits present in kimberlite pipes like those located in Kimberley and Cullinan. The country also has notable deposits in Free State and Limpopo provinces. The lifespan of mines (LoM) differs for various operations; certain mines are anticipated to maintain production for many decades, reliant on ongoing exploration and technological innovations that improve extraction efficiency (Mining Technology, 2023). Venetia underground project is an example of an extended project as a result of exploration which is expected to last up to 2043 production approximately 111 million carats due to expansions to underground (Minerals Council of South Africa, 2022).

In recent times, South Africa's diamond output has demonstrated resilience, showing a reported rise of 13% in 2023 over the prior year (GlobalData, 2023). Key producers in South Africa are De Beers and Petra Diamonds, both of which have adopted approaches to improve local beneficiation and sustainable methods. The production environment is changing, with projections indicating a compound annual growth rate (CAGR) of 4% between 2023 and 2027, propelled by rising demand for ethically sourced diamonds and innovations in mining technology (Mining Technology, 2023).

The diamond value chain is rather a simple process with several stages from mining to retail and distribution as shown in Figure 36.

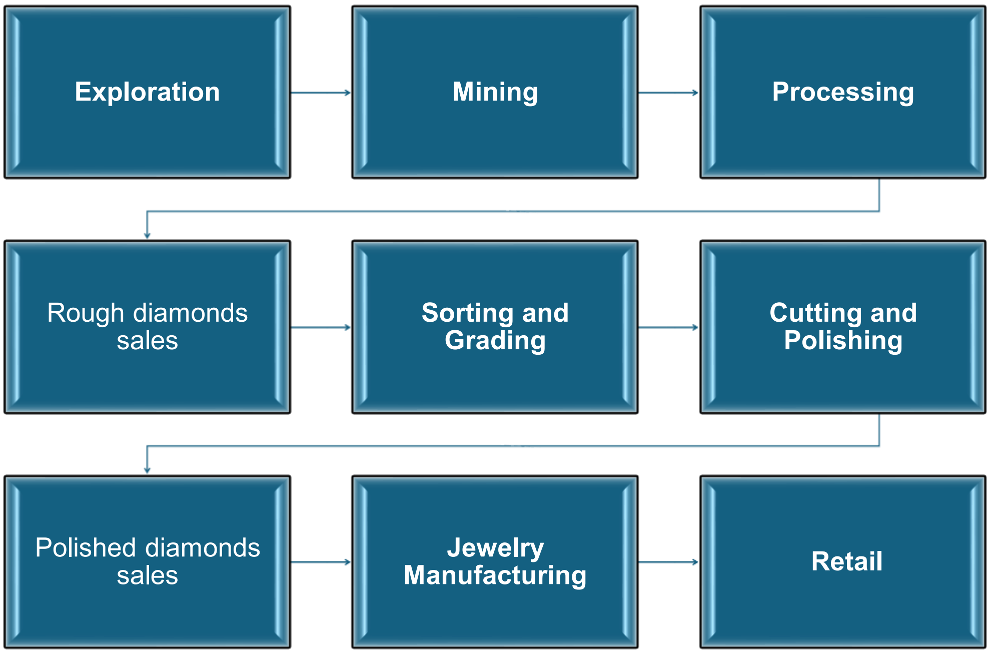


Figure 36: Diamond Value Chain

Source: (Gawanab, 2010)

The beneficiation process is crucial for transforming raw diamonds into market-ready products. Unlike metals such as copper and gold, diamond processing does not involve chemical refining or alteration. This process consists of several key stages: Initially, diamond ore is crushed into smaller sizes using grinding rolls (Wills & Finch, 2016). The ore is then cleaned to remove loose materials and screened, with particles smaller than 1.5mm being discarded as uneconomical for diamond recovery (Ndlovu et al., 2020). In the dense medium separation phase, the diamond-bearing ore is mixed with a ferrosilicon powder and water solution of specific density and introduced into a cyclone. Heavier materials, including diamonds, settle at the bottom, forming a concentrated layer (Schouwstra et al., 2010). Post-separation, rough diamonds are sorted by size, shape, carat weight, colour, and clarity using advanced technologies like X-ray transmission machines. Experts typically grade the diamonds, assigning value based on market demand (De Beers Group, 2021).

Following this, diamonds are sent to cutting and polishing centres, where skilled artisans use precision tools, including lasers, to shape and enhance the gems' brilliance. These refined diamonds are evaluated against global standards and can achieve purity levels of 95-98% (Petra Diamonds, 2023; GIA, 2023). This ensures that the diamonds meet international quality benchmarks and can be confidently traded or used in various applications where high-purity diamonds are required. Finally, the refined diamonds are crafted into jewellery pieces such as rings, bracelets, and necklaces. This stage often involves additional artistry and design efforts and typically takes place outside South Africa, although some local jewellers engage in custom design (Minerals Council of South Africa, 2022). The final stage of the chain involves distributing diamonds to consumer through stores, auctions, and online platforms. South Africa is a home to jewellery stores. However, most of the retail distribution happens in international markets (De Beers, 2023). Key technologies involved in the beneficiation process include X-ray transmission machines, precision laser cutters, and polishing machines.

Companies Involved in Diamond Processing

There are companies involved in sorting, polishing, and jewellery manufacturing of diamond in South Africa. Table 20 illustrates some of the diamond sorting and polishing companies.

Table 20: diamond sorting and polishing companies

Company	Location
The Diamond Works Institute	Cape Town
De Beers Group	Johannesburg
South African Diamond Corporation	Johannesburg
Nungu Diamonds	Johannesburg
Jenna Clifford	Johannesburg
Inclusive Diamond Processing	Johannesburg
Trans Hex Group	Cape Town
Thoko's Diamonds	Johannesburg
Kwame Diamonds	Johannesburg
Molefi Letsiki Diamond Holdings	Johannesburg
Diamonds Africa	Johannesburg
Dimakatso Makgoe Diamonds	Johannesburg
Gussy Diamonds	Kimberley
Irresistible Rough Diamonds LTD	Johannesburg

Future of South Africa's Diamond Beneficiation Industry

Most of the country's raw material are exported as semi-processed products with just a little value or no value added at all (Tom, 2015). South Africa's diamond cutting and polishing industry faces tough competition from India due to the latter's skilled workforce and cost-efficient manufacturing sector (Moodley, 2021). Beneficiation is the correct strategic move for the industry and for South Africa. According to Mining Review Africa (2021), De Beers, along with the SA government and Anglo American Zimele, initiated the Diamond Enterprise Development Project for South Africa. The project aims to support the expansion and transformation of the diamond beneficiation sector while also generating new job opportunities. Five historically marginalised South African diamond cutting and polishing companies have been chosen to take part in the initiative.

The minerals found in Africa are extracted and sent out as raw materials, which are transformed into luxury items that are often too expensive to purchase again. According to Moodley (2022), the State Diamond Trader (SDT) has established its presence at the OR Tambo Airport's Special Economic Zone, which is expected to become a hub for numerous diamond beneficiators in the future. The new site is in proximity to important transportation hubs, allowing diamond producers from the Northern Cape, North West, and Limpopo provinces, as well as international clients, to easily reach it. The OR Tambo jewellery is a project in progress focused on mineral beneficiation to promote diamond trading and beneficiation. To help South African diamond beneficiators compete fairly, the SDT is looking into obtaining cutting-edge technology and teaming up with the Council for Scientific and Industrial Research (CSIR) and Mintek to enhance research and development in producing advanced technology, machinery, and tools within the country (Moodley, 2022). At present, Israel is the country where technology and tools related to diamonds are manufactured (Rosenberg, 2018). Succeeding in expanding the diamond value chain will be achieved if the technology of Israel can be created and replicated in South Africa, this would give South Africa the chance to emerge as a key player on a global scale in diamond processing.

Table 21: Diamond products (Google images)

Stage	Product	Visuals
Mining	Raw diamond ore	 
Sorting and Grading	Rough diamonds	
Cutting and Polishing	Polished diamonds and chips	 

Jewellery Manufacturing	Finished diamond jewellery		

5. SKILLS ACROSS BENEFICIATION VALUE CHAIN

Generally, skills and/or occupations required to undertake beneficiation are informed by the key activities and/or processes along the mining value chain. Moreover, these skills and/or occupations can be broadly mapped under different OFO classification levels which has been discussed under beneficiation skills in literature review. These skills can be process and/or commodity specific, as such, understanding specific value chains forms the basis of identifying skills required for beneficiation. Against these backgrounds, figures 37 to figure 48 show the critical skills mapped along different stages of beneficiation for the value chains discussed in chapter 4.

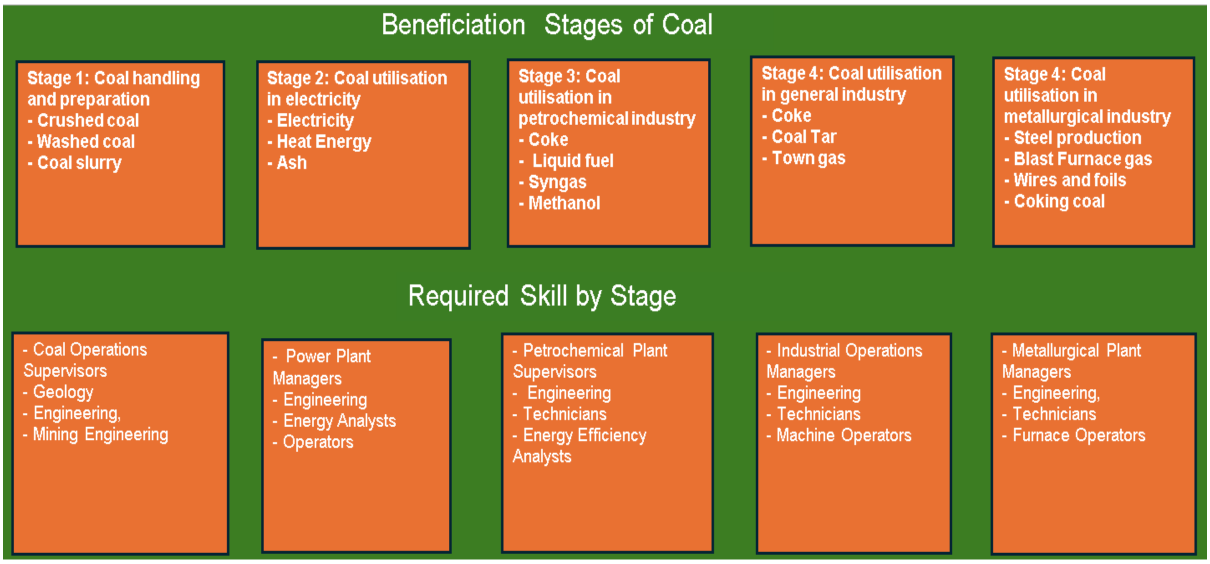


Figure 37: Required Skills in the beneficiation of coal

Processing coal requires proficiency in converting raw coal into forms suitable for diverse industrial applications. These diverse applications of coal require precision and process control skills because different industries require coal of different qualities. This involves coal preparation techniques such as crushing, screening, and washing to remove impurities and enhance coal quality. Chemical engineers and metallurgists play a pivotal role in refining coal for specific uses, including the production of coke for steel manufacturing and the generation of coal-derived chemicals. Advanced knowledge in thermal and chemical processes is vital to transform coal into valuable products efficiently, as such, in addition to engineering skills such as chemical and metallurgy, operation of furnace as well as maintenance are also critical. The climate objectives of decarbonisation significantly impact the future skills needs in coal mining and beneficiation. Workers will need to be trained in areas such as carbon capture and storage, energy efficiency, and the use of alternative energy sources (World Coal, 2025). Additionally, skills in environmental management, regulatory compliance, and sustainable development will become increasingly important to ensure that mining operations align with climate goals and contribute to a just transition towards a low-carbon economy.

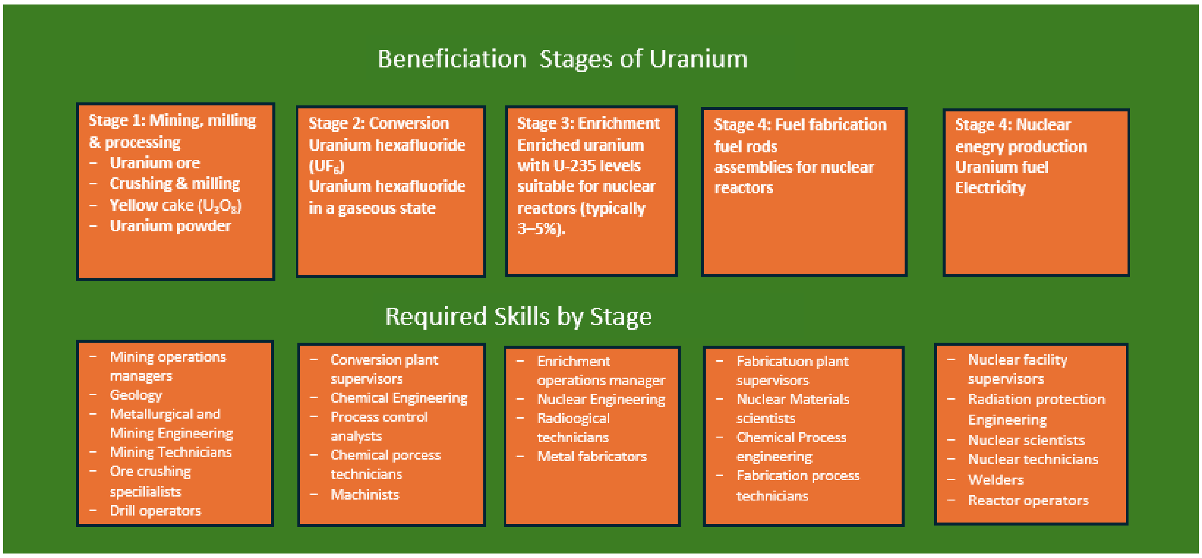


Figure 38: Required skills/occupations in the beneficiation of uranium

Uranium and thorium play significant roles in the clean energy transition. However, uranium and thorium extraction requires exceptional radiation safety and precision geological targeting skills. Thus, mining professionals should demonstrate comprehensive knowledge of rare earth mineral extraction techniques, advanced mining methods, and advanced radiation protection protocols which may be obtained from knowledge of physics and chemistry. Processing of these minerals requires advanced nuclear chemical engineering and metallurgical expertise. Chemical engineers should be conversant with separation technologies, including solvent extraction, ion exchange, and advanced chemical processing techniques. Professionals need comprehensive understanding of thorium's potential in nuclear fuel cycle applications, demanding high-level skills in isotopic separation, material science, and advanced chemical engineering methodologies.

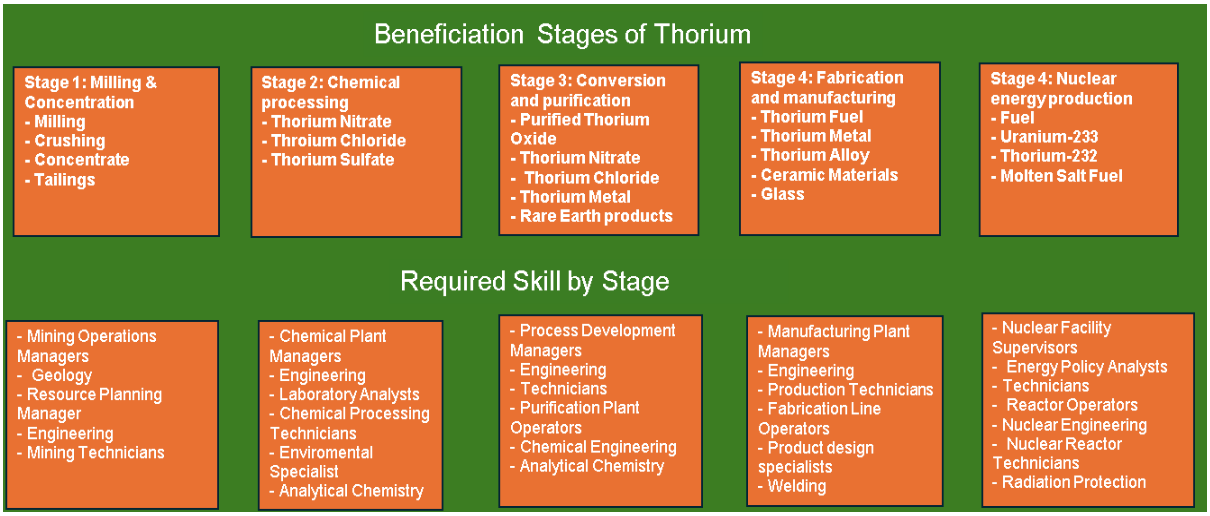


Figure 39: Required skills/occupations in the beneficiation of thorium

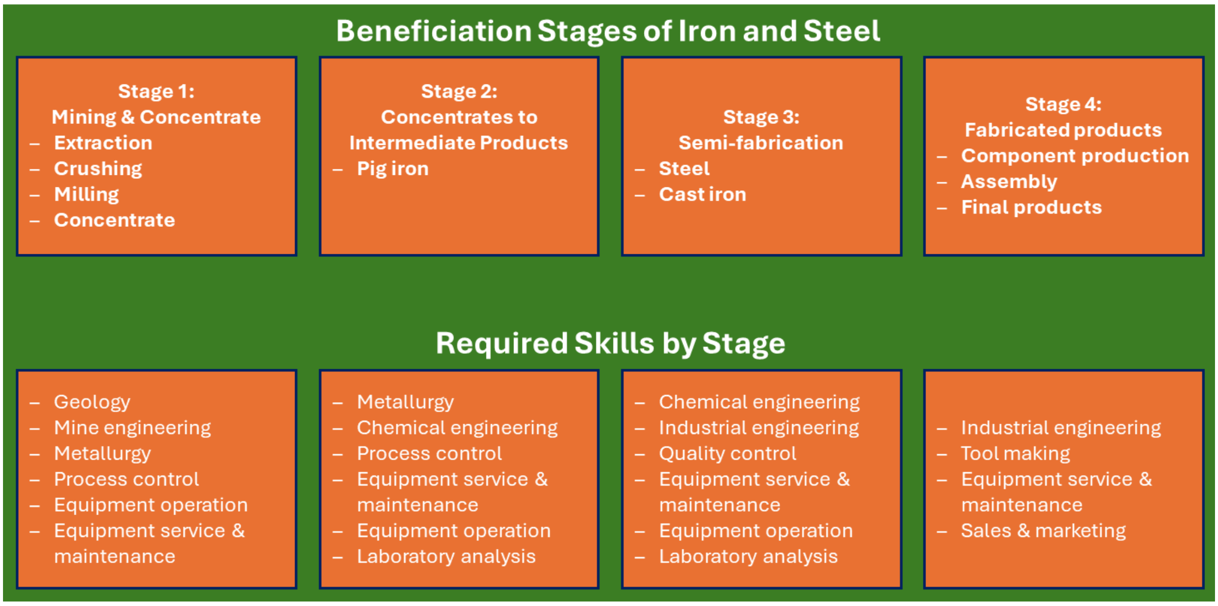


Figure 40: Required critical skills in the beneficiation of iron ore

Iron plays a crucial role in addressing the infrastructure deficit in South Africa. The country's infrastructure, including railways, bridges, and buildings, relies heavily on iron and steel. Iron ore processing requires metallurgical engineering skills focused on quality optimisation and value addition. Noting that different market requires different specifications for iron and/or iron products, precision and process control are among other key skills required. Like other steel making minerals, tool making skills are also required as well as cross-cutting skills of sales and marketing.

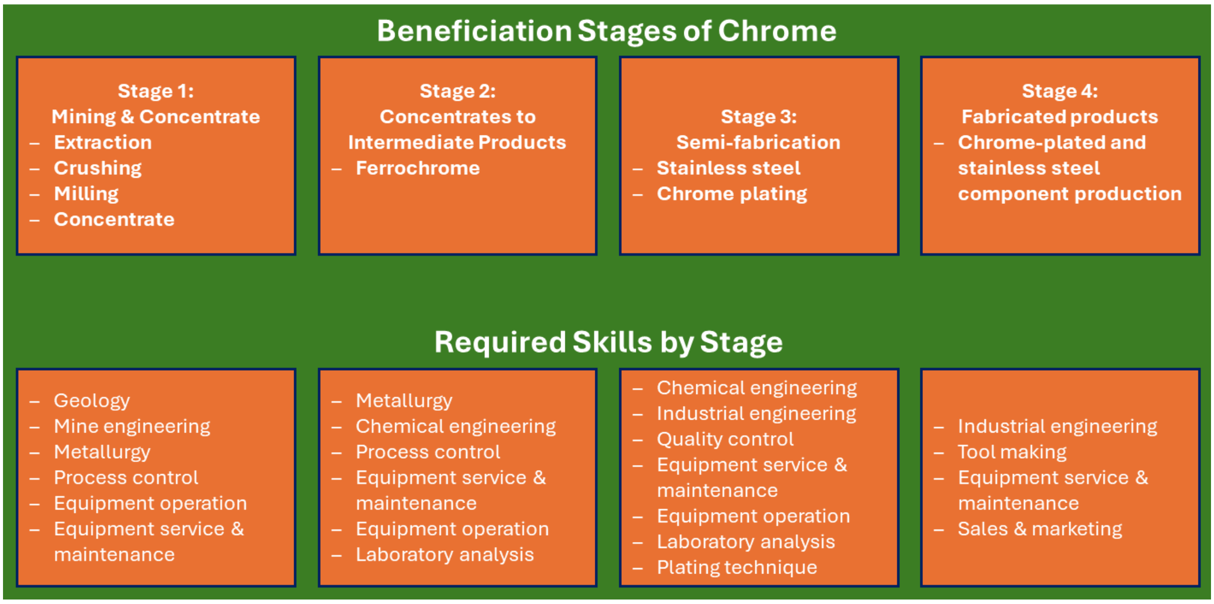


Figure 41: Required critical skills in the beneficiation of chrome

Chrome beneficiation requires skills like other steel group minerals. A unique skill emerging here is plating technique.

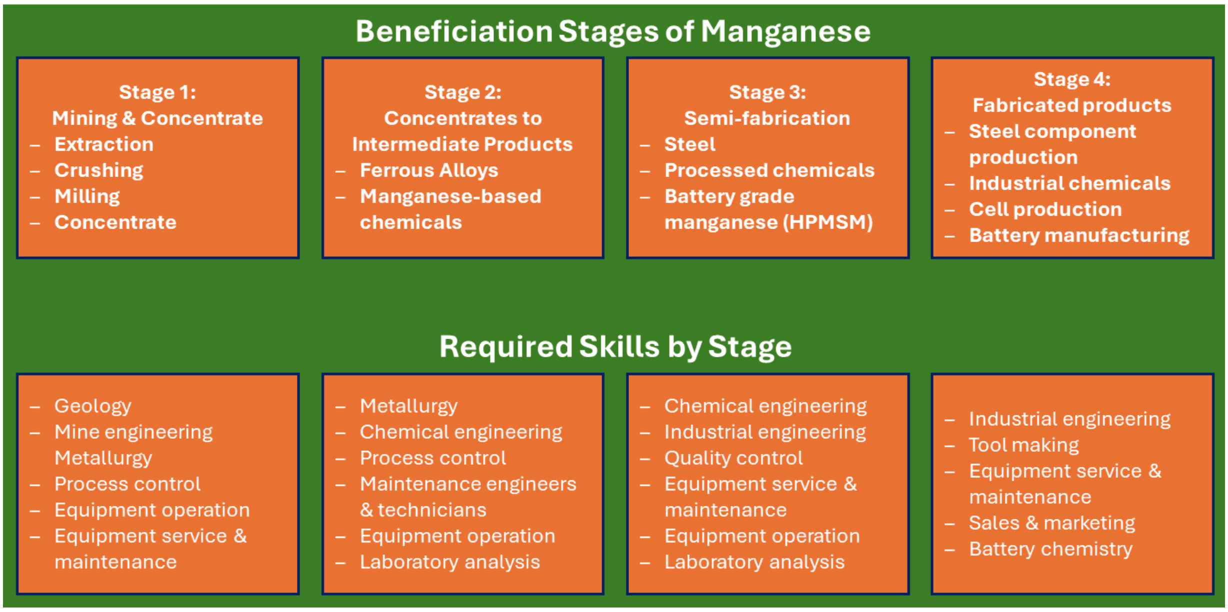


Figure 42: Required critical skills in the beneficiation of manganese

Skills required along the manganese value chain are like those of nickel and vanadium discussed below. As such, they are collectively summarised below vanadium.

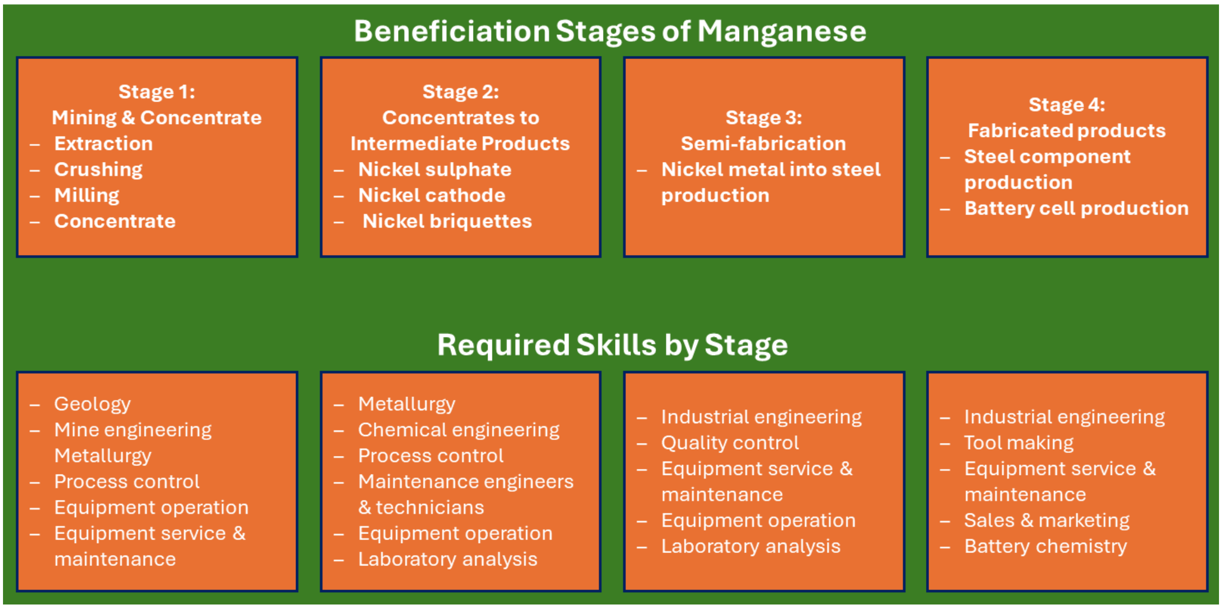


Figure 43: Required critical skills in the beneficiation of nickel

Skills required along the nickel value chain are like those of vanadium discussed below.

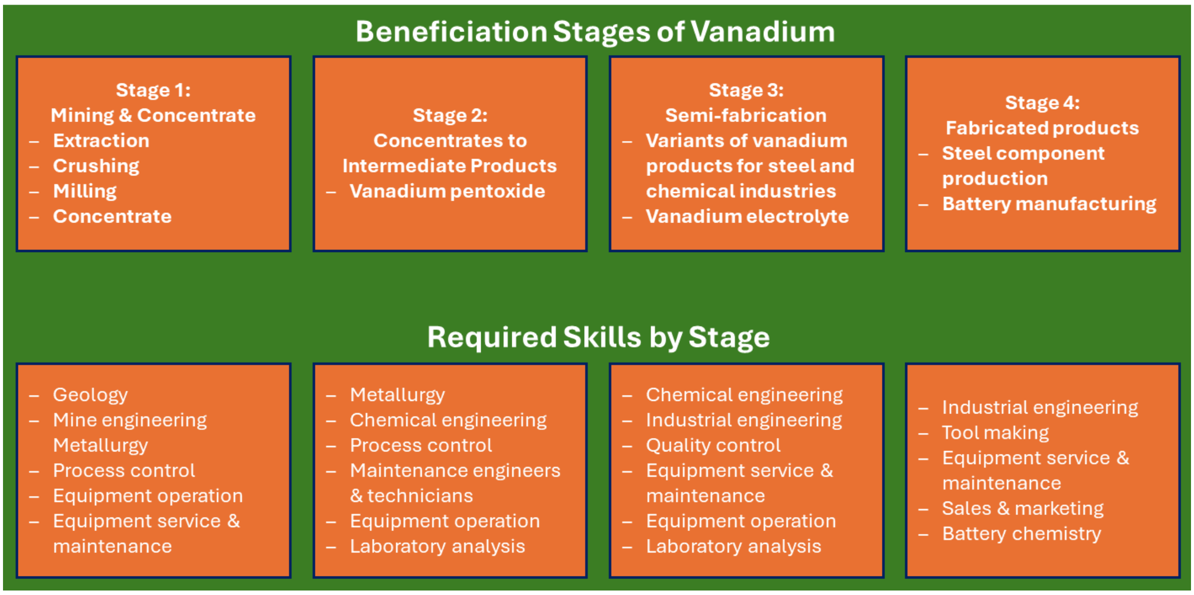


Figure 44: Required critical skills in the beneficiation of vanadium

Vanadium mining demands precise underground and open-cast extraction methodologies. Professionals require expertise in selective mining techniques, advanced drilling technologies, and complex geological targeting. Vanadium processing requires advanced metallurgical and chemical engineering skills. Like other minerals, general skills including engineering, equipment operation and maintenance as well as process and quality control are informed by vanadium pentoxide production technologies, complex chemical separation techniques, and high-temperature metallurgical processes. Industrial engineering, tool making and specialised knowledge of battery chemistry characterise the manufacturing stage of this mineral like nickel.

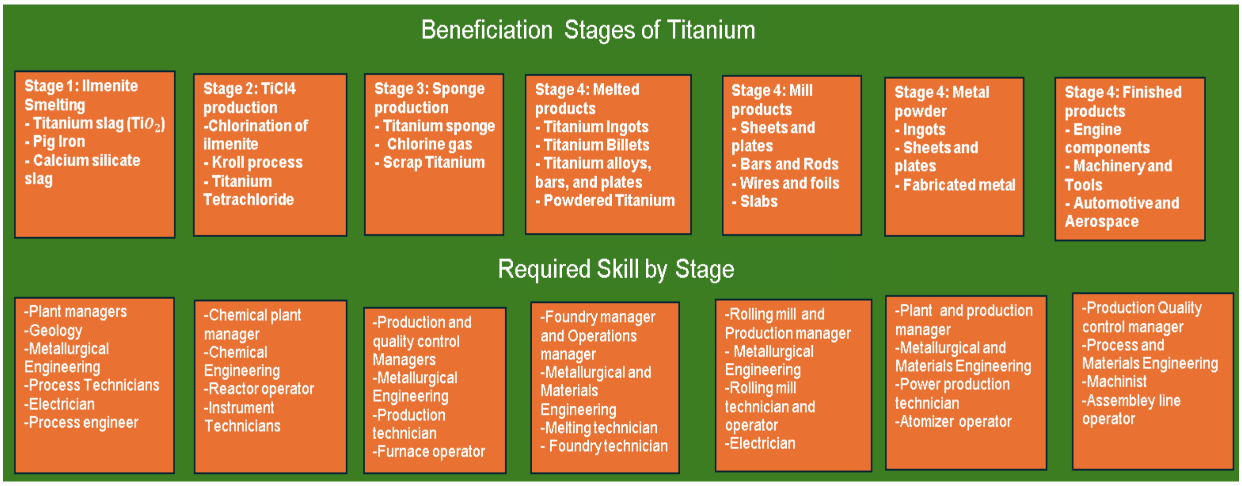


Figure 45: Required critical skills/occupations in the beneficiation of titanium

Titanium mining requires precise underground and surface extraction methodologies. Professionals need expertise in selective mining techniques and advanced drilling technologies. Titanium processing requires advanced metallurgical and chemical engineering skills. Moreover, specialised knowledge titanium dioxide production technologies which include chemical separation techniques, and high-temperature metallurgical processes is required. At manufacturing stage comprehensive knowledge of titanium alloy development, focusing on high-value aerospace, medical, and industrial applications is necessary.

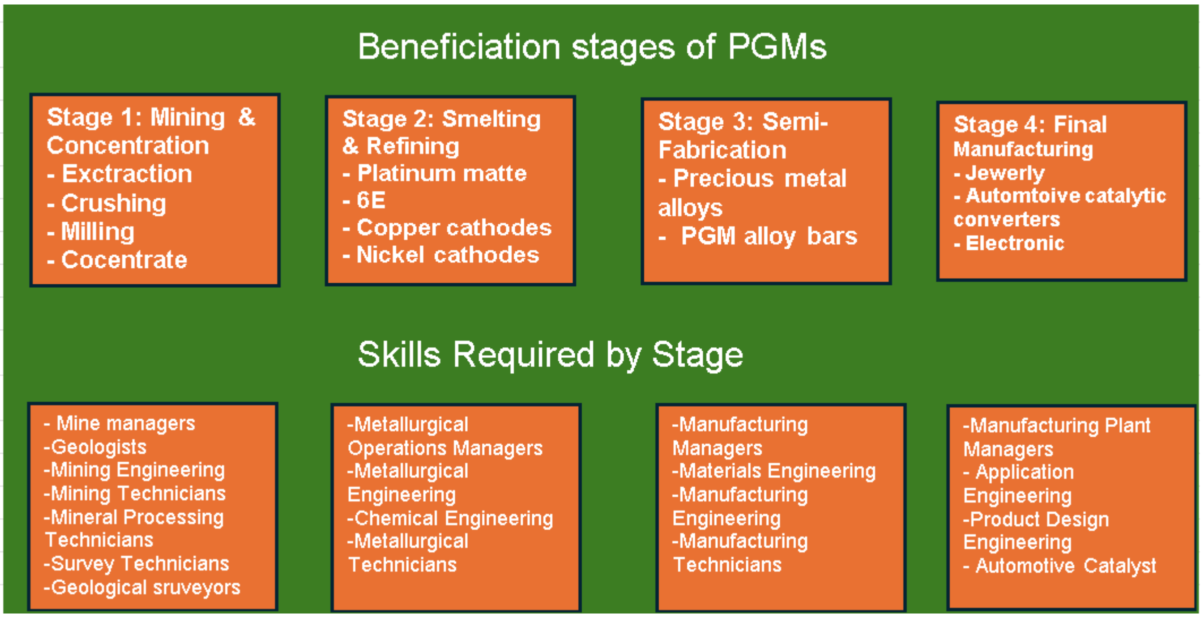


Figure 46: Required critical skills/occupations in the beneficiation of PGMs

PGM mining demands highly specialised underground mining technologies. Professionals require expertise in precision extraction techniques, advanced geological targeting, geometallurgical evaluation and complex mineral separation methodologies. PGMs processing requires advanced metallurgical and chemical engineering skills. Specialists should have knowledge of complex refining technologies, chemical separation techniques, and precision metallurgical processes. Chemical engineers need comprehensive knowledge of platinum group metal extraction, focusing on high-value industrial, automotive, and technological applications.

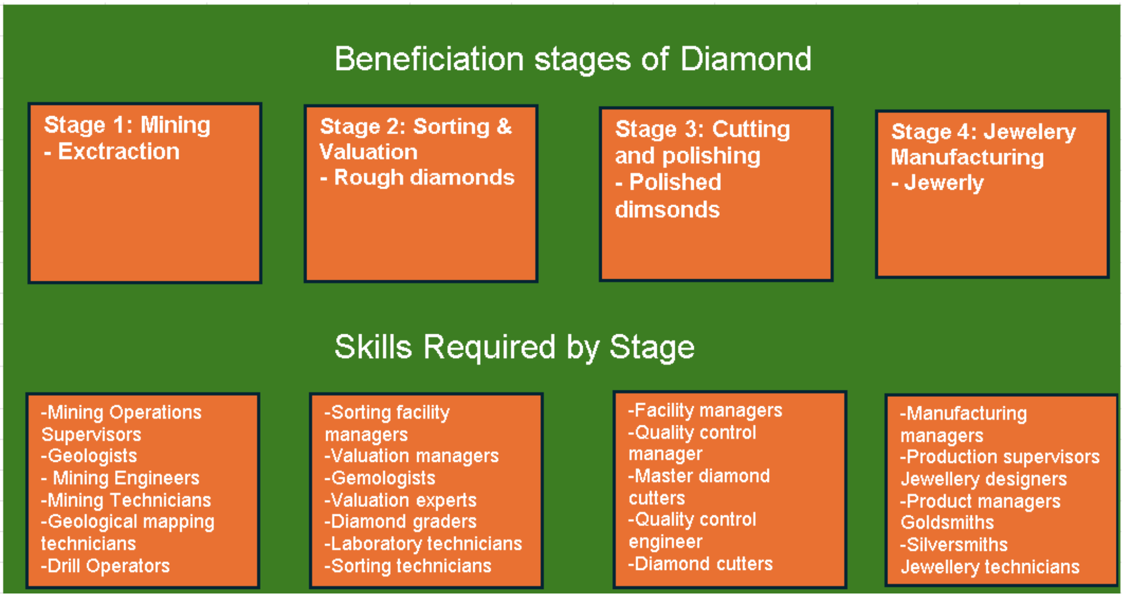


Figure 47: Required critical skills/occupations in the beneficiation of diamond

Diamond mining demands highly specialized underground and open-cast extraction methodologies. Professionals require expertise in precision extraction techniques, advanced geological targeting, and complex mineral separation methodologies. Diamond processing requires advanced gemological and metallurgical skills. Specialists must master complex sorting, grading, and cutting technologies, geological assessment techniques, and precision stone evaluation methodologies. Experts need comprehensive knowledge of diamond valuation, focusing on high-value jewellery and industrial applications.

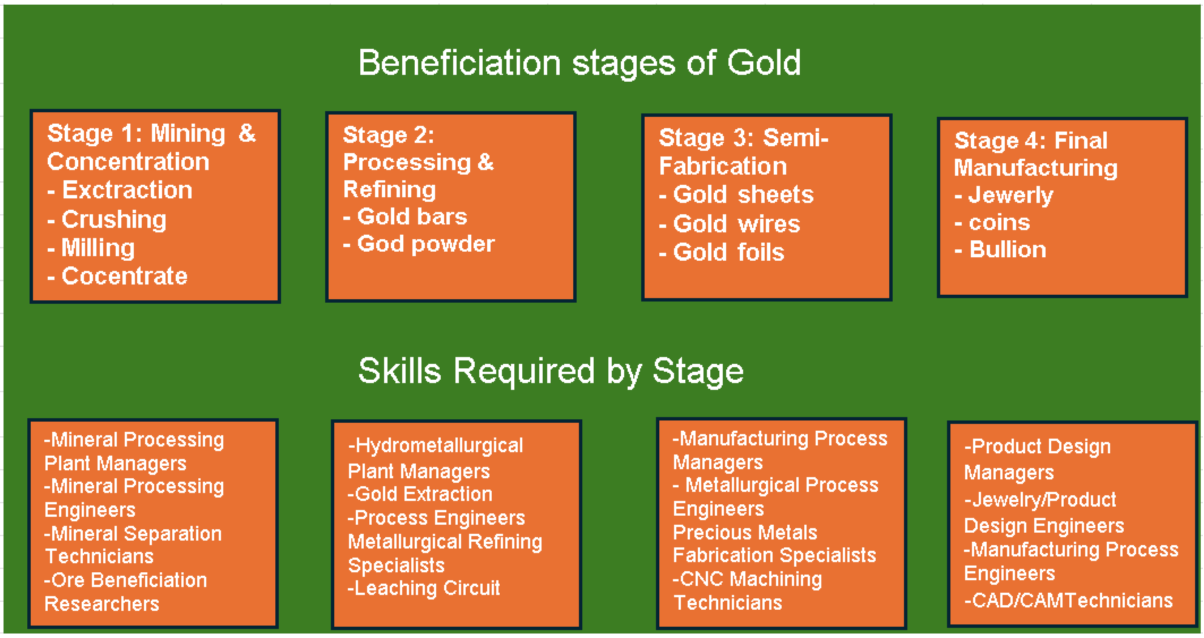


Figure 48: Required critical skills/occupations in the beneficiation of gold

Gold mining requires precise underground and open-cast extraction methodologies. Professionals need expertise in selective mining techniques, advanced drilling technologies, and complex geological targeting. Gold processing requires advanced metallurgical and chemical engineering skills. Knowledge of complex gold refining technologies, chemical separation techniques, and precision metallurgical processes is required. Chemical engineers need comprehensive knowledge of gold extraction, focusing on high-value jewellery, technological, and financial applications.

6. TRAINING FOR BENEFICIATION SKILLS IN SOUTH AFRICA

6.1. Introduction

This analysis explores the state of training and skills development in South Africa's mineral beneficiation sector, highlighting its alignment with the country's economic goals. It explores the training programmes available at various levels, emphasising their focus on foundational processes such as crushing, milling, and flotation, as well as advanced stages like final manufacturing. The analysis examines the inclusivity of entry requirements, the diversity of target audiences, and the gaps in coverage for advanced processing techniques and emerging commodities. By addressing skills shortages and identifying underrepresented areas, this work provides a comprehensive overview of the current state of beneficiation training and its potential for growth, offering insights into opportunities for improving workforce development and industry competitiveness. To this end, beneficiation related courses and/or training programmes were identified considering all public universities in South Africa, TVETs and as well as other MQA accredited training providers. Table 22 and Table 23 show data collected for universities & TVETs and MQA accredited training providers, respectively. Detailed results are found in Annexures A and Annexure B, for universities & TVETs and MQA accredited training providers, respectively.

Table 22: Information collected for Universities and TVETs

Name of Institution	Programmes offered	Type of training	Level	Details (Duration, entry requirements, costs etc)
University of Cape Town	BSc Chemical Engineering	Degree	NQF level 8	4 years, full time, >=500 Faculty Point Score (FPS) with Level 7 in Maths, and level 6 Physical sciences

University of Johannesburg	Jewellery design and manufacture	Diploma	NQF level 6	3 years, full time, APS of 20 with maths or 21 Maths lit or 22 Tech Maths and with Level 3 in Maths, 4 in Maths lit, 5 in Tech Maths, and 5 in English.
	BEngTech in Chemical Engineering	Degree	NQF level 7	3 years, full time, APS 30 with Level 5 in Maths, 4 in English, and 5 in Physical sciences.
	BEngTech in Extraction Metallurgy	Degree	NQF level 7	3 years, full time, APS 30 with Level 5 in Maths, 4 in English, and 5 in Physical sciences.
	BEngTech in Physical Metallurgy	Degree	NQF level 7	3 years, full time, APS 30 with Level 5 in Maths, 4 in English, and 5 in Physical sciences.

Table 23: Information collected for MQA accredited training providers

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Mining and Mineral Training Institute (MMTI)	Mineral Processing	Training in mineral processing operations	Practical	NQF level 2, 3, and 4	Duration of 16 weeks for individuals working in mining and minerals.
Colliery Training College (CTC)	Mineral Processing	Basic mineral processing techniques	Classroom, on the job, and specialised training	NQF level 2	Requires grade 10 with maths and literacy. Duration of 7 weeks and it aims at training plant operators.
Prisma Training Solutions	National Certificate in Mineral Processing	Crushing, thickening of slurry, handling of chemicals, dense medium separation,	Classroom and practicals	NQF level 2, 3, and 4	Duration of 12 months for individuals working in

		electrowinning, and flotation.			mining and minerals.
Diamond Education College	National Certificate: Diamond Processing	Rough diamond evaluation, marking, Polishing and cutting.		NQF level 3	Rough diamond evaluation; 2 weeks. Rough diamond Marking: 2 weeks. Polishing and cutting: 6 months

6.2. Skills coverage for different beneficiation stages at tertiary institutions

In South Africa, the mining and minerals industry is vital for the economy, and improving skills throughout the value chain is necessary to boost productivity and competitiveness. This section evaluates the skills training provided at different stages in the value chain, highlighting strengths and identifying areas requiring attention.

Mining and Concentration

South Africa has a strong mining industry that specializes in extracting and processing natural resources like platinum, gold, iron ore, and diamonds, due to its abundant reserves. Mining engineers and geologists are available in large quantities, as such, the strength of the country's workforce in this sector is robust at this stage. However, most mining engineers are going to other countries and technical services such as mineral beneficiation lacks engineers with relevant skills (Musingwini et al., 2013).

Metallurgy and Refining

South Africa has built smelting and refining facilities for PGMs, gold, and iron ore, and has many institutions offering programmes in chemical and metallurgical engineering. However, obstacles remain in expanding and enhancing refining procedures for minerals such as manganese, uranium, thorium, vanadium, and diamonds. The country has yet to advance in the downstream processing of these commodities, particularly chromium, which limits its ability to compete in the global market (Bhengu, 2016). Therefore, there is a need to invest in advanced training in smelting and refining techniques to process a wider range of minerals and comply with international quality regulations. Additionally, the country needs to invest in training process technicians. Figure 49 shows beneficiation related programmes offered by universities and TVETs. From these institutions, 32 programmes were identified from which chemical engineering emerges as the commonly offered programme with 56%.

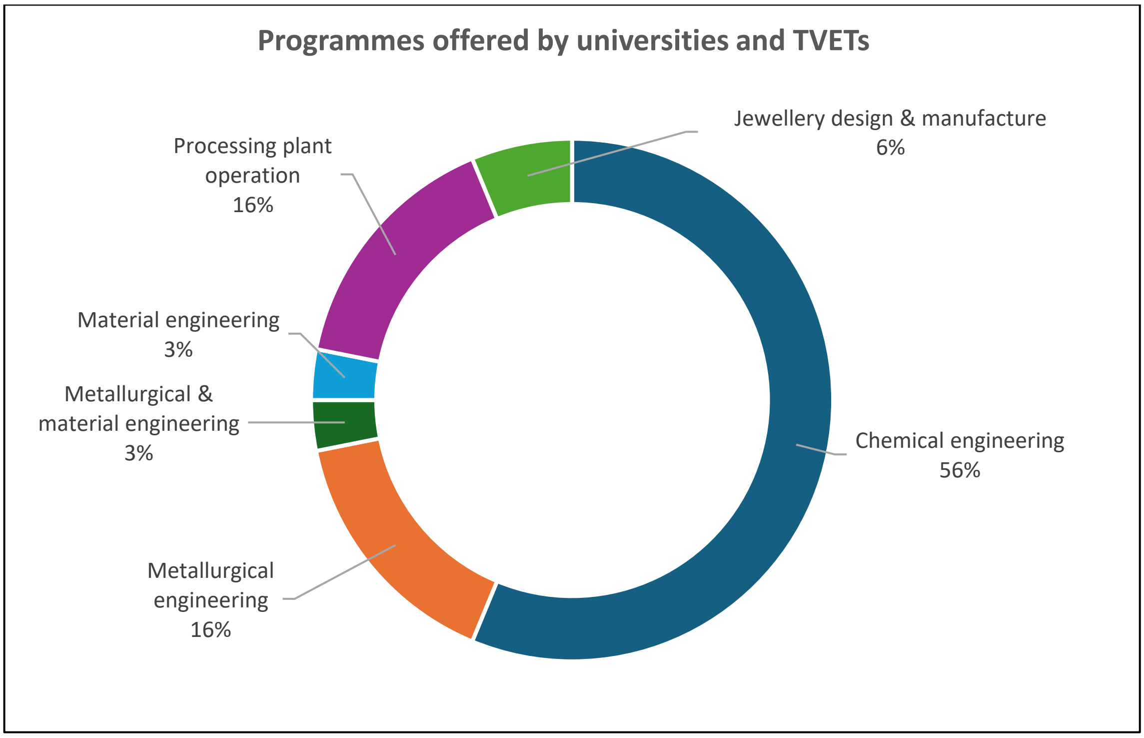


Figure 49: Programmes offered by universities and TVETs

As of August 2022, there were 181 accredited training providers, about 43% of these (78 training providers) were identified to be offering beneficiation related training. From the 78 training providers, 142 beneficiation related programmes were identified. Figure 50 shows programmes offered by MQA accredited training providers. The trend emerging from MQA accredited programmes is like that of universities and TVETs with mineral processing constituting about 45% of the programmes identified. Jewellery manufacturing coincides with final stage of beneficiation as per MPRDAA definition but only constitutes about 14% of the programmes identified. Training programmes predominantly emphasise crushing, milling, and flotation processes which form part of Stage 1, reflecting their critical roles in mineral processing. Skills related to thickening of slurry, solvent extraction, dense medium separation, and water reticulation form part of Stage 2. There is a relatively fair emphasis on diamond cutting and polishing, electrowinning, gold elution, and jewellery manufacturing which form part of Stage 3 and 4. This reflects efforts to add value to raw materials through advanced beneficiation and crafting.

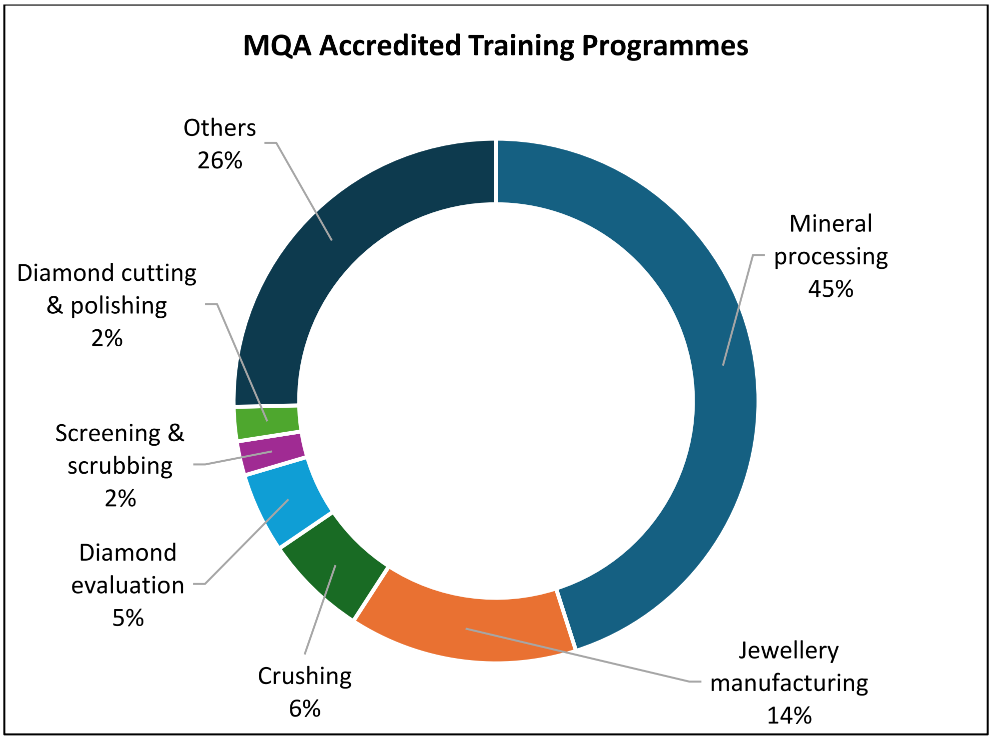


Figure 50: MQA accredited training programmes

Semi-Fabrication

Semi-fabrication skills are present, but they are not as prevalent as in mining and metallurgy. South Africa's downstream metal fabrication is not internationally competitive (Jourdan, 1996). There is a need for improvement in casting and rolling processes for high-tech applications, such as advanced machinery or electronics. There is a need to improve skills in advanced industrial engineering and machinery to enhance semi-fabrication results.

Final Manufacturing

The country is less dominant in this stage, with restricted capability to manufacture valuable final products from its minerals, like jewellery, nuclear power, and electronics. Creating manufacturing capacity by investing in advanced technology, enhancing skills in design and assembly, and supporting industries that transform partially finished goods into end products like the small jewellery manufactures in the country. There have been efforts to grow the downstream at the Special Economic Zones (SEZs) such as OR Tambo but the country lacks a strong base in downstream industries like high-tech manufacturing and finished goods production (Williams et al., 2014). The country needs to invest more into specialised training institutions and companies that train professionals in semi-fabrication, assembly technicians, advanced manufacturing, and product design. This could involve partnerships with global experts.

6.3. NQF Levels of training programmes

The training programmes range widely in their NQF levels, providing pathways for diverse skill sets as follow. Figure 51 shows the different types of training offered by universities and TVETs as well as the NQF levels of the programme offered.

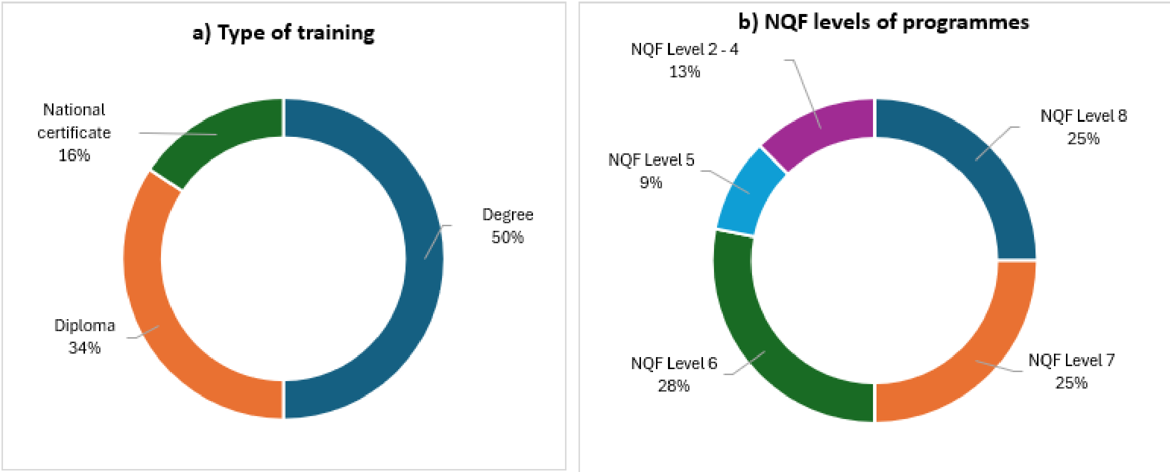


Figure 51: Programmes offered by universities and TVETS a) type of training and b) NQF levels

NQF Levels 1-4: Most training programmes target foundational (Level 2), intermediate (Level 3), and advanced certificates (Level 4) in mineral processing and related skills. There is also focus on foundational and intermediate technical skills (e.g., National Certificates in Mineral Processing at levels 2, 3, and 4) which are predominantly practical and on-the-job training for operators and technicians.

NQF Levels 5-7: Encompass diplomas and advanced technical qualifications (e.g., Chemical Process Technology and Metallurgical Engineering at NQF level 6) which blend theoretical learning with industry-relevant applications.

NQF Level 8: Undergraduate degrees in chemical; metallurgical and material engineering, ensuring competency in core processing and/or refining concepts as well technical innovation. These degrees are found at institutions like University of Johannesburg, Wits University, University of Cape Town, and Stellenbosch University and they are accredited by the Engineering Council of South Africa. This means that engineering curricula offered by these institutions develop graduate attributes or outcomes as outlined by the Engineering Council of South Africa.

6.4. Commodities Focus

The training programmes cater to various mineral and material sectors:

- Base Metals & PGMs: Emphasis on beneficiation processes for platinum, chrome, and copper (e.g., Samancor Western Chrome and Palabora Copper). Programmes include metallurgical operations and lump ore processing.
- Diamonds: Significant focus on cutting, polishing, and evaluation catering to both, primary beneficiation and high-value end-products like jewellery. Several institutions, such as the De Beers Enterprise Development Project and African Minerals College, offer specialised training in diamond processing, including cutting, polishing, and evaluation.
- Precious Metals & Gold: Programmes on refining, fire assay techniques, and sample preparation target high-precision beneficiation. Programmes at Anglo American Platinum and Bafokeng Rasimone Platinum Mine emphasise refining and processing of precious metals, particularly platinum.
- Coal: Programmes on Coal preparation which is offered by Colliery Training College (CTC).
- General Mineral Processing: Institutions like the Mining and Mineral Training Institute (MMTI) and Prisma Training Solutions provide broad mineral processing training covering various techniques applicable to multiple commodities.

While diamonds and precious metals dominate the training offerings, there is less focus on commodities, particularly steel-making commodities such as iron ore. The country exports semi-processed iron ore due to limited access to raw material for local downstream beneficiation and a shortage of skills (Radinku, 2018). Some of the commodities may be covered in beneficiation of other primary commodities, since they are not primary commodities but come as by products. An example is Uranium and Base metals which are by products of Gold and PGMs.

In summary, prominent training emerges in gold, coal, platinum group metals (PGMs), diamonds, and base metals. Training programmes on flotation, electrowinning, and refining highlight the focus on these commodities. However, some commodities such as manganese, base metals, titanium, vanadium, thorium and other emerging commodities like rare earth elements, are not well-represented in current curricula. The limited focus on these commodities may indicate gaps in preparing for global demands in green energy and technology-driven markets.

6.5. Overall coverage of Training Programmes

Training programmes in the mineral processing field emphasise foundational skills, particularly in crushing and milling, which are critical for initial beneficiation stages. These skills dominate both institutional and on-the-job training, with examples like Anglo Platinum’s crushing and milling modules and MMTI's mineral processing courses. Specialised programmes, such as those by Anglo American, also incorporate practical applications.

Crushing: Crushing is a highly emphasised entry-level skill across various institutions, forming the cornerstone of mineral processing training. Advanced techniques like flotation, thickening, and water reticulation are included but not in as many training institutions as crushing. The inclusion of crushing in most programmes attests to the fact that crushing is a common process in value chains of different minerals. In contrast, advanced processing skills, such as hydrometallurgy, Alloying, refining and smelting processes, are underrepresented.

Diamond Processing and Jewellery Manufacturing: Diamond processing and jewellery manufacturing are extensively covered, preparing individuals for artisanal and industrial roles. Programmes by organizations like De Beers and Kimberley International Academy cater to small-scale entrepreneurs and historically disadvantaged groups, emphasising beneficiation linked to socio-economic upliftment.

The training spectrum of programmes identified leans toward entry-level operations, with fewer programmes addressing advanced technologies or sustainability practices. This observation is in line with the study’ focus on beneficiation related programmes which emerge to be deficient on advanced technologies or sustainability practices. However, the MMS is multidisciplinary in nature, as such, some cross-cutting skills maybe adequately covered in other training programmes. Programmes are structured to meet industry needs, emphasising practical, on-the-job training complemented by theoretical foundations.

Targeted Interventions: Institutions focus on economic empowerment through accessibility and diversity, enabling broader participation in the mining value chain. This alignment ensures that both foundational and advanced skills are developed, fostering a well-equipped workforce for the mining and beneficiation industry.

Diversity in Entry Requirements: Entry requirements for mining-related training programmes vary widely, reflecting inclusivity and catering to a diverse audience (i.e. different entry requirements) as summarised below.

Foundational Levels (NQF 1-4): These programmes typically have minimal entry requirements, such as a Grade 9 education with basic mathematics and science, making them accessible to individuals transitioning into the mining sector. Vocational training institutions, like South West Gauteng TVET College and MMTI, also accept lower academic thresholds, such as AET Level 4, expanding opportunities for learners with limited formal education.

Intermediate and Advanced Levels (NQF 5-8): Diploma and degree programmes at institutions like Wits, UP, and TUT require higher APS scores and specific subjects, such as mathematics and physical sciences, at NSC level. These prerequisites target academically strong candidates aiming for supervisory or specialist roles.

Diversity in entry requirement: Programmes like the De Beers Enterprise Development focus on historically disadvantaged South Africans (HDSA), offering training in diamond cutting, jewellery manufacturing, and enterprise development to promote socio-economic upliftment. Institutions like MPTech at UCT provide professional short courses for career advancement. This range of entry requirements ensures inclusivity while maintaining pathways for both entry-level participants and those pursuing specialized or advanced roles.

7. SUMMARY OF FINDINGS

The study has several objectives which can be summarised using different keywords namely, policy, value chains, key beneficiation skills, training providers & programmes, international lessons. The study relied on information available from the public domain. Some information such as the exact number of employees as well as skills at companies partaking in beneficiation could not be obtained from secondary sources. Thus, one objective, "*the assessment of the economic impact of current beneficiation efforts, including job creation, value addition, and export diversification*" was not met. Table 24 summarises the key observations and/or findings of this study.

Table 24: Summary of findings

Study Objective (Focus Area)	**Finding**
Policy	At the national level, key frameworks include the Beneficiation Strategy for Minerals Industry, which focuses on developing value chains, the Mineral Petroleum Resources Development Act (MPRDA) that provides a legal framework for mineral beneficiation, and the Re-imagined Industrial Strategy that leverages the country's mineral wealth to build a dynamic industrial economy.
	The Beneficiation Strategy identifies specific value chains for development, including energy commodities, iron and steel, pigment and titanium metal production, autocatalytic converters and diesel particulate filters, and jewellery fabrication.
	The Mining Charter promotes sustainable development and transformation in the mining industry, with specific projects aimed at adding value before export, such as in the iron and steel, and polymer value chains. Industrial Development Zones (IDZs) also play a crucial role by

	providing infrastructure and incentives for businesses to invest in value addition activities.
	These combined efforts aim to maximize economic benefits, create jobs, and promote sustainable development.
Value chains	MPRDAA defines beneficiation in four stages namely, primary – producing a concentrate e.g. uranium yellow cake; secondary – converting a concentrate into an intermediate product e.g. refined uranium oxide; tertiary - semi-fabrication: converting an intermediate product into semi-finished products e.g. uranium fuel pellets; and final – final manufacturing of finished products e.g. nuclear fuel rods. Most of the minerals prioritised by the Beneficiation Strategy are obtained from primary production except uranium and nickel which are byproducts of gold/copper and PGM mining, respectively.
Key beneficiation skills	**Categorised as follows:** **Primary & secondary**: Metallurgical engineering, chemical engineering, process control, material science, equipment operation, service & maintenance and laboratory analysis **Tertiary & final**: Industrial engineering, tool making, product design and some specialised ones such as battery chemistry for vanadium **Cross-cutting**: regulatory compliance; environmental management; expertise in safety protocols; project management; quality control; logistics and supply chain management; and expertise in innovative technologies.

Table 25: Summary of findings continues

Study Objective (Focus Area)	Finding
Training providers & programmes	**Universities & TVETs:** Chemical, metallurgical and material engineering; on-the job processing plant operation; and jewellery design & manufacture constitute 78%, 16% and 6%, respectively. Most programmes identified (78%) are at NQF levels 6 – 8. **MQA Accredited Providers:** Mineral processing is commonly offered among the beneficiation related courses identified. Most programmes are at stages 1 and 2 as per definition of beneficiation by the MPRDAA.
International practices	Key lessons emerging include strong public-private partnerships, institutions and policy framework, sustainable practices and focus on skills development. Additionally, beneficiation enablers include digitalisation and innovation, global need to prioritise environmental, social, and corporate governance (ESG) issues and skills thereof.

8. CONCLUSION AND RECOMMENDATIONS

8.1. Conclusion

South Africa is endowed with a variety of minerals including coal, manganese, platinum group metals & chrome and the contribution of the MMS to the economy is significant but fluctuates year on year. The country has a long history of participating in extracting these minerals using several activities and/or processes which can be mapped along a value chain. While different commodities have varying value chains, four beneficiation stages are identified namely, stage 1: mining & concentration; stage 2: metallurgy & refining; stage 3: semi – fabrication and stage 4: final manufacturing. South Africa has been partaking in stages 1 and 2 for decades but shows limited participation in stages 3 and 4.

The government's commitment to beneficiation is evident in its strategic approach, which aims to dramatically increase the mining sector's contribution to GDP. Policies are designed to move beyond traditional raw material exportation, encouraging local processing and manufacturing that can generate significantly more economic value. This approach represents a fundamental shift from a resource extraction model to a more advanced value-creation strategy that leverages South Africa's rich mineral endowments. Among others, beneficiation related policies include The Mineral and Petroleum Resources Development Act of 2002, the National Development Plan Vision 2030, and the Beneficiation Strategy of the Department of Mineral Resources and Energy. Common objectives among these legislative instruments include but not limited to increasing local value addition, creating downstream employment opportunities, developing technological capabilities, and promoting economic transformation. Among other enablers emerging from the international case studies is a robust and functional policy foundation, thus, South Africa seems to have the necessary policy.

The national beneficiation strategy prioritizes specific minerals with high potential for value addition. Platinum Group Metals (PGMs), gold, diamonds, titanium, chromium, manganese, vanadium, and nickel have been identified as strategic commodities for focused development. Additionally, the beneficiation strategy has identified energy minerals namely, coal, uranium and thorium for beneficiation. Each of these minerals presents unique opportunities for advanced processing and manufacturing, potentially creating complex networks that extend far beyond traditional mining activities. South Africa has evidence of participation in full value chain for some of the prioritised minerals. This is evident in the generation of electricity from coal, manufacturing of autocatalytic converters from PGMs, and fabrication of jewelleries from gold.

From the value chains mapped, it is evident that there are some common activities and/or processes along different value chains as well as equipment enabling skills transfer between commodities. There is adequate participation in stage 1 and stage 2 for all prioritised minerals. However, semi-fabrication and final manufacturing efforts vary from commodity to commodity. For example, while PGMs and gold demonstrate relatively successful beneficiation, titanium remains predominantly focused on raw material export, indicating substantial untapped potential for value addition.

The beneficiation of South Africa's prioritised minerals requires multidisciplinary set of skills at different OFO categories, but some skills are common between different stages of beneficiation and/or minerals. For example, professionals in the PGM subsector should demonstrate advanced metallurgical engineering skills encompassing catalyst manufacturing, precision chemical processing, nanotechnology applications, and sustainable chemical engineering approaches. These competencies enable the transformation of raw PGMs into high-value technological components, medical devices, and sophisticated industrial catalysts. Similarly, gold beneficiation requires complex materials engineering capabilities, including nano-gold technology development, electronic materials processing, and precision manufacturing techniques that extend beyond traditional refining methodologies.

Titanium beneficiation skills necessitate advanced materials engineering expertise, focusing on aerospace materials development, medical implant manufacturing, and specialised alloy production, which require intricate understanding of high-temperature processing, chemical reduction technologies, and sustainable manufacturing approaches. Chromium value addition demands profound metallurgical engineering skills, particularly in ferrochrome production, stainless steel manufacturing, and advanced alloy development, with a critical emphasis on corrosion-resistant materials design and complex separation techniques. Key skills emerging for stages 2 and 3 include metallurgical engineering, chemical engineering, process control, material science, equipment operation, service & maintenance and laboratory analysis. Required skills for final manufacturing include industrial engineering, tool making, product design and some specialised ones such as battery chemistry for vanadium.

There are several public institutions and accredited training providers currently providing vast range of training along the mining value chain. Most programmes identified predominantly focus on entry-level skills such as crushing, milling, and flotation, which are critical for early beneficiation processes. However, the training landscape supports multiple stages of the mineral value chain, with representation in basic beneficiation and final product manufacturing. Despite a strong emphasis on practical, on-the-job training for operators and technicians, gaps remain in addressing the beneficiation of emerging commodities like rare earth elements and titanium. Accessibility to training is diverse, with vocational institutions accommodating learners with lower OFO skills levels such as grade 9, while universities input target is mainly matriculants. However, the lack of focus on emerging commodities and advanced technologies presents challenges in adapting to global demands.

8.2. Recommendations

This section provides some recommendations which are specific, measurable, achievable, relevant and time bound. Table 25 summarises the key recommendations, key activities required, potential stakeholders and envisaged timelines.

Table 25: Summary of recommendations

No.	Research recommendations	Research proposed activities/tasks	Key stakeholders and responsibilities	Timelines
1	**Create an inventory of mineral specific products for each stage of beneficiation**	• Create live inventory digital application from further research using an MSc student. • Gather comprehensive data on mineral reserves, production volumes, and beneficiation processes for various minerals. • Engage mining companies, government agencies, and entities like MINTEK to obtain accurate and up-to-date information. • Use a systematic approach, advanced technologies and/or	• MQA to lead in terms of making funds available. • Wits University to identify and supervise an MSc student. • MSc student to conduct the research. • Mining and/or beneficiation companies to provide input data • MQA to ensure regular update of the inventory.	2 years Year 1: Identification of an MSc student and compilation of a draft proposal as well as literature review. Year 2: Data collection, compilation of the research report and development of an inventory.

No.	Research recommendations	Research proposed activities/tasks	Key stakeholders and responsibilities	Timelines
		data analytics to ensure reliability and validity of data. • Continuously update the inventory (i.e. digital application) to reflect changes in production, new discoveries, and advancements in beneficiation techniques.		
2	**Evaluate beneficiation related skills using multiple criteria decision-making techniques**	• Assessing various competencies and attributes necessary for effective mineral beneficiation which will aid in identification of best skills and best suited training programmes.	• MQA to lead in terms of making funds available. • Wits University to identify and supervise an MSc student. • MSc student to conduct the research.	2 years Year 1: Identification of an MSc student and compilation of a draft proposal as well as literature review.

No.	Research recommendations	Research proposed activities/tasks	Key stakeholders and responsibilities	Timelines
		• Engage mining companies, government agencies, and entities like MINTEK, CSIR to obtain accurate and up-to-date primary and secondary data.	• Mining and/or beneficiation companies/entities to provide input data.	Year 2: Data collection, compilation of the research report.
3	**Establishing a National Beneficiation Skills Implementation Task Force**	• Develop practical mechanisms for beneficiation skills planning in South Africa, ensuring alignment between industry needs and training programmes • Collaborate with mining companies, industry associations, and employers to identify current and future skill requirements.	• Wits University will create a database of beneficiation skill training service providers in South Africa. • Wits University will organise a workshop where skill training providers, relevant SETAs, and economists and/or statisticians come together to discuss impediments to widespread beneficiation in South Africa. The major workshop outcomes will be:	• Two students will collect data and develop a database in 6 months. MQA to provide funding. • The workshop arranged and Implementation Task Forces will be established 4 months after the database is

No.	Research recommendations	Research proposed activities/tasks	Key stakeholders and responsibilities	Timelines
		• Continuously study market trends, technological advancements, and industry forecasts to anticipate skill needs. • Determine the existing skill gaps and areas where training programmes need to be enhanced or developed. • Work with universities, technical and vocational education and training (TVET) colleges, and other educational institutions to develop relevant courses. • Regularly review and update training programmes to ensure	– to development a national beneficiation implementation framework; and – establish national and regional beneficiation implementation task forces. • Develop a framework to update the database of beneficiation skill training service providers in South Africa at least annually. • MQA to update the database periodically.	completed. MQA to provide funding. • Annual update of the database

No.	Research recommendations	Research proposed activities/tasks	Key stakeholders and responsibilities	Timelines
		they remain relevant and effective in meeting industry standards. • Implement monitoring and evaluation mechanisms.		

No.	Research recommendations	Research proposed activities/tasks	Key stakeholders and responsibilities	Timelines
4	**Establish capacity of existing local beneficiation facilities**	• Evaluate the current state of local beneficiation facilities (i.e. equipment, processes, technology and infrastructure) • Engage personnel at these facilities to identify exact skills utilised by entities.	• Wits University will draft the database of local beneficiation facilities. • Wits University will lead the investigation (i.e. outlined activities). • Entities partaking in beneficiation need to participate in the study.	1 year but the database should be updated at least once a year.

No.	Research recommendations	Research proposed activities/tasks	Key stakeholders and responsibilities	Timelines
		• Determine any limitations or inefficiencies in the current setup that may hinder optimal performance.	• MQA to assist in encouraging participation where required to ensure comprehensive participation. • MQA also to review the database as well as the report.	
5	**Establish a Beneficiation Skills Academy focused on identified value chains and/or strengthen existing training programmes**	• Engage MerSETA and other relevant stakeholders • Source funds for the Beneficiation Skills Academy as well as the technology and innovation acceleration programme • Reinforce current beneficiation skills programmes and establish new beneficiation skills programmes	• MQA to lead and facilitate discussion with relevant stakeholders. • Wits University will use the database in Action Plan 3 above as basis to kick starting a Beneficiation Skills Academy in conjunction with relevant SETAs and a suitable SEZ Authority.	New academy to be operational 3 to 5 years from the implementation of Action Plan 3.

No.	Research recommendations	Research proposed activities/tasks	Key stakeholders and responsibilities	Timelines
6	**Develop comprehensive beneficiation skills mapping framework & database based on primary data collection**	• Collaborate with mining companies, industry associations, educational institutions, and government agencies to gather insights and support for the skills mapping project. • Database design and reporting system creating a dynamic match between processes and skills.	Wits University and/or other institutions of higher learning will develop a beneficiation skills mapping framework using strategic or critical minerals in South Africa to serve as the basis of mapping critical and important mineral beneficial mineral in South Africa	6 – 12 months

REFERENCES

Africa Nickel Developments: Opportunities and risks for participation in the Battery Revolution (no date) *Fitch Solutions*. Available at: https://www.fitchsolutions.com/bmi/commodities/africa-nickel-developments-opportunities-and-risks-participation-battery-revolution-12-04-2021 [Accessed: 18 November 2024].

Africa Union Commission and OECD (2024). Skills for mining in Southern Africa. Chapter 3 in Africa's development dynamics 2024: Skills, jobs and productivity.

African Export-Import Bank (2024). *Platinum Group Metals (PGMs) - Analyzing Recent Price Trends*. Available at: Platinum Group Metals (PGMs): Analyzing Recent Price Trends - African Export-Import Bank [Accessed: 27 November 2024].

African Union. (2009). African Mining Vision. African Union and Economic Commission of Africa, Addis Ababa.

Ancheta, A. (2023). How Do Factor Endowments Impact a Country's Comparative Advantage? Available: https://www.investopedia.com/ask/answers/041615/how-do-factor-endowments-impact-countrys-comparative-advantage.asp. [Accessed: 18 October 2024].

Anglo American. (2017). Transformation Performance Report 2017. Building on Firm Foundations Delivering a Sustainable Future.

Ault, T., Gosen, B.V., Krahn, S. and Croff, A. (2016). Natural thorium resources and recovery: options and impacts. *Nuclear Technology*, *194*(2), pp.136-151.

Australian Steel Institute. (2024). The Australian Steel Industry - our future depends on it. Available at: https://www.steel.org.au/about-us/our-industry/ [Accessed on 19 October 2024]

Baawuah, E., Kelsey, C., Addai-Mensah, J. and Skinner, W., (2020). Economic and socio-environmental benefits of dry beneficiation of magnetite ores. *Minerals*, *10*(11), p.955.

Bakwena, M., (2023). Diamond Beneficiation and Economic Diversification in Botswana. *Economic Diversification in Africa: Lessons from Botswana*, p.115.

Barros, K.S., Vielmo, V.S., Moreno, B.G., Riveros, G., Cifuentes, G. and Bernardes, A.M., (2022). Chemical composition data of the main stages of copper production from sulfide minerals in Chile: a review to assist circular economy studies. *Minerals*, *12*(2), p.250.

Bastida, A.E. (2014). From extractive to transformative industries: paths for linkages and diversification for resource-driven development. Mineral Economics. Vol. 27, pp. 73–87 https://doi.org/10.1007/s13563-014-0062-8.

Baxter, R. (2019). Mining in SA today: What's happening economically and how is this impacting the mining industry? Joburg Indaba - October 2019

Bester, M., Russell, T., van Heerden, J. and Carey, R., 2016. Reconciliation of the mining value chain-mine to design as a critical enabler for optimal and safe extraction of the mineral reserve. *Journal of the Southern African Institute of Mining and Metallurgy*, *116*(5), pp.407-411.

Bhengu, N. (2016). *How can South Africa, a resource rich and labour-abundant economy, employ upstream and downstream mineral beneficiation as a way of developing its economy further? A critical focus on the chromium mineral value chain as a case study* (Doctoral dissertation).

Bushveld Minerals. (n.d.). *Home - Bushveld Minerals*. Retrieved November 18, 2024, from Bushveld Minerals | Vanadium Products

Bykhovskii, L.Z. and Tigunov, L.P. (2011). Titanium raw materials of Russia. *Russian Journal of General Chemistry*, *81*(6), pp.1328-1344.

Cheng, S., Li, W., Han, Y., Sun, Y., Gao, P. and Zhang, X. (2024). Recent process developments in beneficiation and metallurgy of rare earths: A review. *Journal of rare earths*, *42*(4), pp.629-642.

Coetzee, R., (2023). Factors enabling copper beneficiation in Botswana. A thesis submitted to the University of the Witwatersrand, Johannesburg.

Committee on Uranium Mining in Virginia. (2011). *Uranium mining, processing, and reclamation*, *Uranium Mining in Virginia: Scientific, Technical, Environmental, Human Health and Safety, and Regulatory Aspects of Uranium Mining and Processing in Virginia.* Available at: https://www.ncbi.nlm.nih.gov/books/NBK201050/ [Accessed: 19 November 2024].

Cornish, L. (2021). De Beers drives true diamond beneficiation transformation. *Mining Review Africa*, 4. Available at: https://www.miningreview.com/diamonds-gemstones/de-beers-drives-true-diamond-beneficiation-transformation-2/ [Accessed 18 Nov. 2024].

Cramer, L.A. (2008) What is your PGM concentrate worth. In *Third International Platinum Conference 'Platinum in Transformation* (pp. 387-394).

De Beers. (2023). Overview of Diamond Mining and Beneficiation in South Africa.

De Bruyne, K., Bam, W. and Engelbrecht, D. (2023). South Africa's titanium industrial policy: A product space perspective. *South African Journal of Economics*, *91*(1), pp.3-27.

De Korte, G.J. (2015). Processing low-grade coal to produce high-grade products. *Journal of the Southern African Institute of Mining and Metallurgy*, *115*(7), pp.569-572.

Denhere, R. (2021). Evaluation of beneficiation constraints for identified critical minerals in Zimbabwe (Doctoral dissertation).

Denton (2024). Dentons Global Mining Guide 2022. Available at: https://www.dentons.com/en/insights/newsletters/2022/january/17/dentons-global-mining-guide/dentons-global-mining-guide-2022 [Accessed on 18 October 2024]

Department of Higher Education and Training. (2019). Skills Development Act, 1998 (Act No. 97 of 1998): Promulgation of the National Skills Development Plan (NSDP), Republic of South Africa.

Department of Mineral Resources and Energy. (2011). A Beneficiation Strategy for the Minerals Industry of South Africa. Department: Mineral Resources. Republic of South Africa. June 2011.

Department of Mineral Resources and Energy. (2021). *South Africa's Mineral Industry*.

Department of Mineral Resources. (2008). An overview of South Africa's titanium mineral concentrate industry. Report R71/2008, Directorate: Mineral Economics, Republic of South Africa.

Department of Mineral Resources. (2008). *An overview of South Africa's vanadium industry during the period 1997 - 2006*. Directorate: Mineral Economics Report R55/2008.

Department of Mineral Resources. (2011). Beneficiation Strategy for the Minerals Industry of South Africa. Department: Mineral Resources. Republic of South Africa. June 2011.

Department of Mineral Resources. (2014). An overview of South Africa's diamond industry, 2000-2012, Report R107/2014, Directorate: Mineral Economics, Republic of South Africa.

Department of Mineral Resources. (2018). Mining Charter, 2018: Broad-Based Socio-Economic Empowerment Charter for the Mining and Minerals Industry. Government Gazette No. 41934, Volume 1002. 27 September. The Republic of South Africa.

Department of Minerals and Energy (2009). Mineral and Petroleum Resources Development Amendment Act, 2008 (Act No. 49 of 2008). Government Gazette No. 32151, Volume 526, 21 April. The Republic of South Africa.

Department of Minerals and Energy. (1998). White Paper A Minerals and Mining Policy for South Africa. Department: Mineral Resources and Energy. Republic of South Africa. October.

Department of Science and Innovation. (2024). Carbon capture and utilisation technology a game-changer for high-emission industries. Available: https://www.dst.gov.za/index.php/media-room/latest-news/4214-carbon-capture-and-utilisation-technology-a-game-changer-for-high-emission-industries#:~:text=The%20CCU%20technology%20supports%20South,for%20affected%20communities%20and%20workers. [Accessed: 15 October 2024].

Department of Trade and Industry. (2016). Industrial Policy Action Plan, IPAP 2016/17 – 2018/19 Economic Sectors, Employment and Infrastructure Development Cluster.

Department of Trade and Industry. (2018). Industrial Policy Action Plan 2018/19 – 2020/2021, Economic Sectors, Employment and Infrastructure Development Cluster.

Department of Trade, Industry and Competition (the DTIC). (2023). A Guide to the DTI Incentive Schemes 2023/24. Pretoria.

Department of Trade, Industry and Competition. (2020). Mineral Beneficiation. Portfolio Committee on Trade and Industry. 19 June 2020. Available: https://www.thedtic.gov.za/wp-content/uploads/Beneficiation19-June2020.pdf. [Accessed 06 October 2024].

Department of Trade, Industry and Competition. (2020). Mineral Beneficiation. Portfolio Committee on Trade and Industry. 19 June 2020. Available: https://www.thedtic.gov.za/wp-content/uploads/Beneficiation19-June2020.pdf. [Accessed 06 October 2024].

Du Preez, W. (2014). Beneficiation of South Africa's titanium resource. In *Presentation delivered at the Science Councils' Symposium, Central University of Technology* (Vol. 17).

Dutta, B. and Froes, F.S. (2017). The additive manufacturing (AM) of titanium alloys. *Metal powder report*, *72*(2), pp.96-106.

Dworzanowski, M. (2013). The role of metallurgy in enhancing beneficiation in the South African mining industry. *Journal of the Southern African Institute of Mining and Metallurgy*, *113*(9), pp.677-680.

ESI-Africa. (2023). *Where does SA fit into the global coal value chain?* Retrieved from ESI-Africa

Fleming, S. (2022). *Gold Processing Technologies.*

Gandolfo, G. (1986). The Heckscher-Ohlin Model. In: International Economics. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-07976-8_4.

Gassen, K.R. (2013). *The interface between mining and manufacturing: Chrome value chain - processing and beneficiation beyond mining*. Presented at Sandton, South Africa, 22 August.

Gawanab, A. C. (2010). The need for the beneficiation of Namibian exports and its impact on economic performance. MBA Dissertation, University of Stellenbosch, Cape Town. Retrieved July 21, 2014, from http://scholar.sun.ac.za/handle/10019.1/8582

Gemma, R. (2018). Introduction to positivism, interpretivism and critical theory. Nurse Researcher, Vol. 25 (4), pp. 14-20. DOI:10.7748/nr.2018.e1466y.

Geological Survey of Sweden (2020). Swedish mines. Available at: https://www.sgu.se/en/mineral-resources/swedish-mines/ [Accessed on 18 October 2024].

Geoscience Australia. (2020). Australian mineral facts. *Available at: https://www.ga.gov.au/education/minerals-energy/australian-mineral-facts. Accessed on 19 October 2024*

GIA. (2023). Gemology and Diamond Processing.

GlobalData (2023) *Diamond Production in South Africa and Major Projects*. Available at: https://www.mining-technology.com/data-insights/diamond-in-south-africa/ [Accessed 14 Nov. 2024].

GlobalData. (2023). Five largest iron ore mines in South Africa. Available at: https://www.mining-technology.com/data-insights/five-largest-iron-ore-mines-south-africa/

Goclawska, J. A. (2023). The Mineral Industry of Sweden in the United States Geological Survey 2019 Minerals Yearbook.

Government gazette (2018). Broad-Based Socio-Economic Empowerment Charter for the Mining and Minerals Industry, 2018. Government Notices, No. 1002, 27 September 2018.

Grilli, M.L., Slobozeanu, A.E., Larosa, C., Paneva, D., Yakoumis, I. and Cherkezova-Zheleva, Z., (2023). Platinum group metals: Green recovery from spent auto-catalysts and reuse in new catalysts—A review. *Crystals*, *13*(4), p.550.

Grynberg, R. (2013). Diamond Beneficiation in Botswana. ECDPM. Available at: https://ecdpm.org/work/from-growth-to-transformation-what-role-for-the-extractive-sector-volume-2-issue-2-feb-march-2013/diamond-beneficiation-in-botswana [Accessed on 17 October 2024].

Hayes, A. (2024). What is comparative advantage? Available: https://www.investopedia.com/terms/c/comparativeadvantage.asp#:~:text=Comparative%20advantage%20is%20an%20economy's,individuals%20can%20benefit%20from%20trade. [Accessed 18 October 2024]

Heale, R. and Forbes, D. (2013). Understanding triangulation in research. *Evidence-based nursing*, 16(4), pp.98-98.

Humphreys, D. (2020). Mining productivity and the fourth industrial revolution. *Mineral Economics*, *33*(1), pp.115-125.

International Cyanide Management Code. (2021). *Code for Manufacture, Transport, and Use of Cyanide in the Production of Gold.*

International Trade Administration (2023). Advanced Manufacturing in Sweden - Country Commercial Guide. Available at: https://www.trade.gov/country-commercial-guides/sweden-advanced-manufacturing. [Accessed on 18 October 2024].

Jaganmohan, M. (2024) *South Africa: Iron ore production 2023*, *Statista*. Available at: https://www.statista.com/statistics/1029229/iron-ore-mine-production-in-south-africa/ (Accessed: 13 November 2024).

Jordan, B.W., Eggert, R.G., Dixon, B.W. and Carlsen, B.W. (2015). Thorium: Crustal abundance, joint production, and economic availability. *Resources Policy*, *44*, pp.81-93.

Jourdan, P. (1996). Adding value to South Africa's minerals. *Minerals and Energy*, *12*(1), pp.3-13.

Jyothi, R.K., De Melo, L.G.T.C., Santos, R.M. and Yoon, H.S., (2023). An overview of thorium as a prospective natural resource for future energy. *Frontiers in Energy Research*, *11*, p.1132611.

Kale, A. and Bisaka, K. (2011). Fluid bed chlorination pilot plant at Mintek. *Journal of the Southern African Institute of Mining and Metallurgy*, *111*(3), pp.193-197.

Kemp, D. (2017). *The feasibility of extraction of thorium and rare earths from monazite through a thermal plasma and a chemical treatment process* (Doctoral dissertation, North-West University (South Africa), Potchefstroom Campus).

Kenan, A. and Chirenje, E. (2014). Uranium in South Africa: Exploration, mining and production.

King, I. (2014) *Application of United Nations Framework Classification – 2009 (UNFC-2009) for Uranium Resources: Uranium Ore Processing*. 10 November 2014.

Kumba Iron Ore, Anglo American plc. (2019). Bulks Seminar & Site visit, Brisbane.

Kumba Iron Ore. (2010). Site Visit to Sishen mine.

Leeuw, P. (2012) A Linkage Model for the South African Mineral Sector: A Plausible Option. An MSc Project Report submitted at the University of the Witwatersrand, Johannesburg.

Leeuw, P. (2021) Determination of an Employment Estimator Formula in Upstream Industries due to Mining Technology in South Africa. A doctorate thesis submitted at the University of the Witwatersrand, Johannesburg.

Leiva González, J. and Onederra, I. (2022). Environmental management strategies in the copper mining industry in Chile to address water and energy challenges. *Mining*, *2*(2), pp.197-232.

Lumadi, V.W. and Nyasha, S. (2024). Technology and growth in the South African mining industry: An assessment of critical success factors and challenges. *Journal of the Southern African Institute of Mining and Metallurgy*, 124(4), pp.163-171.

Machinery, J.M. (2024) *Selection of nickel ore beneficiation process & equipment*, *JXSC Machinery*. Available at: https://mineraldressing.com/blog/selection-of-nickel-ore-beneficiation-process-equipment/ (Accessed: 18 November 2024).

Mahlangu, M.M.S. (2022). South Africa's beneficiation strategy and the proposed chrome ore export tax: the relevance towards economic development. Thesis submitted to the University of the Witwatersrand, Johannesburg.

Makgetla, N. and Patel, M. (2021). The coal value chain in South Africa. Trade & Industrial Policy Strategies (TIPS).

Marsden, J. & House, I. (2006). *The Chemistry of Gold Extraction.* SME.

Mbabazi, P. (2018). What can resource-rich African countries learn from the Botswana success story. Policy Brief, 12, p.13.

Mehdilo, A. and Irannajad, M. (2011). Iron Removing from Titanium Slag for Synthetic Rutile. *Physicochemical Problems of Mineral Processing*, *48*(2), pp.441-455.

Mineral Council of South Africa (2024) Minerals Council position on beneficiation of South Africa's minerals. Available at: https://www.mineralscouncil.org.za/component/jdownloads/?task=download.send&id=2305:minerals-council-position-on-beneficiation-of-south-africas-minerals&catid=102&m=0 Accessed on 10 October 2024.

Minerals Council South Africa. (2022). *Facts and Figures*. Retrieved from Minerals Council

Minerals Council South Africa. (2023). Integrated Annual Review 2023.

Minerals Council South Africa. (2023a). Minerals Council South Africa is Dismayed at the Latest Damaging Price Increases for Eskom. Media Statement. 13 January 2023.

Minerals Council South Africa. (2024). Minerals Council Position on Beneficiation of South Africa's Minerals. Media Statement. 24 July 2024.

Mining Qualifications Authority. (2023). Sector Skills Plan Update 2024/25 for the Mining and Minerals Sector Submitted by the Mining Qualification Authority (MQA) to the Department of Higher Education and Training. Final Submission. 31 August 2023.

Mining Qualifications Authority. (2023). Sector Skills Plan Update 2024/25 for the Mining and Minerals Sector Submitted by the Mining Qualification Authority (MQA) to the Department of Higher Education and Training. Final Submission. 31 August 2023.

Mining Technology (2023) *Nickel production in South Africa and major projects*, *Mining Technology*. Available at: https://www.mining-technology.com/data-insights/nickel-in-south-africa/ (Accessed: 18 November 2024).

Mining Technology (2023) *Diamond Mining Market by Reserves and Production*. Available at: https://www.mining-technology.com/data-insights/diamond-in-south-africa/ [Accessed 14 Nov. 2024].

Mining Technology. (2023). Iron ore production in South Africa and major projects. Available at: https://www.mining-technology.com/data-insights/iron-ore-in-south-africa/

Mining Technology. (n.d.). *Steelpoort Drift Vanadium Project, South Africa*. Available at: https://www.mining-technology.com/projects/steelpoortdrift-vanadium-project-south-africa/?cf-view (Accessed: 18 November 2024).

Moller, H. (2022). Developing the South African PGM Industry. *Journal of the Southern African Institute of Mining and Metallurgy*, *122*(4), pp.iv-iv.

Montevirgen, K (2024). Comparative advantage. Economic theory [Online]. Available: https://www.britannica.com/money/comparative-advantage. [Accessed 19 October 2024]

Moodley, N. (2022). *State Diamond Trader drives the beneficiation agenda*. SA Mining. Available at: https://businessmediamags.co.za/mining/sa-mining/state-diamond-trader-drives-the-beneficiation-agenda/ [Accessed 18 Nov. 2024].

Multotec (2021) *Typical high-grade vanadium beneficiation flow sheet*. Available at: https://www.multotec.com/en/typical-high-grade-vanadium-beneficiation-flow-sheet [Accessed: 20 November 2024].

Musingwini, C., Cruise, J.A. and Phillips, H.R. (2013). A perspective on the supply and utilization of mining graduates in the South African context. *Journal of the Southern African Institute of Mining and Metallurgy*, *113*(3), pp.00-00.

Nahman, A., Godfrey, L., Oelofse, S. and Trotter, D. (2021). Driving economic growth in South Africa through a low carbon, sustainable and inclusive circular economy. The Circular Economy as Development Opportunity, p.1.

National Planning Commission. (2012). National Development Plan: Vision 2030. Pretoria.

Ndlovu, J. (2021). *Overview of PGM processing*. Anglo American Platinum. Available at: http://www.angloamericanplatinum.com/~/media/Files/A/Anglo-American-Platinum/investor-presentation/standardbankconference-anglo-american-platinum-processing-111114.pdf [Accessed: 27 November 2024].

Nex, P.A. and Kinnaird, J.A. (2019). Minerals and mining in South Africa. The Geography of South Africa: Contemporary Changes and New Directions, pp.27-35.

Ngewa, G. and Obama, B.N.V.A. (2024). A Survey on Botswana's Principal Resources and Investment Areas: China-Botswana Case Study. In *SHS Web of Conferences* (Vol. 190, p. 03027). EDP Sciences.

Nkoe, M. and Montja, T. (2019). Mineral Beneficiation in Africa: what was missed and what can now be done? Available at: https://mistra.org.za/wp-content/uploads/2019/10/Nkoe-Montja-Mineral-Beneficiation-in-Africa.pdf. [Accessed: 17 October 2024]

O'Malley (1994). The Reconstruction and Development Programme (RDP). Available: https://omalley.nelsonmandela.org/index.php/site/q/03lv02039/04lv02103/05lv02120/06lv02126.htm. [Accessed: 18 October 2024].

Oluyeju, A., & Tshiamo, O. (2018). The Imperatives of Beneficiation Law for Botswana's Diamond-mining. University of Pretoria.

Oosthuizen, S.J. and Swanepoel, J.J. (2018). September. Development status of the CSIR-Ti Process. In *IOP Conference Series: Materials Science and Engineering* (Vol. 430, No. 1, p. 012008). IOP Publishing.

Oxford Dictionary. (2024) Skill. URL https://www.oxfordlearnersdictionaries.com/definition/english/skill [Accessed 16 October 2024].

Patrick, M.M. (2022). Development of a Downstream Beneficiation Strategy in an underdeveloped Country: Case Study of the Lualaba Province in the Democratic Republic of Congo (Doctoral dissertation, Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg).

Petra Diamonds (2023) *The Value Chain*. Available at: https://www.petradiamonds.com/the-diamond-market/the-value-chain/ [Accessed 14 Nov. 2024].

Pheto, S. (2023). Exploring drivers of vertical forward integration in South Africa's platinum mining industry.

Prager, J. (2024) *South Africa has one of the world's largest manganese reserves. So why does it outsource for processing?*, *CNN*. Available at:

https://edition.cnn.com/2024/04/30/africa/manganese-south-africa-exports-electric-vehicles-batteries-spc-intl/index.html (Accessed: 14 November 2024).

PwC. (2023). SA Mine 2023: Adapt to Thrive. Available at: https://www.pwc.co.za/en/assets/pdf/sa-mine-2023-v3.pdf

PwC. (2023). *SA Mine Report 2023*. Available at: https://www.pwc.co.za/en/publications/sa-mine.html [Accessed: 13 November 2024].

Quiroz, D., Stravens, M., French, L., Xhali, M., Hatting, S. and Rajeevan, C. (2024). The South African mining sector.

Radinku, T. (2018). *The role of mineral beneficiation in the iron and steel industry: exploiting the linkages in the iron and steel value chain for sustainable development* (Doctoral dissertation).

Rand Refinery. (2023). *Refining Gold to Market-Ready Purity.*

Raymond Mills (n.d.) Gold mining and processing flow chart*. Available at: https://raymondmillsale.github.io/case/gold-mining-and-processing-flow-chart.html (Accessed: 14 November 2024).*

Robinson, I.C. & Von Below, M.A. (1990). The role of the domestic market in promoting the beneficiation of raw materials in South Africa. *Journal of the Southern African Institute of Mining and Metallurgy,* Vol. 90 (4), pp. 91-98.

Rosenberg, D. (2018). Israel's Technology Economy: Origins and Impact. Springer.

Rössing Uranium (n.d.) Uranium Production Process. Available at: https://www.rossing.com/uranium_production.htm (Accessed: 19 November 2024).

Roux, N., 2020. *A roadmap for the titanium metal industry of South Africa* (Doctoral dissertation, University of Pretoria (South Africa)).

Roux, R.N., Van der Lingen, E. and Botha, A.P. (2019). A systematic literature review on the titanium metal product value chain. *South African Journal of Industrial Engineering*, *30*(3), pp.115-133.

S&P Capital IQ. (2023) South Africa | Metals & Mining Properties. Available at: fhttps://www.capitaliq.spglobal.com/. (Accessed: 27 Nov. 2024).

Safarzadeh, M.S., Horton, M. and Van Rythoven, A.D. (2018). Review of recovery of platinum group metals from copper leach residues and other resources. *Mineral Processing and Extractive Metallurgy Review*, *39*(1), pp.1-17.

Sánchez, F. and Hartlieb, P. (2020). Innovation in the Mining Industry: Technological Trends and a Case Study of the Challenges of Disruptive Innovation. Mining, Metallurgy & Exploration 37, 1385–1399

Sasol. (2005). Sasol produces 1,5 billion barrels of synthetic fuel from coal in fifty years. Available: https://www.sasol.com/sasol-produces-15-billion-barrels-synthetic-fuel-coal-fifty-years. [Accessed: 16 October 2024]

Sasol. (2023). *Integrated Report 2023*.

School of Mining Engineering. (2024) Mining Value Chain. Lecture presentation in Beneficiation Economics course offered at the University of the Witwatersrand, Johannesburg.

Scott, SA & Matchett, K. (2004). MINATAUR: the Mintek alternative technology to gold refining. *Journal of the Southern African Institute of Mining and Metallurgy*, *104*(6), pp.339-343.

Sekar, S., Lundin, K., Tucker, C., Figueiredo, J., Tordo, S. and Aguilar, J. (2019). Methodology and value chain analysis.

Selby, J. (2010). Monazite production from the heavy minerals deposits of northern Kwa-zulu Natal, in: Thorium and Rare Earths Conference. The Southern African Institute of Mining and Metallurgy, Cape Town, pp. 15–25.

Shah, C. & Burke, G. (2010). Skills Shortages: Concepts, Measurement and Policy Responses. *International Encyclopedia of Education* (Third Edition), PP. 320-327.

Skinner, G.W., (2018). *South African Platinum Group Metals: Possibility for Beneficiation* (Doctoral dissertation, University of the Witwatersrand, Faculty of Engineering and the Built Environment, School of Mining Engineering).

South Africa: Production volume of chromium (2024) *Statista*. Available at: https://www.statista.com/statistics/1271316/production-volume-of-chromium-in-south-africa/ (Accessed: 14 November 2024).

South African Coal Roadmap (SACRM). (2011). Overview of the South African coal value chain. Johannesburg. Accessed from: http://www.sanedi.org.za/coal-roadmap/.Date of access: 13 November 2024.

South African Government (1998). The Skills Development (Act No.97 of 1998). Government Gazette No. 19420, Volume 401, 2 November. The Republic of South Africa.

South African Government (2008). The Mineral and Petroleum Resources Royalty Act (MPRRA) (Act No.28 of 2008). Government Gazette No. 31635, Volume 521. 24 November. The Republic of South Africa.

South African Government. (1996). Constitution of the Republic of South Africa (Act No. 108 of 1996). Pretoria.

South African Government. (2002). Mineral and Petroleum Resources Development Act, (Act No. 28 of 2002). Government Gazette No. 23922, Volume 448. 10 October. The Republic of South Africa.

South African Government. (2006). Precious Metals (Act No. 37 of 2005). Government Gazette No. 28764, Volume 490. 21 April 2006. The Republic of South Africa.

Statista (2023). Leading diamond exporting countries worldwide in 2023, based on value. Available at: https://www.statista.com/statistics/1132297/global-diamond-exports-by-country/ [Accessed: 17 October 2024].

Statista (2024) Mining industry in South Africa - Statistics & facts. Available at: https://www.statista.com/topics/7194/mining-industry-in-south-africa/. [Accessed: 16 October 2024]

Statistics South Africa. (2012) South African Standard Classification of Occupations (SASCO) 2012. Republic of South Africa, Pretoria. URL http://www.statssa.gov.za/classifications/codelists/SASCO_2012.pdf [Accessed: 13 October 2018].

Subasinghe, H.C.S. and Ratnayake, A.S. (2022). General review of titanium ores in exploitation: present status and forecast. *Comunicações Geológicas*, *109*(1), pp.21-31.

Sun, X., Liu, Y., Guo, S., Wang, Y. and Zhang, B. (2021). Interregional supply chains of Chinese mineral resource requirements. *Journal of Cleaner Production*, 279, p.123514.

Talkin, J. (2016). Downstream Beneficiation Case Study: Australia. Columbia Center on Sustainable Investment Policy Paper

Tshabalala, N. and Nyembwe, K., 2024. Optimisation of the beneficiation process of chromite sand to produce raw material for rapid sand-casting purposes. *South African Journal of Industrial Engineering*, *35*(4), pp.91-103.

Tom, Z.Z. (2015). *Analysis of the key factors affecting beneficiation in South Africa*. Master of Science in Engineering. University of the Witwatersrand.

Trade and Industrial Policy Strategies. (2020). *The Coal Value Chain in South Africa*.

Tronox 2024, Fact Sheet: South African Operations. Available at: https://www.tronox.com/download.php?path=15744 Accessed on 12 October 2024

UNAIDS (n.d.). An Introduction to Triangulation. UNAIDS Monitoring and Evaluation Fundamentals.

User, S. (2024) *About Us*, *Manganese Metal Company*. Available at: https://mmc.co.za/ (Accessed: 14 November 2024).

Ushie, V. (2017). The Africa Mining Vision and sustainable solutions for socio-economic development. Smart investment in health, mining as a catalyst for building sustainable communities, Johannesburg, 26th – 27th July 2017.

Van Zyl, Herman & Bam, Wouter & Steenkamp, J.D. (2016). Identifying barriers faced by key role players in the South African manganese industry.

Vanadium Resources. (2024). *Vanadium Resources ups SA project stake*. Mining Technology. Available at: https://www.mining-technology.com/news/vanadium-resources-ups-sa-project-stake/ [Accessed 18 Nov. 2024].

Veiga, C., Davim, J.P. and Loureiro, A.J.R. (2012). Properties and applications of titanium alloys: a brief review. *Rev. Adv. Mater. Sci*, *32*(2), pp.133-148.

Venkataraman, M., Csereklyei, Z., Aisbett, E., Rahbari, A., Jotzo, F., Lord, M. and Pye, J., (2022). Zero-carbon steel production: the opportunities and role for Australia. *Energy Policy 163*, p.112811.

Vera Véliz, M., Videla Leiva, A. and Martínez Bellange, P., (2022). Copper Bioleaching Operations in Chile: Towards New Challenges and Developments. In *Biomining Technologies: Extracting and Recovering Metals from Ores and Wastes* (pp. 163-176). Cham: Springer International Publishing.

Vishnevsky, T. and Beanlands, H. (2004). Qualitative research. Nephrology Nursing Journal, Vol. 31(2), pp.234 – 238.

Visser, M. (2006). An overview of the history and current operational facilities of Samancor Chrome. *Southern African Pyrometallurgy 2006*, pp.285-296.

Voetmann, F. (2018). Natural resources as a driver for the SDGs—the case of Chile and copper mining. International Copper Association. Available at: https://internationalcopper.org/resource/natural-resources-as-a-driver-for-the-sdgs-the-case-of-chile-and-copper-mining/ [Accessed 19 October 2024].

Vorster, A. (2001). Planning for value in the mining value chain. *Journal of the Southern African Institute of Mining and Metallurgy*, *101*(2), pp.61-65.

Western Cape Government. (2020). *Sector Jobs Resilience Plan: Coal Value Chain*. Retrieved from Western Cape Government.

Widodo, T. (2009). Comparative advantage: Theory, empirical measures and case studies. Review of Economics and Business Studies. November 2009.

Williams, G., Cunningham, S. and De Beer, D. (2014). Advanced manufacturing and jobs in South Africa: an examination of perceptions and trends. In *International Conference on manufacturing-led growth for employment and equality* (Vol. 20).

Wilson, R. (1977). The Factor Endowment. In: Trade and Investment in the Middle East. Palgrave Macmillan, London. https://doi.org/10.1007/978-1-349-03299-0_1

World Coal. (2025). How coal mines are integrating sustainable development goals. Available at: https://www.worldcoal.com/mining/13022025/how-coal-mines-are-integrating-sustainable-development-goals/. [Accessed: 27 February 2025].

World Bank (2020). Skills implications of Botswana's Diamond Beneficiation Strategy. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/21082/930490WP0P11940C00Botswana0Note04wc.pdf. [Accessed: 18 October 2024].

World Bank. (2023). *Battery storage market and value chain assessment in South Africa* - Synthesis Report (English). Washington, D.C.: World Bank Group. Retrieved from http://documents.worldbank.org/curated/en/099155502102332395/P17268201ebc89050b1960f40c8377523a

World Gold Council. (2023). *Gold Production*. Retrieved from World Gold Council

World Nuclear Association (no date) *Nuclear Power in South Africa*. Available at: https://world-nuclear.org/information-library/country-profiles/countries-o-s/south-africa (Accessed: 19 November 2024).

Zamora, E. A. (2016). Value chain analysis: A brief review. *Asian Journal of Innovation and Policy.* Vol. 5(2), pp. 116–128. doi: 10.7545/AJIP.2016.5.2.116.

ANNEXURES

Annexure A: Beneficiation related programmes at South African Universities and TVETs

Name of Institution	Programmes offered	Type of training	Level	Details (Duration, entry requirements, costs etc)
University of Cape Town	BSc Chemical Engineering	Degree	NQF level 8	4 years, full time, >=500 Faculty Point Score (FPS) with Level 7 in Maths, and level 6 Physical sciences
Wits University	BSc Chemical Engineering	Degree	NQF level 8	4 years, full time, APS 42+ with Level 5 in Maths, English, and Physical sciences.
	BSc Metallurgy and Material engineering	Degree	NQF level 8	4 years, full time, APS 42+ with Level 5 in Maths, English, and Physical sciences.
University of Pretoria	BEng Chemical Engineering	Degree	NQF level 8	4 years full time, APS of 35 with English Home language or FAL

				with level 5, Mathematics with level 6 and Physical Science with level 6.
	BEng Metallurgical engineering	Degree	NQF level 8	4 years full time, APS of 35 with English Home language or FAL with level 5, Mathematics with level 6 and Physical Science with level 6.

Name of Institution	Programmes offered	Type of training	Level	Details (Duration, entry requirements, costs etc)
Stellenbosch University	BEng Chemical Engineering	Degree	NQF level 8	4 years, full time, Aggregate of 70+ with Level 6 in Maths, 4 in English home language or 5 in English FAL, and 6 in Physical sciences
University of Johannesburg	Jewellery design and manufacture	Diploma	NQF level 6	3 years, full time, APS of 20 with maths or 21 Maths lit or 22 Tech Maths and with Level 3 in Maths, 4 in Maths lit, 5 in Tech Maths, and 5 in English.
	BEngTech in Chemical Engineering	Degree	NQF level 7	3 years, full time, APS 30 with Level 5 in Maths, 4 in English, and 5 in Physical sciences.
	BEngTech in Extraction Metallurgy	Degree	NQF level 7	3 years, full time, APS 30 with Level 5 in Maths, 4 in English, and 5 in Physical sciences.

	BEngTech in Physical Metallurgy	Degree	NQF level 7	3 years, full time, APS 30 with Level 5 in Maths, 4 in English, and 5 in Physical sciences.
University of North West	BEng in Chemical Engineering	Degree	NQF level 8	4 years, APS of 30, full time, APS 30 with Level 6 in Maths, 5 in English, and 6 in Physical sciences

Name of Institution	Programmes offered	Type of training	Level	Details (Duration, entry requirements, costs etc)
Nelson Mandela University	Diploma (Chemical Process Technology)	Diploma	NQF level 6	3 years, AS with Mathematics of 350. Mathematics 55% and Physical Sciences 50%.
Tshwane University of Technology	Jewellery design and Manufacture	Diploma	NQF level 6	3 years, APS of 20 with level 3 in English
	BEngTech (Chemical Engineering)	Degree	NQF level 7	3 years, APS of 30 with level 4 in English, 5 in Maths, and 5 in Physical sciences.
	BEng (Materials Engineering) (Polymer Technology)	Degree	NQF level 7	3 years, APS of 30 with level 4 in English, 5 in Maths, and 5 in Physical sciences.
	BEngTech (Metallurgical Engineering)	Degree	NQF level 7	3 years, APS of 30 with level 4 in English, 5 in Maths, and 5 in Physical sciences.
University of Limpopo	BSc Physical Sciences (Extended programme)	Degree	NQF level 7	4 years, full time, APS of 22 with level 4 in English, Maths, Physical sciences, and 3 in Life Sciences.

University of KwaZulu Natal	BSc Chemical Engineering	Degree		4 years, Full time, NSC degree pass, Mathematics and Physical Sciences level 5 (65%) English and Life Orientation level 4 (50%).
Mangosuthu University of Technology	Chemical Engineering	Diploma	NQF level 6	3 years full time with level 4 in English FAL, Maths and Physical Sciences.

Name of Institution	Programmes offered	Type of training	Level	Details (Duration, entry requirements, costs etc)
University of South Africa	Diploma in Chemical Engineering	Diploma	NQF level 6	1 year, NSC (diploma endorsement) with Maths or Tech Maths level 4, English, Physical Sciences or Tech Sciences with minimum mark of 50%.
Vaal University of Technology	Chemical Engineering	Diploma	NQF level 6	3 years full time, APS of 24 excluding LO with level 4 in English FAL, Maths and Physical Sciences.
	Metallurgical Engineering	Diploma	NQF level 6	3 years full time, APS of 24 excluding LO with level 4 in English FAL, Maths and Physical Sciences.
Cape Peninsula University of Technology	Chemical Engineering	Diploma	NQF level 6	3 years, APS of 30 with level 4 in English, Maths, Physical sciences and level 5 in Maths literacy.

Durban University of Technology	Bachelor of Engineering Technology in Chemical Engineering	Degree	NQF level 7	3 years, NSC bachelor pass, With English, Maths and Physical Sciences level 4 and two recognised 20 credit subject 4
University of South Africa	Diploma in Chemical Engineering	Diploma	NQF level 6	1 year, NSC (diploma endorsement) with Maths or Tech Maths level 4, English, Physical Sciences or Tech Sciences with minimum mark of 50%.

Name of Institution	Programmes offered	Type of training	Level	Details (Duration, entry requirements, costs etc)
South West Gauteng TVET College	Chemical Engineering	National Certificate	N4 - N6	18 Months, N2 requires Grade 10 with 40% in maths and science while N3 requires Grade 10 certificate with Grade 12 passed with 40% in maths and science.
Ikhala TVET College	Waste Treatment Practice	Vocational Certificate	N2	Passed grade 9 with 40% in maths, English and physical sciences.
Flavius Mareka TVET College	Chemical Plant Operations	Specialised training programmes (Learnerships and skills programmes)	NQF level 4	4 years full-time, Pass in grade 12 with Mathematics and Physical Sciences.
Ekurhuleni East TVET College	Process Plant Operations	National Certificate Vocational	NCV level 2-4	NQF level 1 qualification i.e. Grade 9, AET level 4 PLP results, GETC L4.
Umgungundlovu TVET College	Plant Processing Operations	National Certificate Vocational	Level 2 -4	Grade 9, students are required to do 7 subjects.

Capricorn TVET College	Plant Processing Operations	National Certificate Vocational	Level 2-4	3 years, Grade 9 minimum requirement.
	Chemical Engineering	National Diploma	N4-N6	18 months classroom and 18 months practicals. Grade 12 with 40% in maths and science.
Vhembe TVET College	Process Plant Operations	NCV	Level 2-4	3 years, Grade 9,
	Chemical Engineering	National Diploma	N4 -N6	Grade 12 with 40% in maths and science, 6 months classroom and 18 months practical.

Annexure B: Beneficiation related programmes at MQA accredited training institutions

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Mining and Mineral Training Institute (MMTI)	Mineral Processing	Training in mineral processing operations	Practical	NQF level 2, 3, and 4	Duration of 16 weeks for individuals working in mining and minerals.
Colliery Training College (CTC)	Mineral Processing	Basic mineral processing techniques	Classroom, on the job, and specialised training	NQF level 2	Requires grade 10 with maths and literacy. Duration of 7 weeks and it aims at training plant operators.
Prisma Training Solutions	National Certificate in Mineral Processing	Crushing, thickening of slurry, handling of chemicals,	Classroom and practicals	NQF level 2, 3, and 4	Duration of 12 months for individuals working in mining and minerals.

		dense medium separation, electrowinning, and flotation.			
MetSkill	National Certificate in Mineral Processing	Metallurgical operations control	Classroom and practicals	NQF level 2, 3, and 4	Duration of 12 to 18 months for individuals working in mining and minerals.

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
The Beneficiation Academy	• National Certificate in Mineral processing Level 2-3. • Further education and training certificate in Mineral processing Level 4	Handling of chemicals, Solvent extraction, Ore reception, milling of material, Flotation, Crushing, Scrubbing and screening, water reticulation, Electro-winning, gold elution and carbon regeneration	On the Job training and classroom	NQF level 2 - 4	For mining employee's development

De Beers Enterprise Development Project	Diamond cutting and Polishing	Diamond cutting and Polishing	Practical	-	3 years full time, targeting HDSA who won diamond cutting and polishing companies
MPTech at UCT	Short courses on comminution and flotation	Circuit optimisation, mass balancing and flotation techniques	Classroom and Practical	Equivalent to a Postgraduate Diploma	Duration: 1 week per course. Audience: mining professionals
African Minerals College	• Rough Diamond Evaluation course. • National Certificate: Diamond Processing and Polishing	Diamond processing and Polishing		National Certificate level 3	One week for Rough Diamond Evaluation course and 6 months for National Certificate: Diamond Processing and Polishing course.

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Nungu Training College	Mineral Processing	Mineral separation and processing		NQF level 2	Targets individuals working in mining and minerals.
Akapo Jewels	• National Certificate: Jewellery Manufacturing Level 2 and Level 3. • Further Education and Training Certificate: Jewellery Manufacturing Level 4	Manufacturing and production of jewellery			Audience: Young and upcoming entrepreneurs in the jewellery industry

AMC Training Centre	National Certificate: Mineral Processing			NQF level 2	
The Beneficiation Academy	Mineral Processing	Diamond processing and precious metals	Practical and theoretical	National Certificate (L2, L3), and FET Certificate	Targets mining employees and individuals looking for self-improvement.
Diamond Education College	National Certificate: Diamond Processing	Rough diamond evaluation, marking, Polishing and cutting.		NQF level 3	Rough diamond evaluation; 2 weeks. Rough diamond Marking: 2 weeks. Polishing and cutting: 6 months
Zurel Bros SA (Pty)	• Diamond and Gemstone Setter • Diamond Cutter	Diamond cutting, polishing	Workplace and practical training	NQF level 2	

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Anglo American Amandelbult Concentrators	Crushing (Version 3)	Crushing	On the job training	MQA/SP/0172/17 A MQA/SP/0172/17B	Contact person: Cyrill Woodroffe, Telephone: 014 598 3105, Email: CyrillWoodroffe@angloamercian.com
Anglo American Platinum Ltd: Precious Metals Refineries V690713724/ 16	• Water Analysis in a Laboratory (MQA/SP/0087/09). • Skills Programme: Primary Sample Preparation in an Analytical Laboratory (MQA/SP/0111/09).		On the job training		Contact persons:Stephen Rutherford and Pogiso Mogorosi, Telephone: 014 567 9291, Cell phone: 076 735 9249, Email: Stephen.Rutherford@angloamerican.com and pogiso.mogorosi@angloamerican.com

	• Skills Programme: Preparation of Samples and Instrumental Analysis (MQA/SP/0147/13) • Skills Programme: Secondary Sample Preparation in an Analytical Laboratory (MQA/SP/0131/1)				

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Anglo American Platinum Ltd: People Development V690713724/18	General Education and Training Certificate: Mining and Minerals Processes (58267)		On the job training		Contact persons: Netsai Zindi and Natalie Venter. Telephone:011 373 6763, Email: Netsai.zindi@angloamerican.com Natalie.venter@angloamerican.com
Anglo American Platinum Ltd: Mototolo Concentrators V690713724/15	• Skills Programme in Crushing (Version 2) **(MQA/SP/0088/09)** • Skills Programme in Milling of Material (Version 2) **(MQA/SP/0052/09)**	Crushing, Milling, Flotation, Water reticulation and Thickening of a slurry.	On the job training		Contact persons: Martin Mare & Welhemina Makhafula. Telephone: 013 231 9328 and 013 230 4565. Cell phone: 060 321 4618. Email: Martin.mare@angloamerican.com and Welhemina.makhafula@angloamerican.com

	• Skills Programme: Flotation **(MQA/SP/0072/09)** • Skills Programme: Water Reticulation **(MQA/SP/0090/09)** • Skills Programme: Thickening of a Slurry (Version3) **(MQA/SP/0109/09)**				
Anglo American Platinum Ltd: Waterval Smelters V690713724/17	Skills Programme: Handling of Chemicals **(Version 2) (MQA/SP/0011/09)** Skills Programme: Scrubbing and	Handling of chemicals, Scrubbing and screening.	On the job training		Contact persons: Walter Monyatsi & Gibson Machebele.Telephone: 011 555 1234. Cell phone:083 455 9087 Email: Walter.Monyatsi@angloamerican.com Gibson.Machebele@angloamerican.com

	Screening **(Version 2) (MQA/SP/0089/09)**				
Name of Organisation/Company	**Programmes offered**	**Skills**	**Type of training**	**Level**	**Details (duration, target audience, etc)**
Anglo American Platinum Ltd: Mogalakwena Concentrators V690713724/19	• National Certificate: Mineral Processing:**(59305 L2)** • Skills Programme: Primary Sample Preparation in an Analytical Laboratory **(MQA/SP/0111/09)** • Skills Programme: Secondary Sample Preparation in an		On the job training		Contact Persons:Tshidiso Motumi and Thabo Mathobela. Telephone: 0145914234.Cellphone:083 455 3102. Email: tshidiso.motumi@angloamerican.com thabo.mathobela@angloamerican.com

	Analytical Laboratory (**MQA/SP/0131/11)** • Skills Programme: The separation of precious metals by means of the fire assay technique (**MQA/SP/0146/13)** • Skills Programme: Preparation of Samples and Instrumental Analysis (**MQA/SP/0147/13)**				

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Anglo Ashanti	• Further Education and Training Certificate: Mineral Processing **(64889)** • General Education and Training Certificate: Mining and Minerals Processes **(58267)**, **ABET 1** • National Certificate Mineral Processing **(59305) L2**		On the job training	L1 to L3	Contact Person: Andries Grobbelaar. Telephone: 0187003337. Cell Phone: 083 4194887. Email: AGrobbelaar@anglogoldashanti.com

	• National Certificate: Mineral Processing **(62769) L3** • General Education and Training Certificate: Mining and Minerals Processes **(58267)**				
Assmang Beeshoek Mine	• Mineral Processing Skills Programme: Ore Reception - **(MQA/SP/0029/09)** • Skills Programme in Crushing	Crushing and Ore reception	On the job training		Contact Person: Thembeka Makhoba. Telephone: 053 3116672. Cell Phone: 079 4045908. Email: Thembeka.Makhoba@assmang.co.za

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
	(Version 2) (MQA/SP/0088/09)				
Assmang Black Rock Mine	Skills Programme: Crushing (Version 3) **(MQA/SP/0172/17) A**	Crushing	On the job training		Contact Person: Nkateko Makhaliva. Telephone:053 7515930. Cell Phone: 084 6809788. Email: Nkatekom@brmo.co.za
Assmang Khumani Mine	National Certificate Mineral Processing **(59305) L2**		On the Job training	Level 2	Contact Person: Dumisile Dladla. Telephone: 053 723 8621. Email: Dumisile.Dladla@assmang.co.za
Bafokeng Rasimone Platinum Mine	• General Education and Training Certificate: Mining	Flotation, crushing, scrubbing and screening,	On the Job training		Contact person: Oupa Thomas Mothibi. Telephone: 014 5731619. Cell phone: 082 823 9493. Email: Oupam01@bafokengplatinum.co.za

	and Minerals Processes **(58267)** • Skills Programme: Flotation **(MQA/SP/0072/09)** • Skills Programme: Crushing **(Version 3) (MQA/SP/0172/17) A** • Skills Programme: Crushing **(Version 2) (MQA/SP/0172/17) B)** • Skills Programme: Scrubbing and Screening	refining, backfilling and dense medium separation.			

	(Version 2) (MQA/SP/0088/09) • Skills Programme: Water Reticulation **(MQA/SP/0090/09)** • Skills Programme: Relining of a mill **(MQA/SP/0094/09)** • Skills Programme: Backfilling **(MQA/SP/0096/09)** • Skills Programme: Dense Medium Separation **(Version 2)**				

	(MQA/SP/0107/09)				
Cullinan Diamond Mine	National Certificate: Mineral Processing **(62769) L3** National Certificate Mineral Processing **(59305) L2** Further Education and Training Certificate: Mineral Processing **(64889) L4** General Education and Training Certificate: Mining and Minerals Processes **(58267)**		On the Job training	Level 2 - 4	Contact Person: Mbali Mkwanazi. Telephone: 012 3052384. Cell Phone:072 305 2911. Email: Mbali.mkwanazi@pretradiamonds.com

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
De Beers Sightholder Sales South Africa	• Further Education and Training Certificate: Diamond and Evaluation **(64249) L4** • Further Education and Training Certificate: Diamond Design and Evaluation: Rough Evaluation **(64249) L4** • Further Education and Training Certificate: Diamond Design	Diamond evaluation, design, marking and inspecting.	On the Job training	Level 4	Contact person: Salomien Castles. Telephone: 053 8307291. Cell phone:083 633 3663. Email: Salomlen.Castles@debeersgroup.com

	and Evaluation: Basic Marking and Design **64249 L4** • Further Education and Training Certificate: Diamond Design and Evaluation: Inspecting **64249 L4**				

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
De Beers Venitia Mines	• National Certificate Mineral Processing **L2 (59305)** • National Certificate Mineral Processing **L3 (62769)** • Further Education and Training Certificate: Mineral Processing **L4 (64889)**		On the Job training	Level 2 - 4	Contact Persons: Koos Nel / Neetash Harish Daya. Telephone: 015 5752 107 / 015 575 2570. Cell Phone:061 764 7994/ 082 4944988. Email: koos.nel@debeersgroup.com And Neetash.Daya@debeersgroup.com

Ekapa Minerals (Pty) Ltd	• Skills Programme: Dense Medium Separation (Version 2) **MQA/SP/0107/09** • Skills Programme: Crushing and Screening **MQA/SP/0171/17** • Skills Programme: Thickening of a Slurry (Version3) **MQA/SP/0109/09**	Crushing, screening and thickening	On the Job training		Contact Persons: Gail Hope and Ester Gumede. Telephone: 053 8387797. Cell Phone:084 556 4755 /078 623 1649. Email: Gail.Hope@ekapagroup.com and Ester.Gumede@ekapagroup.com

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Ergo Mining	• National Certificate: Mineral Processing **(59305)** • General Education and Training Certificate: Mining and Minerals Processes **(58267)**		On the Job training		Contact Person:T Malow. Telephone:011 7421051. Email: tendanim@ebda.co.za
Exxaro Grootegeluk Mine	• National Certificate: Mineral Processing **(59305) L2**		On the Job training	Level 2- 4	Contact Person: Willem Hoffmannn. Telephone:014 7639149. Cell Phone:083 452 6581 Email: willem.hoffmann@exxaro.com

	• National Certificate: Mineral Processing **(62769) L3** • Further Education and Training Certificate: Mineral Processing **(64889) L4**				
Finsch Diamond Mine	• National Certificate: Mineral Processing **(59305) L2** • National Certificate:		On the Job training	Level 2- 3	Contact Person: Acker Georgenie. Cell Phone:079 881 2188 Email: Georgenie.Acker@petradiamonds.com

	Mineral Processing **(62769) L3**				

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Foskor	• National Certificate: Mineral Processing L2 (59305) • National Certificate: Mineral Processing L3 (62769)		On the Job training	Level 2 -3	Contact Person: Emmanuel Qheuben Sekgobela. Telephone:015 7892253. Cell Phone:083 420 7100 Email: emanuels@foskor.co.za
Fraser Alexander	• National Certificate Mineral Processing L2 (59305) • Skills Programme in Milling of	Milling	On the Job training	level 2	Contact Person: Josiah Tsheko. Telephone: 014 591 3312. Cell Phone:082 808 0579 Email: JosiahT@fraseralexander.co.za

	Material (Version 2) (MQA/SP/0052/09) • Skills Programm • Tailings Dam Operations (V2) (MQA/SP/0164/16)				
Glencore Opertions South Africa - Coal	Mining and Minerals Processes	Mineral processing (Coal)		General Education and Training Certificate (L1)	Reyno Dupreez, 013 686 4274, Emai: reyno.dupreez@glencore.co.za, Mpumalanga
Global Jewellery Academy	Jewellery manufacturing and designing	Manufacturing, cutting, design	Practical and theoretical training	National Cerificate L2 and Level 3, and FET Certificate	Robert Buys, 011 857 2854, Email: robertb@globaljewelleryacademy.co.za, Gauteng

Harry Oppenheimer Diamond Training School	Diamond polishing, evaluation,crossworking, Brillianteering and design	Polishing, design, evaluating, and grading polished diamonds	Practical and theoretical training	National Certificate L3 and FET Certificate L4	D.G.J Rademeyer, 011 334 8420, Email: neil@diamondtrainingschool.co.za, Gauteng

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
House Of Lemba Designs (Pty) Ltd	Jewellery Manufacturing Operations	Manufacturing of Jewellery skills	Theory and practical	National Certificate L3 and FET Certificate	Pearl Bernice Dickson, 010 035 2046, Email: pbernice777@gmail.com, ~~Guateng~~Gauteng
Iketleng Mo Afrika Skills Development	Jewellery Manufacturing	Manufacturing of Jewellery skills	Theory and Practical	National Certificate L2	Tebogo Molefe, 0719570202 0760752122, Email: iketlengmoafrika@gmail.com, North West
Imfundiso Skills Development	Jewellery Manufacturing	Manufacturing of Jewellery skills	Practicals	National Certificate L2 and L3 and FET Certificate L4	I, Nkwe, 012 734 0245, Email: imfundiso@mweb.co.za, Gauteng
Impala Platinum Limited (~~Rusterburg~~Rustenburg)	Mineral processing and metal production		On the job training	National Certificate L2	Elsabe Howes, 014 569 0084, Email: ElsabeH@implats.co.za, North West

Intsika Skills Beneficiation Project	Jewellery Manufacturing and Design		Practical training	National and FET Certificates	S. Mkhize, 011 873 2261, Email: intsika@telkomsa.net, North West
Kabelano Training Solutions (Pty) Ltd	Mineral processing	Milling and crushing	Theory and practical training	National Certificate L2 and L3 and FET Certificate L4	Thabo Sekhaolelo, 065 982 9768, 014 784 0076 , Email: thabo@kabelanotraining.co.za, North West
Kimberley International Diamond & Jewellery Academy	Diamond cutting, polishing, evaluation,crossworking, Brillianteering and design	Cutting, polishing, evaluation, and grading of diamonds	Theory and practical training	National Certificate L2 and L3 and FET Certificate L4	Desmond Ratsama, 053 831 1867, 072 504 0515, Email: ratsomad@gmail.com , Northern Cape
Kumba Sishen Human Resources Development Programme	Mineral processing		On the job training	National Certificate L2 and L3 and FET Certificate L4	Alan Esterhuyse, 053 739 3308, 082 766 9121, Email: allan.esterhuyse@angloamerican.com, Northern Cape

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Kumba Human Resources Development Kolomela Mine	Mineral processing		On the job training	National Certificate and FET Certificate	Alan Esterhuyse Derenthea van den Heever Victoria Molongwana, 053 739 3308 053 313 9173 053 313 9173, Emails: Alan.Esterhuye@angloamerican.com Derenthea.vandenHeever@angloamerican.com Victoria.Molongwana@angloamerican.com, Northen Cape
Minepro	Mineral processing of Lump ore	Crushing and processing	Practical training	National Certificate L2 and L3	Goodman Moeti, 063 272 3489, Email: moetig@gmail.com, Gauteng

Mintek	Jewellery Manufacturing and Designing	Research, processing	Theoretical and practical training	National Certificate L2 and L3, and FET Certificate L4	Nirdesh Singh / Andre Van Niekerk , 011 709 4335 / '011 709 4075 , Email: nirdeshs@mintek.co.za /andrien@mintek.co.za , Gauteng
Modikwa Platinum Mine	Mineral processing		On the job training	National Certificate L2 and L3, and FET Certificate L4	Peet, Herbst, 013 230 2019, 082 771 6696, Email: peet.herbst@angloamerican.com, Limpopo
Nokaneng Environmental Management Consulting	Minerals Processing Gold Extraction		On the job practical training	National Certificate L2 and L3, and FET Certificate	T. Nokaneng, 076 795 9654, '076 759 9654, Email: nokanengnme@gmail.com, Guateng

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Palabora Copper (Pty) Ltd	Mineral processing of copper		On the job practical training	National Certificate L2 and L3	Tshidi Moila, (015) 780 2145, 082 885 0889, Email: Tshidi.Moila@palabora.co.za
Pneuma Jewellers Cc	Jewellery Manufacturing and Design		Theory and practical training	National Certificate L2 and L3, and FET Certificate L4	Michael Pneuma, 011 702 1462, '073 166 4375, Email: Admin@PneumaJewellers.co.za, Gauteng
Pride of Success	Mineral Processing		Theory and practical training	National Certificate L2 and L3, and FET Certificate L4	Sylvia Gombi, 012 753 753, Email: sylviag@prideofsuccess.co.za, Mpumalanga
Progressive Training Development Projects (Pty) Ltd	Mineral Processing Lump Ore		Theory and practical training	National Certificate L2 and L3	Future Mohlala, 076 574 1244, Email: futuremohlala@gmail.com, Mpumalanga
Rare Earth Creations (Pty) Ltd	Jewellery Manufacturing and Setting		Theory and practical training	Education and Training and	Noloyiso Poto, '011 326 1727, '072 431 9789, Email: noloyiso@rarearth.co.za, Gauteng

				National Certificates	
Richards Bay Mining Pty Ltd	Mineral Processing		On the job training	National Certificate L2 and L3, and FET Certificate L4	Taygen Moonsamy Naicker, (035) 901 3942, Email: Taygen.naicker@riotinto.com, KwaZulu Natal
Safety and Training Solutions	Mineral Processing		Theory and practical training	National Certificate L2 and L3	George Fourie, '012 997 0351, Email: george@satsolutions.co.za, Gauteng
Samancor Eastern Chrome	Mineral processing		On the job training	National Certificate L2 and L3	Adriana van Rooyen, '013 230 7008, '082 672 5811, Email: adri.vanrooyen@samancorCr.com, Mpumalanga

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Samancor Western Chrome	Mineral processing of Base Metals, PGMs and Lump Ore		On the job training	National Certificate L2	Jacqueline van der Westhuizen / Gavin Coveaux, '014 574 6046 '014 574 6215, Email: Jacqueline.VanderWesthuizen@samancorCR.com Gavin.Choveaux@samancorCR.com, Northwest
Seda Limpopo Jewellery	Jewellery Manufacturing and Design		On the job training	National and FET Certificates	Tessa Ngobeni, '015 293 0214, '073 844 1974, Email: tessa@slji.org.za, Limpopo
Sibanye Gold Business Leadership Academy (Pty) Ltd	• National Certificate Mineral Processing **(59305) L2** • National Certificate: Mineral		On the Job training	Level 2 -3	Terisa Greyling 011 751 4031 Email: Terisa.Greyling@sibanyegold.co.za

	Processing **(62769) L3** • General Education and Training Certificate: Mining and Minerals Processes **(58267)**				
Soweto Diamond Academy	National Certificate: Diamond Processing: **(59851) L3**	Diamond processing	On the Job training	Level 3	Lebongang Moima 079 914 1904 Email: misslebo@msn.com

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Talent Factor (Pty) Ltd	• National Certificate: Mineral Processing **L2 (59305)** • National Certificate: Mineral Processing Platinum **L3 (62769)** • Further Education and Training Certificate: Mineral Processing **L4 (64889)**		On the Job training	Level 2- 4	Carol Brandt and Jacques Farmer 018 293 3184 Email: carol.brandt@prisma.co.za jacques@prisma.co.za

Tau Lekoa Gold Mining Company Limited	• Skills Programme in Milling of Material **(Version 2) [MQA/SP/0052/09]** • Skills Programme: Crushing **(Version 3) (MQA/SP/0172/17)**	Milling and crushing	On the Job Training		Jerry Kekana 018 473 7083, 0726231118 Email: JerryK@taulekoa.co.za
Tharisa Minerals	• National Certificate: Mineral Processing **(62769) L3** • National Certificate Mineral		On the Job training	Level 2-3	Wilson Mello and Linda Mosito 014 572 0700 / 014 572 0798 Emails: wmello@tharisa.com lmosito@tharisa.com

	Processing **(59305) L2**				

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
The Bera Diamond Academy	• National Certificate Jewellery manufacturing L2 (65049) • National Certificate: Diamond Processing L3 (59851) • National Certificate: Jewellery Manufacturing L3 (65209) • Further Education and Training		On the Job T raining	Level 2-3	Bera Muhammad /Rahima Muhammad 076 155 2786 /'082 924 2986

	Certificate: Diamond Processing L4 (64729)				
Thusang Metco	• National Certificate: Mineral Processing **(62769)** • Further Education and Training Certificate: Mineral Processing **(64889)**		On the Job training		Dr W Bolha-Welo 0114987501/082 4728588 Email: wbolha@thusangmetco.com

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Total Coverage Consulting	National Certificate Mineral Processing **(59305) L2**		On the Job training	Level 2	Onica Mphahlele 0118082000/084 4684590 Email: onicam@totalcov.co.za
Top Performers For Africa	National Certificate Mineral Processing **(59305) L2**		On the Job training	Level 2	Simon Skhosana 013 935 1912 /083 450 9518 Email: ss@topperformers.co.za
Two Rivers Platinum	• Certificate Mineral Processing **(59305) L2** • General Education and Training Certificate: Mining		On the Job training	Level 2	Harold Mahlangu 0132 302 891 /082 904 1680 Email: harold.mahlangu@trp.co.za

	and Minerals Processes (58267)				

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Vika Training Academy	• Skills programme: Crushing (version 3) (MQA/SP0172/17) • Skills programme: Primary sample preparation in an analytical laboratory (MQA/SP/0111/09) • Skills programme: Ore reception (MQA/SP/0029/(V 4)	Crushing Sample preparation	On the Job Training		Kabelo Sehako, 083 387 6090, Email: Kabelo.Sehako@vikatraining.co.za

Virginia Jewellery School	Further Education and Training Certificate: Jewellery Manufacturing Operations (57876) National CertificateL: Jewellery Manufacturing (65049) National Certificate: Jewellery Manufacturing (65209)	Jewellery Manufacturing	On the Job Training		Velile Isaac Jonas, 073 481 1051, Email: velile@vjsjewellers.co.za

Name of Organisation/Company	Programmes offered	Skills	Type of training	Level	Details (duration, target audience, etc)
Zurel Private College	National Certificate: Jewellery Manufacturing (65049) L2 National Certificate: Diamond Processing Operator L2 (21846) National Certificate: Jewellery Manufacturing Production Environment (65209) L3 National Certificate: Diamond Processing L3 (59851)	Jewellery Manufacturing and production, Diamond processing	On The Job Training	Level 1- 4	Shikara Maharaj, 0152932306, 0862040365, Email: zureltraining@gmail.com

	Further Education and Training Certificate: Jewellery Designing L4 (57875) Further Education and Training Certificate: Jewellery Manufacturing Operations L4 (57876) Further Education and Training Certificate: Diamond Processing L4 (64729)				

Reviewed by: ______________________________

Nelly Mashaba, Skills Development and Research Manager

Approved by ____

Joseph Komane, Skills Development and Research Senior Manager