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A VALUE CHAIN ANALYSIS OF ANTIMONY BENEFICIATION OPPORTUNITIES FOR SOUTH AFRICA

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science in Engineering by advanced coursework and research to the University of the Witwatersrand, Johannesburg. It has not been submitted before any degree or examination to any other University.

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Signed on the _22nd day of _June, 2021.

ABSTRACT

Antimony is considered a critical and strategic commodity by the European Commission because its production is highly concentrated in China, and it is used in various applications. Antimony in South Africa was historically mined in the Limpopo Province from the early 1940s. Production ceased in 2014 after the antimony mine was placed under provisional liquidation. The mine was reported to have over 25 000t of underground antimony reserves and over 200 000t of antimony resources at the time (Village Main Reef, 2013). The antimony value chain is not prioritized in South Africa's Mineral Beneficiation Strategy; however, antimony demand is likely to grow. This presents South Africa with an opportunity to re-enter the antimony market as a supplier of various antimony-based products. The report finds that if certain constraints are mitigated, the country has the potential to successfully re-enter the antimony market in the short–medium term.

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LIST OF SYMBOLS AND ABBREVIATIONS

Au:	Gold
Cons Murch Mine:	Consolidated Murchison Mine
EU:	The European Union
GDP:	Gross Domestic Product
ICMM:	International Council on Mining and Metals
MCSA:	Minerals Council of South Africa
MGB:	Murchison Greenstone Belt
MQA:	Mining Qualifications Authority
MPRRA:	Mineral and Petroleum Resources Royalty Act 2008
PGMs:	Platinum Group Metals
R&D:	Research and Development
Sb:	Antimony
Stibium Mine:	Stibium Mopani Mine
UNECA:	United Nations Economic Commission for Africa
USA:	The United States of America
VMR:	Village Main Reef

1 INTRODUCTION, BACKGROUND AND PURPOSE OF RESEARCH

1.1 Introduction and Background

Mineral resources are finite and provide a country with an opportunity to attain economic growth and address socio-economic development issues such as poverty and unemployment (Davis and Tilton, 2002; Deloitte, 2011). The mining sector contributes to the economic development of a country through foreign direct investment (FDI), mineral exports, Gross Domestic Product (GDP), job creation and government revenue generated from taxes, rent and royalty payments (ICMM, 2014). Some countries also rely on mineral resources for industrialization, and this has solidified their strategic importance on a global scale (Ramdoo, 2013). The African Union (2009) recognizes that mineral resource-endowed countries in Africa could use mineral resource extraction to cultivate industrialization on a local and regional scale.

Figure 1.1 below notes the mining sector's contribution in low-middle income countries globally by accessing data obtained from the International Council on Mining and Metals and Oxford Policy Management over various years. For some low - middle income countries, the largest economic contribution made by the minerals sector is in the form of FDIs (Dorin et al., 2014; ICMM, 2014).

In South Africa, however, Baxter (2015) notes mineral exports as the mining sectors' largest contributor to the economy compared to the other revenue-generating streams noted above. South Africa's mining sector also contributes to the employment of its citizens (10-12%), which is higher than that of low and middle-income nations globally (1-2%) as depicted in Figure 1.1. The South African mining sector had employed over 454 000 people in 2019 (MCSA, 2020).

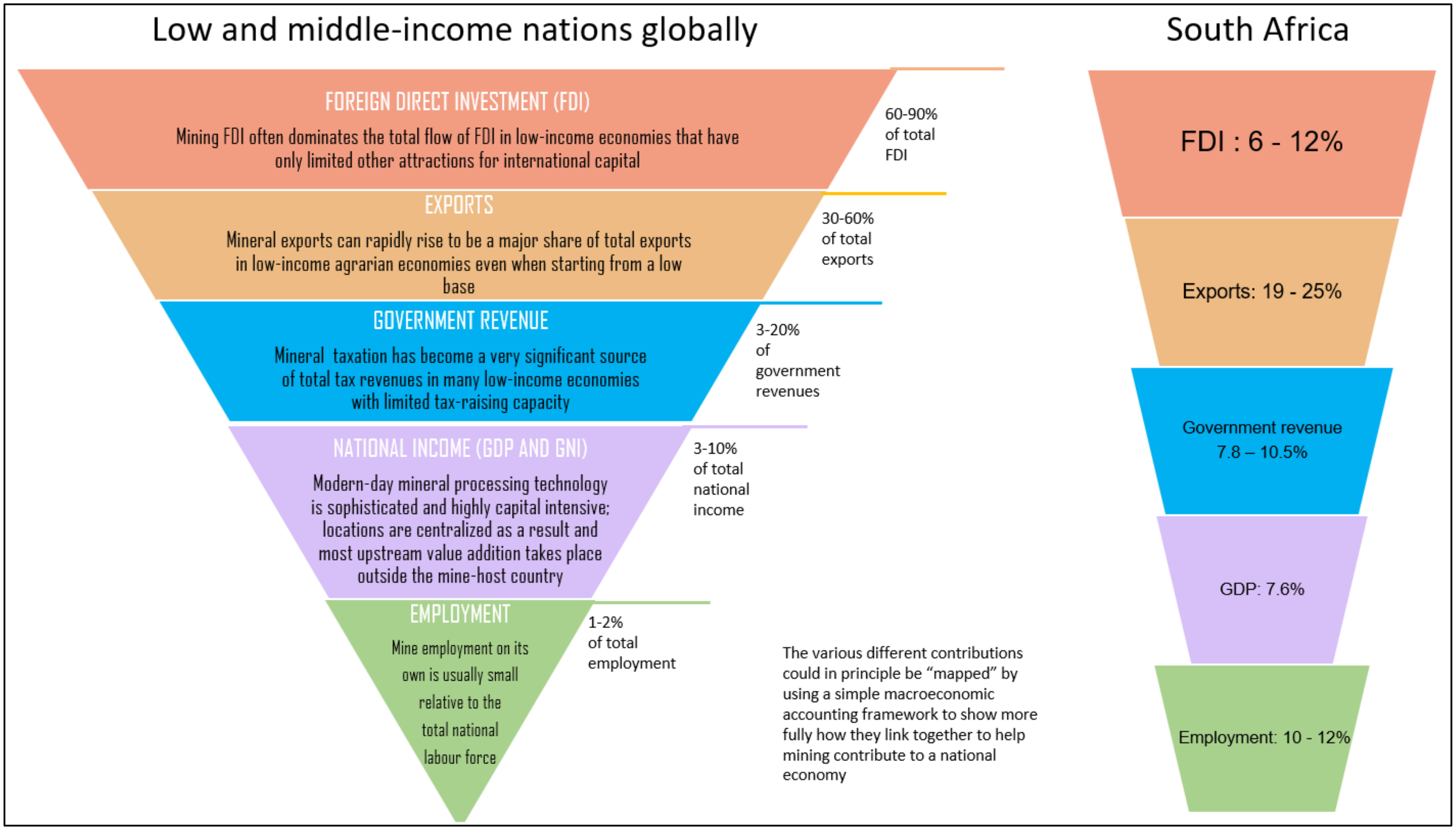


Figure 1.1 Schematic representation of mining's economic contribution in low to middle income countries compared to South Africa (adapted from Baxter, 2015)

South Africa is prone to export the bulk of its mineral commodities in their most basic form (Baxter, 2005; Walker and Minnitt, 2006). Mineral commodities do not undergo value adding processes for various reasons. Factors such as limited access to raw materials resulting from long term contractual agreements in the mining sector; non-feasible pricing mechanisms, inadequate infrastructure, insufficient research conducted on downstream processing methods, lack of skills, and trade barriers, hinder the transfer of beneficiated minerals (South Africa. Department of Mineral Resources, 2011). The exported, unrefined mineral commodities are used as inputs to manufacture various products in foreign countries. South Africa then imports the manufactured goods at a higher price compared to the revenue obtained from the sale of the unrefined minerals (Baxter, 2005). South Africa has thus developed an unsustainable growth trajectory of the economy because of the high number of manufactured products that the country imports (Samanga, 2015).

South Africa’s revenue from export sales of primary minerals has amounted to over R3 billion in recent years (Figure 1.2). Revenues generated by the mining sector from the sale of mineral commodities are variable because of the volatility of commodity prices. The sector thus has the potential to maximize the revenue generated from primary mineral commodities sales when prices are higher than expected (South Africa. Department of Mineral Resources, 2019)

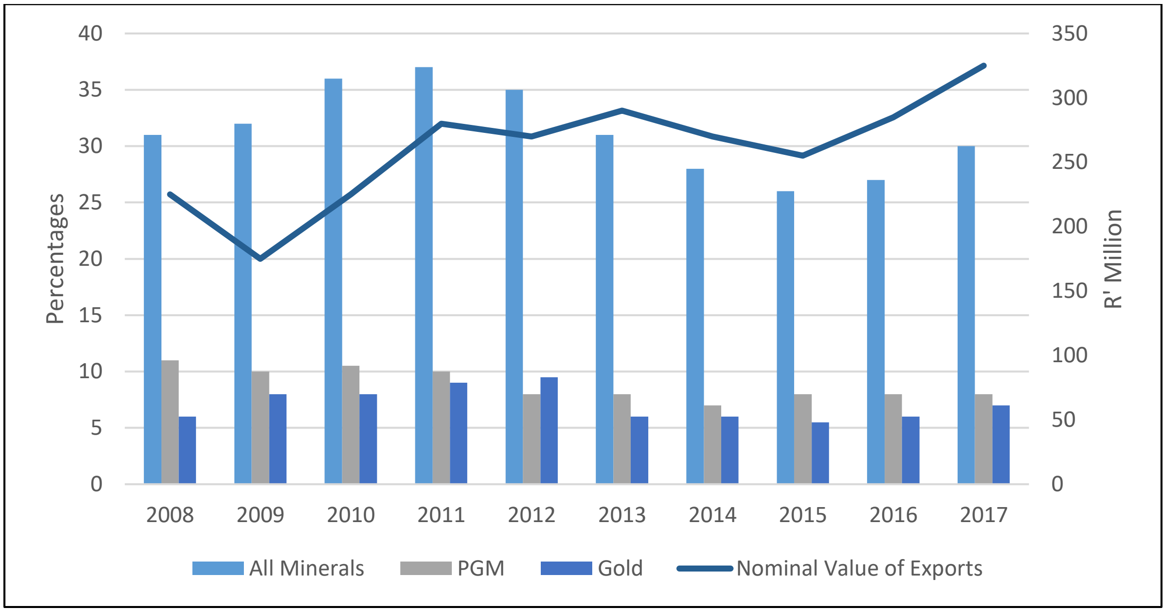


Figure 1.2 Graph depicting primary mineral export sales for South Africa from 2008 - 2017 (South Africa. Department of Mineral Resources, 2019)

In 2018, the South African mining sector accounted for 38% of the country’s total exports (Vegter, 2018). Mineral exports contained both primary minerals and secondary beneficiated products (Vegter, 2018). Table 1.1 outlines the local and export sales of primary minerals produced in South Africa (South Africa. Department of Mineral Resources, 2019).

Table 1.1 South Africa's primary mineral production, local sales and export sales in 2017 (South Africa. Department of Mineral Resources, 2019)

COMMODITY			**LOCAL SALES (FOB)**		**EXPORT SALES (FOB)**		**TOTAL SALES**	
		Quantity	**Quantity**	**Value (R)**	**Quantity**	**Value (R)**	**Quantity**	**Value (R)**
1. Precious								
Diamonds	ct	9 698 038	**	**	**	**	**	**
Gold	kg	137 133	34 181	17 849 770 286	119 592	65 102 402 101	153 773	82 952 172 382
Platinum- group metals	kg	260 264	**	11 966 659 946	251 354	85 069 236 519	**	97 035 896 465
Silver	kg	62 536	2 868	21 788 134	53 207	339 888 522	56 075	361 676 656
2. Semi-precious stones			*	*	*	*	*	*
3. Ferrous	t	102 574 312	*	17 694 772 007	79 064 124	87 568 978 007	*	105 263 750 014
4. Non-ferrous	t	2 840 493	1 954 152	4 981 922 909	937 368	15 788 242 066	2 891 520	20 770 164 975
5. Energy								
Coal	t	252 347 846	181 346 975	69 105 622 815	70 049 139	61 277 987 000	251 396 114	130 383 609 815
Uranium oxide	kg	303 684	**	**	**	**	**	**
6. Industrial				15 040 046 322		2 971 870 309		18 011 916 631
7. Miscellaneous				1 459 626 073		174 709 423		1 634 335 496
TOTAL				**146 046 946 887**		**328 523 968 686**		**474 570 915 573**

Except for coal, most primary minerals mined in South Africa are exported unprocessed (South Africa. Department of Mineral Resources, 2019). This affirms that a sizeable portion of the total export sales of country's primary mining output is not processed into other products. Most of the coal mined in South Africa is consumed by coal power stations (South Africa. Department of Mineral Resources, 2011; MCSA, 2020). In 2019, only 30% of the coal produced in South Africa was exported, and the remainder was consumed domestically. A total of 117.1 Mt of coal was consumed by Eskom in 2019, out of a total annual production of 258.9 Mt (MCSA, 2020). The country's residual coal production was used to generate the country's electricity (45%), a lesser amount (30%) was used for the generation of liquid fuels by Sasol and only 25% was used for industrial and household purposes (MCSA, 2020). Exported primary mineral commodities generate higher revenues than those sold locally. In 2017, the export sales value for primary mineral commodities exceeded that of local sales by a staggering 125% (South Africa: Department of Mineral Resources, 2019). The quantity sold and the commodity price both contribute to the higher revenues generated (South Africa: Department of Mineral Resources, 2019).

A similar trend is depicted for the sale of processed mineral products in South Africa. A larger quantity of processed minerals produced in South Africa are exported. This results in much higher revenue generated from the export sale of processed minerals, compared to local sales of processed mineral products (Figure 1.3) (South Africa. Department of Mineral Resources, 2019). The quantity of minerals exported is dependent on the adequacy of infrastructure available in the country (South Africa. Department of the Presidency, 2011).

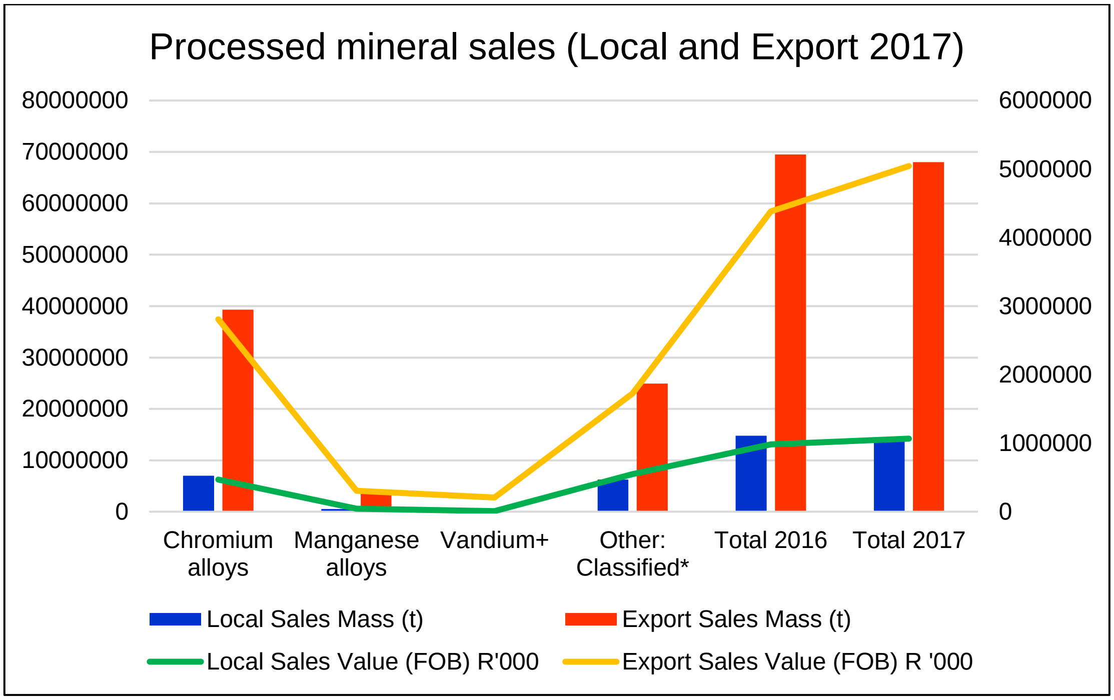


Figure 1.3 South Africa's processed mineral production, local sales and export sales in 2017 (South Africa. Department of Mineral Resources, 2019)

Note: + Contained vanadium

x Comprises aluminium, titanium slag, zinc metal, low-manganese pig iron, silicon alloys and metal, phosphoric acid, and antimony trioxide.

Investment in the mining sector depends on factors such as the economic and political stability of a country (The World Bank, 2019), the current market climate, infrastructure availability and other costs, to name a few (South Africa. Department of Mineral Resources, 2019). As seen in Figure 1.1, employment contribution (10% - 12%) and foreign direct investment (6% – 12%) are the South African mining sector's second and third-largest contributions to the country's economy (adapted from Baxter, 2015). In 2018, South Africa obtained

$5.3 billion in investment funding and the country was ranked the second-highest recipient of foreign direct investments in the continent (Mining Indaba, 2019). In 2019, FDI attained by South Africa in its manufacturing, mining and services sectors decreased to $4.6 billion (UNCTAD, 2020).

GDP (7.6%) and government revenues (6-8%) represent the smallest contributions made by the mining sector in the South African economy (Baxter, 2015). The GDP is impacted by the various income streams that result from mining activity, and it increases with growing levels of industrialization, linkage development and local consumption of industry inputs (ICMM, 2014). In 1980, South Africa’s mining sector accounted for the country’s second-highest GDP contribution (21%) in comparison to other sectors of the economy. The mining sector’s GDP contribution has evolved greatly since then (Figure 1.4); and although the sector has increased the value of its revenue contribution to the country’s total GDP, the sector’s GDP contribution has remained under 10% for over ten years (South Africa. Department of Mineral Resources, 2019). This is due to the expansion of the total size of the economy as discussed below.

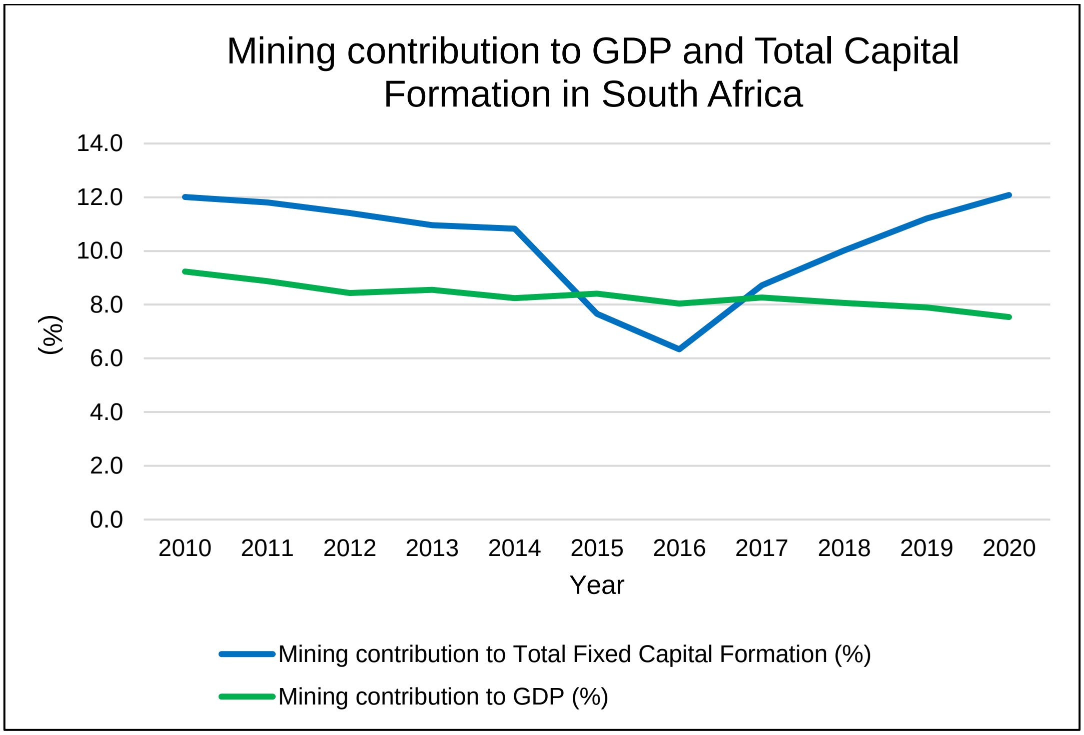


Figure 1.4 Graph depicting mining sector GDP and investment contribution to the South African economy from 2010 to 2020 (South Africa. Reserve Bank, 2021)

By 2016, South Africa's mining sector contribution to the country's GDP ranked 6th compared to other sectors of the economy. Even at that time it had become evident that the impact of the mining sector in the South African economy had declined; whilst other sectors (such as the finance and trade sectors) had expanded over the years (Vegter, 2018). In 2019, the South African mining sector contributed over R360 billion (8%) to the country's GDP. This represents a slight increase in revenue contribution compared to the previous year (MCSA, 2020).

With an estimated in situ mineral resource value of over R2.5 trillion and greater potential to uncover more reserves through exploration activities (South Africa. Department of Mineral Resources, 2019), South Africa holds a comparative advantage over most resource endowed countries (Lundall et al., 2008; Deloitte, 2011). The country boasts diverse mineral resources (South Africa. Department of Mineral Resources, 2011); and it is the world's leading producer of commodities such as platinum, chromium, manganese and vanadium, to name a few (Vegter, 2018). Mineral beneficiation activity can increase the South African mining sectors' contribution to the national GDP (South Africa. Department of Mineral Resources, 2011). The mineral beneficiation process creates job opportunities and acts as a catalyst for economic growth through the optimal extraction of mineral resources. Mineral commodities that have undergone refining processes increase the value of the mineral when it is sold (Deloitte, 2011). Mineral beneficiation stimulates ancillary sector development alongside the mining industry, and it also structurally transforms a resource-rich country (Hausmann et al., 2008).

By implementing local mineral beneficiation activities, regional socio-economic development and industrialization as described by the African Mining Vision could be achieved (Bam and De Bruyne, 2017). The Africa Mining Vision (AMV) realizes the comparative advantage that the African continent has with regards to its mineral resources. By developing and maintaining linkages with other African countries, industrialization can be achieved throughout the continent (South Africa. Department of Trade and Industry, 2018). The AMV seeks to address socio-economic development issues and achieve regional industrialization across the African continent through optimized linkage development between countries that have mineral resources (African Union, 2009; Bam and De Bruyne, 2017).

South Africa’s Mineral Beneficiation Strategy aims to achieve socio-economic development by optimizing the country’s linkages, promoting industrialization, and creating employment opportunities (South Africa. Department of Mineral Resources, 2011). It also has an objective to prioritize mineral value chains of some high-earning minerals found in South Africa, and to expand on the applied beneficiation activities in the country. Although South Africa hosts a variety of mineral commodities that have beneficiation potential, only ten strategic mineral commodities are targeted in the Beneficiation Strategy of South Africa (South Africa. Department of Mineral Resources, 2011). Only some minerals are considered for local beneficiation because first stage processing of minerals is both energy and capital-intensive (South Africa. Department of the Presidency, 2011). The mineral commodities selected are the most compelling minerals to generate optimum value through domestic beneficiation activity (South Africa. Department of Mineral Resources, 2011).

Some commodities beneficiated in South Africa are Platinum Group Metals (PGMs), gold, chrome, iron ore and manganese, to name a few (Lundall et al., 2008).

One mineral, however, that South Africa has in abundance yet does not receive much exposure, is antimony. The mineral commodity was historically mined in the Limpopo Province at the now-renamed Stibium Mopani Mine (formerly Consolidated Murchison Mine). The mine’s underground antimony reserves last reported at over 25 000t at 2.23%Sb (Village Main Reef, 2013). Antimony (symbol Sb) is a lustrous silvery–white metal. It is brittle and has both metallic and non-metallic properties. Antimony is not malleable and can be crushed into powder (United States. Geological Survey, 2006). It is also a poor conductor of heat and electricity (United States. Geological Survey, 2004; Anderson, 2012); however, antimony’s unique properties allow it to be used for both metallic and non-metallic applications. The mineral commodity is used in flame retardant applications and in the production of lead-acid batteries. Antimony is categorized as a critical and strategic commodity by the European Commission because of its end-use applications and its supply being dominated by China - thus posing some level of supply risk (European Commission, 2014). The United States of America (USA) also relies on imported antimony ores and concentrates to manufacture various antimony-bearing products (United States. Geological Survey, 2021).

Antimony deposits are found in various locations around the world (Figure 1.5). In China, the Xikuangshan deposit is the country's largest antimony deposit and covers an area of 16km^2 (Seal et al., 2017). The deposit has accounted for 800 000t of antimony production over its life and the mine has since shut down (Anderson, 2019). Other major antimony deposits are the Beaver Brook deposit in Canada, the Antimony Line in the Limpopo Province of South Africa, the Yellow Pine deposit in the United States of America and the Sarylakh and Sentachan deposits in eastern Russia (Seal et al., 2017).

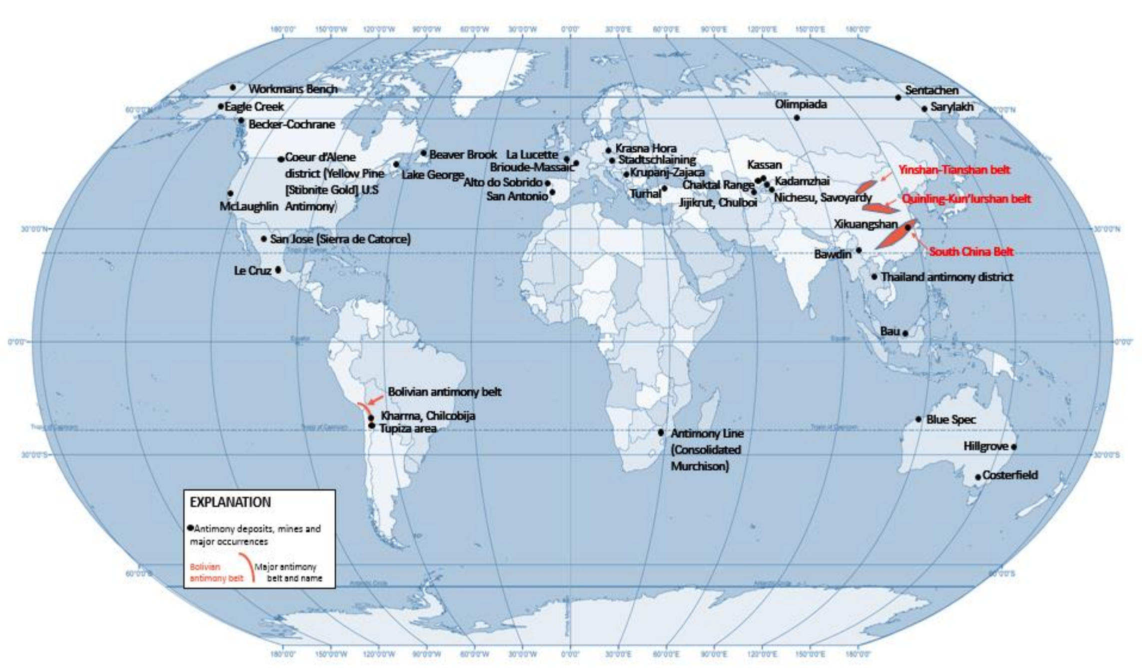


Figure 1.5 Global distribution of major antimony deposits (after Seal et al., 2017)

Two known antimony deposits are identified in South Africa (Figure 1.6). These are the antimony deposits located in the Murchison Greenstone Belt (MGB), in the north-eastern part of the Limpopo Province; and those located in the Barberton Greenstone Belt in the Mpumalanga Province (Graupner et al., 2014). This research focuses on the antimony deposit of the MGB in the Limpopo Province. This antimony deposit has been the sole source of antimony production in South Africa and the orebody represents the second-largest antimony orebody in the world (South Africa. Department of Mineral Resources, 2019). The antimony is hosted in the 35km long Antimony Line along the Murchison Greenstone Belt in South Africa (Vearncombe et al., 1992; Schwarz-Schampera et al., 2010).

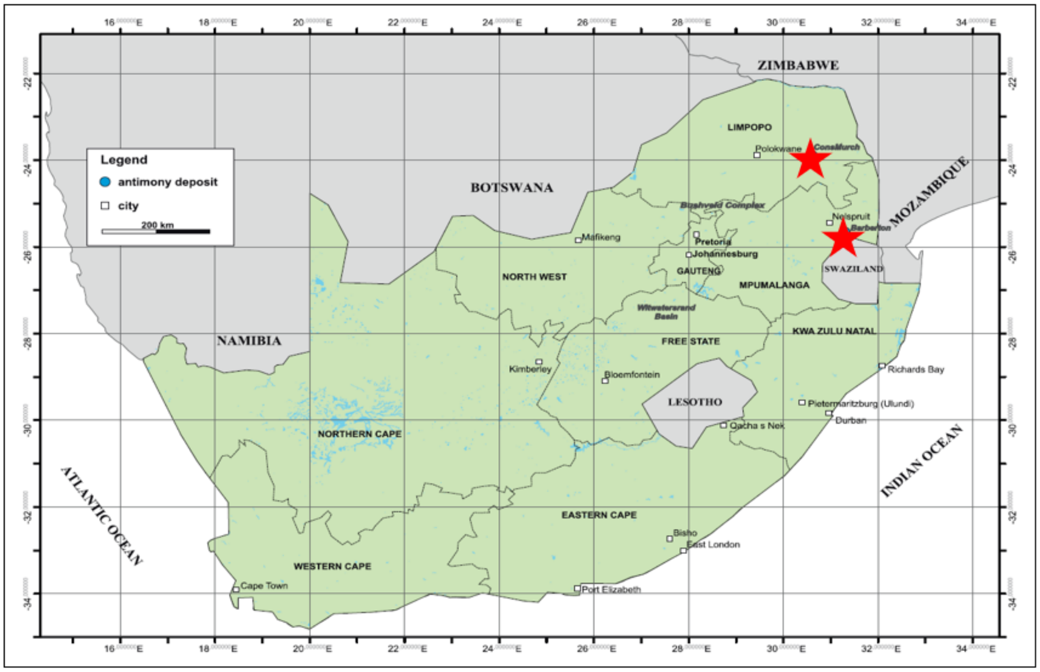


Figure 1.6 Map of depicting the location of antimony deposits in South Africa (after Graupner et al., 2014)

1.2 Purpose of the Research

Since introducing the South African Beneficiation Strategy a decade ago, South Africa has implemented beneficiation activities for a few of the country's mineral commodities. The aim is to optimize the benefits obtained through the extraction and processing of the country's minerals. The commodities that are selected in the Beneficiation Strategy were chosen because they showed the greatest potential (South Africa. Department of Mineral Resources, 2011). The South African mining sector generates most of its revenue through the export sales of its primary and processed minerals. In 2019, total primary mineral sales amounted to R538.9 billion and sales from export sales amounted to R348.2 billion (MCSA, 2020). South Africa does not optimally benefit from the extraction of most of its mineral resources because most of the minerals that are exported, are exported in their primary form. A large proportion of the few that are processed further, are also exported (South Africa. Department of Mineral Resources, 2019). Mineral beneficiation activity can unlock the full potential of the country's mining sector because it fuels the development of linkages across sectors and generates employment opportunities in the mining industry and ancillary sectors (United Nations Environment Programme, 2020). Manufacturing processed mineral products in South Africa increases the overall value of the resultant end-product; and this translates to increased revenues generated from the country's mining sector.

Antimony is identified as one of the world's critical and strategic mineral commodities by the European Commission. The mineral commodity is forecast to have supply and demand variations (Dupont et al., 2016); and this presents an opportunity for alternative suppliers to enter the global antimony market. South Africa has great potential to become an active player in the global antimony market by becoming a supplier of antimony to other countries. South Africa also has the potential to use its comparative advantage of hosting antimony resources, to address the socio-economic issues outlined in the country's Beneficiation Strategy.

This report aims to explore how South Africa can optimally position itself as a supplier of antimony and antimony-based products on a global scale. The report also aims to explore the country's potential to implement domestic antimony beneficiation activity by:

- Analyzing the various stages of the antimony value chain;
- Exploring the opportunities that may exist for South Africa to further increase value from this material by identifying the various factors and conditions that need to exist for optimal antimony beneficiation processes to occur in the country; and
- Determining the feasibility of a potential antimony value chain strategy for South Africa

To achieve this, the research will assess the antimony value chain at a global scale and align it with that of South Africa. Linkages and factors impacting antimony beneficiation are identified and assessed in comparison to the existing linkages in the country.

1.3 Research Report Structure

Chapter One: Introduction, Background and Purpose of Research

This Chapter introduces the research topic, background, and its purpose.

Chapter Two: The Mining Value Chain

A literature review is provided relating to the mining value chain, its linkages and mineral beneficiation in South Africa. Mining industry linkages and broad-based developmental impacts across industries within an economy are also examined. In addition, the stages of mineral beneficiation are discussed. The Chapter also explores the roles of government and the public relating to mineral beneficiation activities. Antimony value chain challenges and opportunities are noted.

Chapter Three: Global Overview of Antimony

This Chapter unpacks and analyses the various attributes of antimony on a global scale. An analysis of the geological background of antimony deposits and mineralization characteristics is presented. The Chapter also presents global antimony reserves and production trends. The antimony supply chain is also identified with its end-uses noted. A discussion on the current antimony market climate is given and supply and demand forecasts are noted.

Chapter Four: The Antimony Value Chain

This Chapter focuses on the stages of antimony beneficiation along the value chain. The Chapter breaks down each beneficiation stage and outlines some of the linkages and support activities required. Details of the required infrastructure and conditions required to facilitate each activity are noted. The resultant outputs from each stage are noted and discussed.

Chapter Five: The Antimony Value Chain in South Africa

This Chapter discusses South Africa’s past and current stance in the global antimony industry. Antimony deposits in South Africa are identified and a study is conducted on the antimony deposits located at Stibium Mine premises in the Limpopo Province. Historical antimony beneficiation practices undertaken in South Africa are discussed and the uses and applications of antimony in South Africa are noted. The Chapter concludes with an outline of the potential opportunities along the antimony value chain for South Africa.

Chapter Six: Discussion

This Chapter discusses the key findings obtained from the research.

Chapter Seven: Conclusion and Recommendations

This Chapter concludes on whether antimony beneficiation activity is a credible opportunity to be considered in South Africa. This Chapter reflects on the findings of the research and outlines recommendations on how South Africa can optimally beneficiate its antimony.

2 THE MINING VALUE CHAIN, LINKAGES AND MINERAL BENEFICIATION

2.1 Introduction

This Chapter explores the fundamental concepts related to the research topic. The mining value chain, its linkages and mineral beneficiation are discussed, and their importance noted. The Chapter begins with a broad overview of these concepts and their significance to the economic development of a country. South Africa’s position regarding mineral beneficiation is then discussed and potential mineral beneficiation opportunities are outlined.

2.2 The Mining Value Chain

Introduced by Michael Porter in 1985, a value chain is a set of value-adding activities that, when performed in sequence, optimum value is created in the overall product created (Vorster, 2001). The value chain process involves the transformation of raw materials into end-products of higher value (Ensign, 2001). Value-adding activities in a value chain are grouped into two generic types: namely primary activities and support activities (Porter, 1985). Primary activities are actions that physically make the product, to market and sell it. Support activities refer to the inputs required to facilitate the primary activity (Ensign, 2001; Vorster, 2001; Rajagopalan, 2015).

Value chain activities are separated according to their technological and strategic contributions to the creation of a specific product (Porter, 1985). Primary activities align in the form of a value chain; with each activity having a specific contribution to the resultant product created (Ensign, 2001; Rajagopalan, 2015). The value chain concept aims to have an end-product that meets the requirements of its customer. Value chains consider the competition and the market in which the product is sold (Rajagopalan, 2015). A value chain assists companies to develop strategies that optimally produce their end-product (Ensign, 2001).

Porter (1985) notes that primary activities, when assessed separately, help identify the potential sources of differentiation in the product formation process. The alignment of activities, and their effect thereof, influences a company's ability to gain a competitive advantage over its competitors (Ensign, 2001; Vorster, 2001). When a company conducts its activities more cheaply and more strategically and effectively than its industry peers, it gains a competitive advantage. Alternatively, competitive advantage is based on a company's ability to specialize in an end-product. Improving both primary and secondary activities lead to a sustainable competitive advantage in the industry (Ensign, 2001). The mining value chain describes the various processing activities involved in the extraction of minerals up to the creation of refined end-products.

The value of the product increases from one stage of activity to the next (Figure 2.1) (Vorster, 2001; Deloitte, 2011).

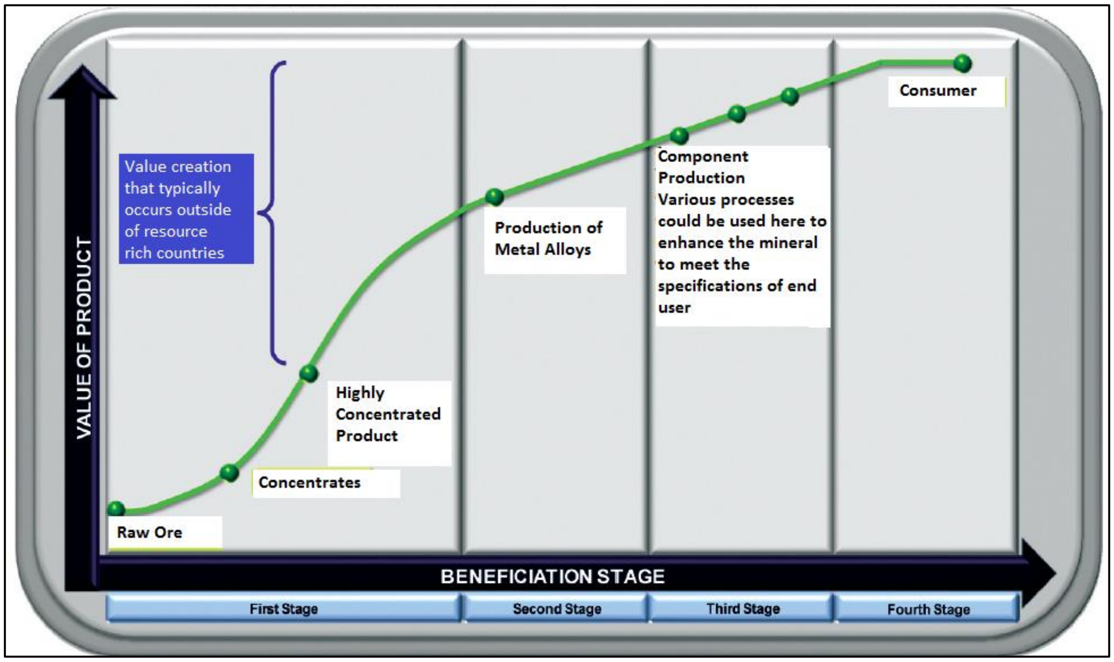


Figure 2.1 Representation of the mining value chain and increased value generated with each advanced stage of beneficiation activity (after Deloitte, 2011)

The strength of the mining value chain depends on factors such as an existing enabling policy and framework, adequate infrastructure and communities that are economically and environmentally sustainable (South Africa. Department of Mineral Resources, 2011; Ritchken, 2017). Each stage of the mining value chain has a series of capital goods, consumables and services required to facilitate the activity at that stage (Walker and Minnit, 2006; Ritchken, 2017). Each stage also requires specific skills to implement activities (Napier-Munn, 1997). By observing and analyzing the costs and benefits of each activity separately, the true value created by the activity is determined (Ensign, 2001).

2.3 Linkages in the Mining Sector

Linkages are the vertical relationships that exist between activities within a value chain. It is through linkages that effective economic policies are derived for developing countries (Hausmann et al., 2008). Linkages that form around the dominant sectors of the economy are important drivers of the economic development of a country (Ramdoo, 2013; Dietsche, 2014). They encourage the realization of broad-based development across various sectors and widen the spectrum of people sharing in the benefits generated through mining activity (Dietsche, 2014). Linkages also encourage the development of local supply chains within an economy (Ramdoo, 2013). The revenue generated from the mining sector may facilitate the establishment of local suppliers and linkages with other industries (ICMM, 2014). Upstream, downstream and sidestream linkages are found in the mining sector (Figure 2.2).

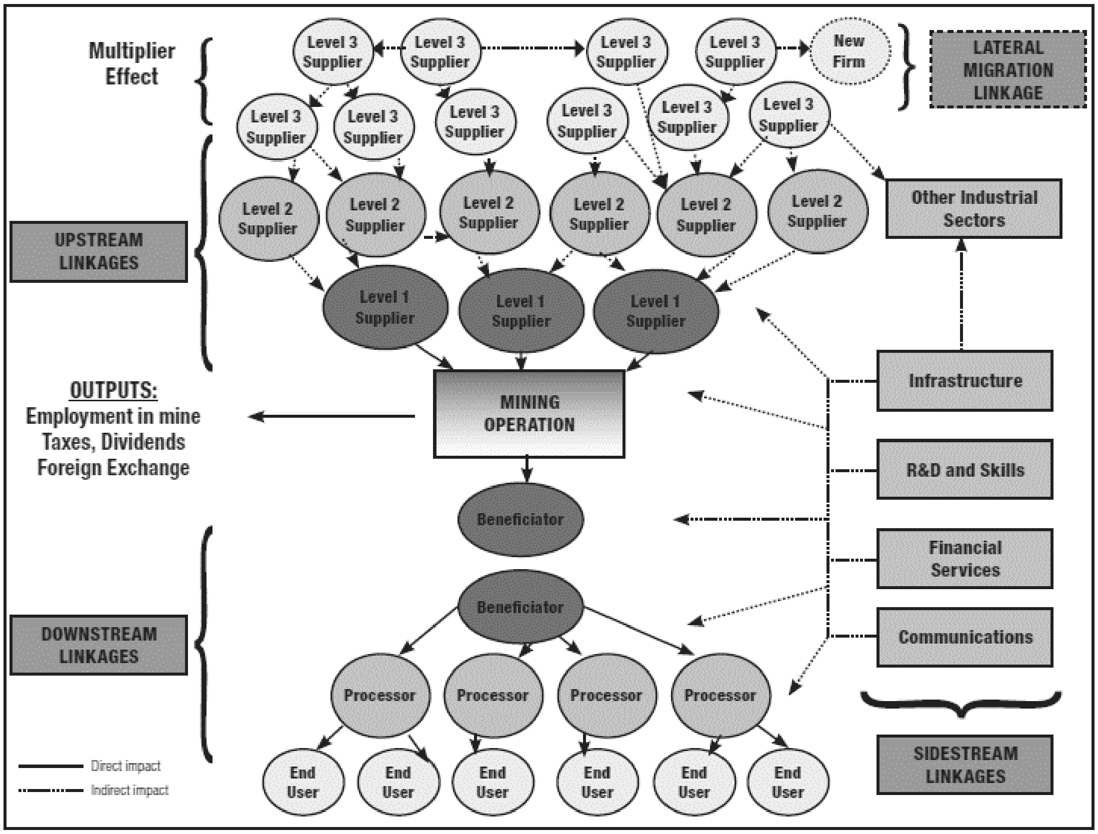


Figure 2.2 Schematic representation of the multiplier effect of mining industry linkages (Lydall, 2014)

The African Union (2009) notes that sustained growth and socio-economic development issues across the African continent are attainable through the establishment of effective linkages with the mining sector. The Africa Mining Vision aims to use mineral beneficiation to attain sustainable development across Africa (United Nations Environment Programme, 2020). Linkages enhance the benefits obtained from mineral beneficiation activity (Lydall, 2014). Effective linkages across various sectors of the economy can lead to positive spillover effects that generate value across industries (South Africa. Department of Trade and Industry, 2020). Mineral beneficiation activity may also cause technological spillovers in ancillary sectors where sidestream and downstream linkages exist (South Africa. Department of Mineral Resources, 2011). Linkages provide various businesses with the opportunity to source their requirements (skills, materials, services, etc.) in the most economical way possible when conducting beneficiation activities. They help businesses gain a competitive advantage and specialization in producing their products; and they also create opportunities for increased productivity and product diversification (UNECA and African Union, 2011).

2.3.1 Backward (Upstream) Linkages

Backward linkages refer to the relationships that the mining industry has with the sectors that supply inputs to the mining sector (Ramdoo, 2013). The mining sector has backward linkages with companies that manufacture equipment and machinery used to facilitate mining activity (Ramdoo, 2013; Jourdan, 2017). Backward linkages affect the social, economic and technical activities in a country. They also give rise to new market entrants, create employment opportunities, and increase skills and knowledge (Lydall, 2014). Most resource-rich countries do not have established input industries, and this causes mining companies to import goods and services. The lack of domestically produced inputs thus hinders the development of domestic upstream linkages (UNECA and African Union, 2011). South Africa has manufactured mining machinery and equipment over many years and has supplied such mining inputs to various countries in southern Africa. Zambia, Zimbabwe, Botswana are some countries that have imported such goods from South Africa, thus making them reliant on inputs sourced externally (Arndt and Roberts, 2018). It is beneficial for the mining sector to source locally manufactured inputs to facilitate mining activity because this contributes to the growth of the local economy (Ramdoo, 2013; Leeuw and Mtegha, 2016). Local suppliers of mining industry inputs are likely to have an advantage over other suppliers that are further away, geographically (Ramdoo, 2013). The quality of the supplied inputs also affects a country's decision to purchase them. As noted in (Ghebrihiwet, 2018), mining companies rely greatly on robust machinery and equipment that is used for the extraction of mineral commodities.

Strengthening backward linkages in mining-intensive countries also creates opportunities for the establishment of local enterprises that can directly supply inputs to the sector (Östensson and Roe, 2017). The provision of locally manufactured mining inputs also has the potential to develop linkage multipliers (Leeuw and Mtegha, 2016). The multiplier effect is common in upstream linkages as more and more enterprises form business linkages. Increased inputs from local service and goods suppliers lead to linkage development between the local suppliers and other smaller enterprises that supply goods and services to the mining sector. An increase in the interrelationships amongst suppliers of inputs in the mining sector expands the sphere of influence that the mining sector has in an economy (UNECA and African Union, 2011). The effectiveness of backward linkages is closely linked to the level of technological expertise, skills, knowledge, the state of the host country and the ancillary sector into which the inputs are supplied (Ramdoo, 2013).

2.3.2 Forward (Downstream) Linkages

Forward linkages refer to the linkages formed between the mining sector and the consumers of products generated from the sector (Ramdoo, 2013). The resultant output generated from mining activity acts as an input to ancillary sectors. As depicted in Figure 2.2, forward linkages facilitate the production of manufactured products that can be sold to an end-user (Lydall, 2014). The mining sector has downstream linkages with the manufacturing (steel making, polymers), agriculture (fertilizers), construction (cement supply, aggregate) and energy (fossil fuels, coal, oil, gas) sectors (Jourdan, 2017). Other industries that obtain inputs directly from the mining sector are the basic metals sector, motor vehicles, parts and accessories, electricity, and jewellery manufacturing to name a few (Maia, 2013).

Downstream linkages in the mining sector enable the transformation of the extracted mineral into a refined product of higher value (Lydall 2014). Ideally, a country’s manufacturing sector should source inputs from local suppliers to strengthen the country’s domestic economy and its industrialization (Ramdoo, 2013; Östensson and Roe, 2017). Developing local supplies of industry inputs and downstream industries also creates platforms for spillovers to exist. Partnerships between mining companies and refining equipment manufacturers give rise to mutually beneficial knowledge outcomes for all involved (Ghebrihiwet, 2018). Local consumption of mining output is promoted by the government in various ways. The government may impose export taxes and bans on companies that export unprocessed products (Hausmann et al., 2008). Countries such as Zimbabwe (banned the export of unrefined gold) and Indonesia (banned the export of unrefined minerals) have adopted this approach (Bam and De Bruyne, 2017). Governments also promote the consumption of locally produced goods by providing incentives (Deloitte, 2011). Regulations are implemented that provide tax incentives to mining companies that invest in local mineral beneficiation activities. This includes investing in research and development initiatives and purchasing equipment and machinery to conduct value adding processes (Collyer, 2016). There is a general notion that downstream linkages drive the structural development of a country. This however is not entirely true because structural transformation depends on the existence of robust ancillary sectors (Hausmann et al., 2008).

2.3.3 Sidestream (Horizontal) Linkages

Sidestream linkages in the mining sector refer to support services or industries that support the mining industry. Sidestream linkages help the mining sector to remain competitive (Lydall, 2014). Indirect employment and business opportunities in ancillary sectors of the economy result from existing sidestream linkages (Ramdoo, 2013). Sidestream linkages are important in that their availability and scale thereof affect the development of both upstream and downstream linkages along the value chain (UNECA and African Union, 2011). Sidestream linkages with the mining sector promote spillover effects such as infrastructure development within the local economy (Bam and De Bruyne, 2017). Other examples of sidestream linkages in the mining sector are skills, technological inputs, human resources and financial services to name a few (South Africa. Department of Mineral Resources, 2011; UNECA and African Union, 2011).

Numerous goods and services inputs exist throughout the mining value chain. The various inputs and services vary from one stage of the mining value chain to the next as depicted in Figure 2.3.

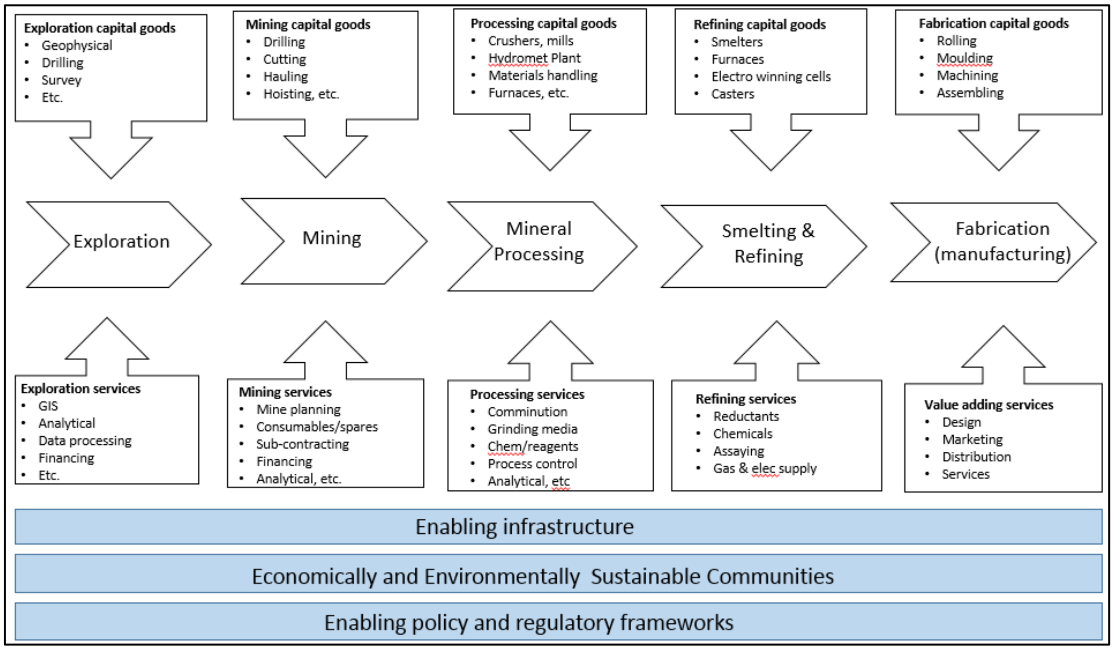


Figure 2.3 Schematic representation of the linkages and support services identified along the mining industry value chain (Ritchken, 2017)

All linkages are most effective in a country that has locally sourced inputs. In most developing countries, the mining industry is reliant on exports and non-domestic products to support its existence (Davis and Tilton, 2002). Good quality education and skills development are important for the development of local industry inputs (UNECA and African Union, 2011). Investment in skills, technologies and processing plants lead to effective industrialization throughout various sectors of the economy. The mining sector has become increasingly reliant on industrialization processes to facilitate the optimal extraction of mineral resources (South Africa. Department of Trade and Industry, 2020).

2.4 Mineral Beneficiation

Mineral beneficiation is a process that transforms a mineral into a product of higher value (Lydall, 2014). Value is added to the product throughout its production process (Baxter, 2005). Mineral beneficiation activities promote growth and economic development opportunities. Mineral beneficiation occurs in various countries around the world. Countries such as Papua New Guinea and Fiji have incorporated mineral beneficiation activities into their respective industries. Australia has investigated the further processing of its uranium, whilst Zambia has focused on the advanced processing of its copper ore (Hausmann et al., 2008). Botswana has successfully optimized the benefits garnered through the beneficiation of its diamonds through policy implementation and good governance (United Nations Environment Programme, 2020).

In most resource–rich countries, governments have realized the importance of having policies that promote the consumption of locally produced goods. Policies are used to promote industrialization, the development of local industries and job creation (African Union, 2009; Ramdoo, 2013; Bam and De Bruyne, 2017; United Nations Environment Programme, 2020). Industrial policies are used to drive value creation, design frameworks to attract new entrepreneurs involved in local manufacturing, and to develop additional manufacturing activities for the extractive sector (Ramdoo, 2013). The manufacturing sector is crucial in the mining value chain because manufactured products attain increased revenue through exports and trade. Exporting products of a higher value to countries that have varying exchange rates affects the revenue generated. Beneficiated products are not subjected to the same level of susceptibility of volatile commodity prices and market conditions as raw metal commodities, thus making beneficiation more attractive (South Africa. Department of Trade and Industry, 2013).

Mining companies that do not process their extracted resources further may not be doing so for various reasons. Locations of processing plants, inadequate infrastructure and overall costs of processing may make downstream processing an unattractive option for some (Östensson and Roe, 2017; South Africa. Department of Trade and Industry, 2018). Sometimes, the cost of constructing a processing plant exceeds the revenue to be generated from the sale of the refined end-product. It may also exceed the cost saved through the evasion of imposed export taxes. The construction of a processing plant may require imported infrastructure from another country if the host country does not have the expertise and ability to construct these locally. This increases the overall costs for the mining company (Östensson and Roe, 2017).

2.4.1 Mineral Beneficiation in South Africa

Mineral beneficiation was introduced as a component of South Africa's envisioned 'New Growth Path' (Deloitte, 2011; South Africa. Department of Mineral Resources, 2011). South Africa's Beneficiation Strategy presents an opportunity for the country to achieve various objectives by leveraging from the comparative advantage the country holds regarding its mineral wealth (South Africa. Department of Trade and Industry, 2013; Lydall, 2014). The Beneficiation Strategy also describes how mineral beneficiation can address South Africa's key socio-economic development issues. These include poverty, unemployment and inequality (South Africa. Department of Mineral Resources, 2011). The Strategy focuses on increased long-term value addition through the exploitation and exportation of its processed mineral products (South Africa. Department of Mineral Resources, 2011; van der Zwan and Nel, 2010).

The National Development Plan has prioritized some mineral commodities that have already advanced processing capacity and capabilities in South Africa (South Africa. Department of the Presidency, 2011). Prioritized value chains to promote backward and forward beneficiation activity are iron-ore and steel, polymers, titanium, platinum group metals, upstream mining inputs as well as oil and gas (Samanga, 2015). South Africa has large reserves of coal, iron ore, PGMs and gold to name a few. Coupled with favourable market conditions the extraction of these commodities has generated many jobs and has positively contributed to South Africa’s economic growth (South Africa. Department of Mineral Resources, 2011). The potential exists for the same benefits to be realized for South Africa through the extraction and processing of the country’s other mineral commodities (Samanga, 2015).

Linkages are important for implementing mineral beneficiation activities in South Africa (South Africa. Department of Mineral Resources, 2011). The country has a strong base of various mining industry inputs that supply the mining sector. Domestic mineral beneficiation activity is facilitated by promoting downstream linkages via the local consumption of extracted raw materials (Lydall, 2014). The country also boasts a range of tools and infrastructure required to facilitate mineral beneficiation (Walker and Minnitt, 2006). Hausmann et al., (2008) argued however, that implementing mineral beneficiation activity in South Africa would prove impractical because of the country’s inadequate state of ancillary sectors that partake in the value-adding process. This is plausible because the successful implementation of mineral beneficiation activity is highly reliant on the support and inputs from ancillary industries, and activities are not restricted to the mining sector (Baxter, 2005; Ritchken, 2017). Mineral beneficiation activities that are implemented locally are also dependent on the medium to long-term sustainability of the ancillary sectors required to facilitate the value-adding process (Bam and De Bruyne, 2017). Some sub-Saharan African countries in have failed to translate the extraction of mineral resources into sustainable developmental streams because they have not considered the robustness of ancillary sectors available within their respective local economies (Bam and De Bruyne, 2017). Weak linkages across sectors in South Africa limit the country’s ability to achieve optimum benefits from mineral beneficiation (Samanga, 2015). Strong linkages across sectors (Samanga, 2015), an enabling environment, available skills and infrastructure (South Africa. Department of Mineral Resources, 2011), and good governance are some conditions required to attain this (United Nations Environment Programme, 2020).

2.4.2 Stages of Mineral Beneficiation

Mineral beneficiation in South Africa was largely considered the mining sector’s responsibility (Deloitte, 2011). Baxter (2005) importantly notes that mineral beneficiation activities are reliant on both the mining and manufacturing sectors. For the successful implementation of mineral beneficiation practices, activities should be allocated to the appropriate sectors. Four generic stages of mineral beneficiation are noted. The advancement from one stage of beneficiation to the next depends on factors such as demand, commodity type and production processes (Lydall, 2014).

The four generic stages of mineral beneficiation are:

Stage One: Exploration, mining, ore extraction and concentrate production

Stage Two: Process concentrate into metal alloy

Stage Three: Use of metal alloy in the production of a refined product

Stage Four: Use of refined product in the manufacture of the final product for sale

Baxter (2005) notes that the first two stages of mineral beneficiation are more mining-focused and require skills predominantly from the mining sector; whilst the third and fourth stages are more manufacturing centered (Table 2.1). Turok (2014) also supports this notion. To facilitate beneficiation practices up to the fourth stage, the interface between the mining and manufacturing sectors needs to be better understood. There are variations in the amount of capital and labour required at each stage of activity (Baxter, 2005). As the beneficiation stages advance from one level to the next, the value of the output product increases (Lydall, 2014).

Table 2.1 The four stages of mineral beneficiation and associated characteristics (Baxter, 2005)

Stage	**Mineral Beneficiation process category**	**Process flow-chart**	**Labour Intensity**	**Capital Intensity**	**Industry Cluster**	
1	The action of mining and producing an ore or concentrate (primary product)	Run-of-mine ores → Washed & sized concentrates →	High	High	Mining	**MINING**
2	The action of converting a concentrate into a bulk tonnage intermediate product (such as a metal or alloy)	→ Matte/slags/ bulk chemicals → Ferro alloys/ pure metal →	Low	High	Mining	
3	The action of converting the intermediate goods into a refined product suitable for purchase by both small & sophisticated industries (semis)	→ Steel/ alloys → Worked shapes & forms →	Low	High	Refining/ Manufacturing	**MANUFACTURING**
4	The action of manufacturing a final product for sale	→ Worked shapes & forms → Worked shapes & forms	Medium to high	Medium to high	Manufacturing	

The last two stages of the mineral beneficiation process are more focused on the overall quality of the product produced, market access and ensuring that optimum value is achieved at the lowest cost (Baxter, 2005).

2.5 Beneficiation Opportunities for South Africa

For the successful implementation of the Beneficiation Strategy, certain criteria must be considered. Mining exports and their quantity depend on several factors such as mining policy, current market climate, the accessibility of mineral resources, energy and water supply (South Africa. Department of the Presidency, 2011). Post the global financial crisis of 2009 and the effects of low commodity demand, South Africa's mineral exports displayed a negative trajectory. The volatility of mineral commodity prices and the strength of the South African Rand also affect the country’s mineral export trends (South Africa. Department of Trade and Industry, 2018). The country’s inadequate infrastructure and policy frameworks deter investment in the mining sector (South Africa. Department of the Presidency, 2011). South Africa requires an adequate local supply of inputs for downstream sectors that facilitate the value addition process (South Africa. Department of Mineral Resources, 2011, Samanga, 2015).

Currently, no primary antimony is produced in the US or Europe. Antimony is imported from countries such as China to sustain their antimony demand (Dupont et al., 2016). South Africa may consider re-entering the global antimony market by including antimony in its list of minerals to beneficiate locally. This prospect may be plausible depending on the potential mineral beneficiation opportunities and challenges highlighted below:

2.5.1 Government and Stakeholder Participation

The relationship between the government, mining companies and workers is important for the growth and efficiency of the South African mining sector (South Africa. Department of the Presidency, 2011). Conflict between mining companies and stakeholders arises when the benefits from mining activity are unfairly distributed. Policy uncertainty may also deter investors from capitalizing projects in the mining sector (The World Bank, 2019). Government and private companies should work together to address the needs of the mining sector (Samanga, 2015; Östensson and Roe, 2017). The partnership between the government and the mining company is further enhanced when multilateral organizations act as third parties (Östensson and Roe, 2017); and when NGOs and civil society are included in the planning of development strategies (Dietsche, 2014; ICMM, 2014). For optimum outcomes, the roles and responsibilities of each party should be distinguished throughout the mining value chain (Alba, 2009). Some factors that affect the efficiency of the collaboration between the public and private sectors include the availability of skilled labour, availability and access to infrastructure, the strength of mineral policies (Dietsche, 2014); volatile commodity prices, the use of mechanized machinery and changes in demand for mineral commodities (The World Bank, 2019).

Mining activity can also negatively impact the environment and the health of both employees and nearby communities (The World Bank, 2019). Mining companies have a responsibility to ensure the health and safety of its workforce (MQA, 2018; MCSA, 2020). The Government is also responsible for redirecting the funds gained from mining activity into the economy to address the country's socio-economic development objectives (The World Bank, 2019). Governments contribute to the social responsibility of the citizens of the host country by investing in the skills development of workers and development of local mining communities (The World Bank, 2019). Mineral beneficiation provides an opportunity for stakeholder relationships to be strengthened by ensuring that all parties concerned with mineral beneficiation activity participate in the beneficiation process.

2.5.2 Mining Policy and Regulatory Practice

The South African government promotes domestic mineral beneficiation activity through diverse regulatory strategies. The Beneficiation Strategy of South Africa highlights the various policies, laws and incentives that encourage companies to beneficiate their minerals (Deloitte, 2011). South Africa has implemented export taxes, bans and regulated export restrictions on unprocessed minerals to promote local beneficiation activities (Hausmann et al., 2008). The entire mineral beneficiation process is underpinned by regulatory frameworks, which support its functionality (Ritchken, 2017). To optimize the benefits obtained through beneficiation activity, South Africa must have certain pre-existing conditions such as the guaranteed supply of raw materials and inputs, adequate infrastructure, availability of specialist skills and strengthened linkages across sectors in the economy. These factors are addressed through effective policy (South Africa. Department of Mineral Resources, 2011). Some regulations pertaining to mineral beneficiation in South Africa are noted below:

- Minerals and Mining Policy of South Africa (1998) focusses on the realization of optimal value from the extraction and local processing of country's mineral resources. The Policy also notes how Mineral Beneficiation can promote industrial development in the country (South Africa. Department of Mineral Resources, 1998).
- Mineral and Petroleum Resources Development Act, 2002 (MPRDA) promotes mineral beneficiation. The South African Minister of Mineral Resources and Energy has the authority to develop incentives for mining companies that domestically beneficiate their mineral commodities prior to selling or exportation. The Minister, through liaison with the Department of Trade and Industry, may also determine which minerals are economically viable to beneficiate locally.
- The Broad-based Socio-Economic Empowerment (BBSEE) Charter for the Mining and Minerals Industry (2018) identifies the promotion of the

beneficiation of South Africa’s mineral commodities as one of its primary objectives. In addition to the Charter’s requirement of mining companies to source some of their capital goods, services and consumables from BEE entities; mining companies may offset their ownership requirements against their levels of beneficiation activity conducted.

- Precious Metals Act, 2005 (PMA) encompasses all regulatory standards concerning the refining, smelting, beneficiation, use and disposal of the country’s precious metals. The Act gives preference to companies that plan to locally beneficiate their metals in the last stages of the mineral value chain. The Act makes consideration for the BBSEE Charter as stated above. It also authorizes the Minister with the right to allow or deny exportation of minerals when they have not been optimally beneficiated locally. Mines are encouraged to give a preference of provision of their minerals to entities that beneficiate locally.
- Income Tax Act focusses on the growth and development of the industrial sector. Tax incentives are used to encourage investment in new manufacturing initiatives and training. The Act provides a tax incentive for mining companies that undertake, and sponsor research and development related to mineral beneficiation activities. This indirectly results in improved local technological knowledge and enhanced skills that to facilitate mineral beneficiation activities (Collyer, 2016). The Act also promotes skills development by providing incentives to companies that invest in the

training of their workers (Collyer, 2016). Mining companies that provide capital expenditure on mining projects, exploration, mine infrastructure and equipment, to name a few, benefit from this Act. The Income Tax Act also makes provision for mining companies to benefit from the ‘manufacturing allowance’ by claiming as much as 40% of the cost of the manufacturing asset purchased (Collyer, 2016).

- The Industrial Policy of South Africa aims to promote industrial development in the country through investment from the private sector. The government is particularly focused on investment that is aligned with achieving the objectives targeted in the country’s various policies (South Africa. The Department of Trade and Industry, 2018). Mineral Beneficiation in South Africa is one of the key issues considered in the country’s Industrial Policy Action Plan which addresses unemployment and promotes industrialization in the South African economy (South Africa. Department of Trade and Industry, 2018).
- Minerals and Petroleum Resources Royalty Act (MPRRA) provides an incentive for mining companies that locally beneficiate their minerals. Mining companies are provided an opportunity to pay less royalty fees than those that do not beneficiate their minerals (South Africa, 2008). The MPRRA was implemented in 2009 and stipulates that those involved in the extraction of the country’s mineral resources must pay a fee for the permission granted to extract that mineral resource (South Africa, 2008;

van der Zwan and Nel, 2010; Cawood, 2011). The royalty is a form of compensation to the country as the mineral resource is finite and there is only one opportunity given to extract it (Cawood, 2011). Two formulae have been developed in the MPRRA to determine the amount to be paid. These are:

(i) Unrefined Mineral: 0.5 ÷ [EBIT/(Gross sales from unrefined mineral resource x 9)] x 100
(ii) Refined Mineral: 0.5 ÷ [EBIT/(Gross sales from unrefined mineral resource x 12.5)] x 100

Note: EBIT are the Earnings Before Interest and Taxes

One disadvantage of the MPRRA is noted by van der Zwan and Nel (2010). This is that the royalty rate is greatly influenced by the EBIT and the gross sales have less effect on the overall royalty amount paid. This may cause the royalty rate to significantly decrease the mining company's profits, and thus may discourage mining companies from refining their extracted minerals further (van der Zwan and Nel, 2010). Although both rates have a minimum rate of 0.5%, the rate for the refined mineral will not exceed 5% and the unrefined rate has a maximum rate of 7%. Cawood (2011) argues that the minimal difference between the two royalties may cause mining companies to increase their cut-off grades to still achieve their desired profits. The MPRRA structure should not deter investors and should encourage mining companies to refine their minerals (van der Zwan and Nel, 2010; Cawood, 2011). The MPRRA has noted the various commodities extracted in South Africa and the conditions required for the minerals to be classified as refined or unrefined. Antimony is considered refined when there is a minimum of 65% of antimony (Sb) in the concentrate (South Africa, 2008). Mining companies may determine the true financial benefit achieved from mineral refinement by comparing the amount of money to be contributed as royalties for an unrefined mineral against the cost of mineral refinement processing activities (Cawood, 2011; South Africa. Department of Trade and Industry, 2018). Royalties paid to the government contribute to the funds used to address the country's various socio-economic issues (van der Zwan and Nel, 2010).

2.5.3 Skills Availability

Resource endowed countries obtain a high number of skilled human capital from foreign countries because the local workforce has a lower level of skills (Davis and Tilton, 2002; The World Bank, 2019). In most developing countries, acquiring and retaining skilled personnel in the mining sector is challenged by limited pay scales and restrictive human resources policies (Alba, 2009). The availability of skilled personnel enhances a company's or country's competitive advantage over industry peers (Lundall et al., 2005). One challenge identified by Muir (2015) is that most qualified mining professionals in the country do not remain in the mining industry in the long term. Subsequently, the mining industry often experiences a shortage of certain skills. Factors such as the lack of experience required in certain roles, and inadequate qualifications affect skills availability in the South African mining sector (MQA, 2018). Mineral beneficiation activities require specific skills to facilitate activities along the value chain (United Nations Environment Programme, 2020). Adequate skills, research and development can bring forth innovative technological processes that can be implemented in the mineral beneficiation process. Advanced technological methods also generate improved recovery processes (Napier-Munn, 1997). Effective skills development training encompasses a hybrid of skills that can be applied across all sectors that are involved in the mining value chain (Walker and Minnitt, 2006; Östensson and Roe, 2017; MCSA, 2020). This is achieved by developing skills that overlap in the primary, secondary and tertiary sectors (South Africa. Department of Trade and Industry, 2018); thus, creating an environment for skills spillovers across ancillary sectors (Ghebrihiwet, 2018). South Africa has researched ways to incorporate advanced technological methods to extract ores that occur kilometers below surface. Subsequently, the mining sector directly employs a fewer number of people. However, the government has considered ways to absorb the excess labour into other industries through skills sharing initiatives (South Africa. The Department of Trade and Industry, 2018).

Constantly developing skills that are aligned with global standards ensures that skilled workers remain in resource-rich countries (Alba, 2009). Skills development is crucial for the development of sidestream and downstream linkages (South Africa. Department of Mineral Resources, 2011). Downstream beneficiation activities employ both skilled and semi-skilled labour (Lundall et al., 2008). The role of government in skills development and training is vast. Governments can devise specialized labour structures and policies that encourage local skills development (ICMM, 2014; Östensson and Roe, 2017). The government may also consider becoming actively involved with skills training at the early stages of the mining value chain. This is achieved by facilitating the training of the local population in skills that are used throughout the mining project (ICMM, 2014). This pro-activeness would ensure that the local population has adequate skills that are required to conduct the work. Mining companies would subsequently source skills locally as they then would be readily available (UNECA and African Union, 2011).

The South African government has noted the importance of aligning the relevant skills shortages for mineral beneficiation with those that are being provided by various institutions (South Africa. Department of Mineral Resources, 2011). South African educational and training accredited bodies such as the Mining Qualifications Authority (MQA), work closely with the government to identify industry skills shortages and provide training services for workers in the mining sector (MQA, 2018). Skills availability in the South African mining sector, and the level thereof, has declined considerably over the years (Walker and Minnitt, 2006). The country continues to struggle to find suitable candidates to fill certain positions in the mining sector because of skills shortages (MQA, 2018). Skills shortages have continued to hinder the growth of the mining sector (MCSA, 2020), and fewer students have pursued qualifications in mining-related fields (Walker and Minnitt, 2006). The country also has a declined number of skilled personnel in the artisanal and engineering fields (Leeuw and Mtegha, 2016). Walker and Minnitt (2006) note that South Africa does not produce the required standard and quantity of metallurgists required to facilitate the processing industry requirements. There is also a decline in the number of apprenticeship training conducted by mining companies (Walker and Minnitt, 2006). Mining companies are obligated to provide skills development in the mining sector. South Africa’s Skills Development Act and the Mining Charter have made it mandatory for mining companies to contribute a small percentage of their payroll to skills development and human resource development (MCSA, 2020).

2.5.4 Research and Development

Research and development (R&D) is important in the mining sector and throughout its value chain. Mining companies use research and development to identify innovative ways to facilitate mining activity and to empower their workers with advanced skills (South Africa. Department of the Presidency, 2011). South Africa's level of research and development pertaining to the long-term development and focus on innovation in the country's minerals sector has declined over the years. Research and development have shifted more towards the short to medium term focus on product development and design (Walker and Minnitt, 2006). Loss of expertise through restructuring and emigration in the 1990s led to a decline in the quantity of research and development being undertaken by mining companies (Walker and Minnitt, 2006). Limited research and development in South Africa restrict the attainment of optimum benefits from mineral beneficiation activities (Lundall et al., 2008; South Africa. Department of Mineral Resources, 2011). In addition, the lack of investment into R&D can also lead to the non-establishment of potential linkages (Walker and Minnitt, 2006).

R&D collaboration between companies within the same cluster creates an opportunity for knowledge spillovers. Knowledge spillovers may also occur between global companies and local ones. Research joint ventures amongst firms are helpful because they prevent the duplication of ideas whilst sharing knowledge and expertise (Ghebrihiwet, 2018). The South African mining industry has historically advanced from R&D initiatives (Ghebrihiwet, 2018). The country has developed hydraulic mining equipment that has been used to extract gold from the country’s deepest gold mines (Ghebrihiwet, 2018). South Africa has subsequently become a dependable supplier of mining equipment for its regional counterparts (Arndt and Roberts, 2018; Ghebrihiwet, 2018). To sustain the mining inputs cluster, component suppliers of equipment parts require modernized research and development to keep abreast of industry trends. R&D also helps the cluster to remain competitive in a continually evolving industry (Walker and Minnitt, 2006; South Africa. Department of Trade and Industry, 2013; Arndt and Roberts, 2018).

Long-term research and development activities are not encouraged by mining companies (Ghebrihiwet, 2018), and engineering companies (Walker and Minnitt, 2006). Mining companies may deter from solely undertaking research and development initiatives because research requires capital, it takes time and it contains a certain level of risk (Walker and Minnitt, 2006). R&D initiatives driven by mining companies are thus predominantly achieved through collaborative efforts. Collaborations occur between the mining company and entities such as research organizations, academic institutions, engineering suppliers and equipment manufacturers, to name a few (Walker and Minnitt, 2006; Ghebrihiwet, 2018). South African state-funded research entities such as the Centre for Scientific Research (CSIR) (Walker and Minnitt, 2006; Arndt and Roberts, 2018) and the Council for Mineral Processing and Metallurgy (Mintek) conduct research that is beneficial to the advancement of the minerals sector (Walker and Minnitt, 2006). These institutions, however, are seen as more consultancy type firms as skills are not directly imparted to those employed by the mining sector (Walker and Minnitt, 2006).

The South African manufacturing sector also encourages the use of innovation and technology in the sector (South Africa. Department of Trade and Industry, 2013). Foreign manufacturers invest more in innovation compared to local manufacturing companies (Ghebrihiwet, 2018). This results in local manufacturing companies being less productive. The technological gap between global manufacturing companies and local manufacturers hinders the development of knowledge and technological spillovers (Ghebrihiwet, 2018). It is evident that investment into R&D in South Africa creates an opportunity to optimize the benefits obtained from mineral beneficiation activity throughout the mining value chain.

2.5.5 Linkages for Industrial Development

Backward and forward linkages along the mining value chain promote industrial development (African Union, 2009). Domestic linkages in the mining sector are crucial for local industrial development (Ghebrihiwet, 2018). South Africa can use its mineral wealth to promote domestic industrialization activity. The country’s industrialization standards are currently below its desired potential.

This can be mitigated through strengthened linkages between various sectors (Samanga, 2015). Linkage development across different sectors maximizes the objectives of mineral beneficiation (Lydall, 2014). Improving local mining sector linkages enables South Africa to export goods of a higher value (Leeuw and Mtegha, 2016). Strengthening linkages across ancillary sectors and driving industrial development also creates employment opportunities (Samanga, 2015). Industrial policies that are centered on the local beneficiation of mineral resources are crucial to the growth and development of the economy in a country. Industrial policy should embrace the roles of various sectors in the economy (Ramdoo, 2013). Through South Africa’s Industrial Policy Action Plan, the country can promote local industrial development and create long-term value from the extraction and consumption of its mineral resources (South Africa. Department of Trade and Industry, 2018).

2.5.6 Increased Revenue Generation

A product that has undergone beneficiation generates more value from its sale compared to a product that has not undergone value-addition. South Africa has the potential to generate higher revenues from exporting beneficiated products. An increase in potential revenue generated would positively impact the country’s economy (South Africa. Department of Mineral Resources, 2011). Revenue generation is also dependent on the cost of beneficiation activity (South Africa. Department of Mineral Resources, 2011; South Africa.

Department of Trade and Industry 2018), and how well integrated and robust are the conditions required to facilitate the beneficiation process. The five value chains selected in South Africa’s Beneficiation Strategy are included taking into consideration how their beneficiation can be enabled in the most cost-effective way (South Africa. Department of Mineral Resources, 2011). For refiners, sourcing the ore locally may lower transportation costs (Hausmann et al., 2008); however, the value-adding process has other costs to consider. For example, high electricity consumption and costs incurred for conducting beneficiation activities beyond the first stage (South Africa. Department of the Presidency, 2011; Ritchken, 2017); may result in the non-realization of the financial benefits obtained from localized value-adding processes.

2.5.7 Inadequate Infrastructure

The lack of infrastructure in a resource endowed country negatively affects the country’s ability to industrialize (African Union, 2009; UNECA and African Union, 2011). It also hinders the implementation of domestic beneficiation activities (Ramdoo, 2013; Ritchken, 2017), and the country’s ability to facilitate the trade of its mineral resources (Arndt and Roberts, 2018). South Africa’s mining sector relies on infrastructure such as roads, railways, energy and water (Turok, 2014; MCSA, 2020). By improving South Africa’s water, transport and energy infrastructure, the country has an opportunity to maximize the quantity of minerals it exports (South Africa. Department of the Presidency, 2011). Poor infrastructure development deters investors from investing in the South African mining sector (South Africa. Department of Mineral Resources, 2019). Roads and railways are essential for the transportation of ore (Graupner et al, 2014; South Africa. Department of Mineral Resources, 2019). South Africa has the longest road network in Africa (Graupner et al., 2014; South Africa. Department of Mineral Resources, 2019). The country's roads extend over many kilometers and across various regions (Graupner et al., 2014). Major transport routes in South Africa were initially designed for the transportation of non-value-added commodities (Samanga, 2015). Although locally sourced minerals that are beneficiated in the host country have lower transportation costs than those that need to be exported for further processing (Hausmann et al., 2008), when transportation costs are considered too high compared to the potential revenue generated through beneficiation activity, companies may opt not to beneficiate their minerals (Hausmann et al., 2008; Rajagopalan, 2015). Sufficient energy supply is required by both the mining and manufacturing sectors to extract and process minerals (South Africa. Department of Mineral Resources, 2019). High capital and high energy consumption required to operate refineries and smelters may ultimately lead to other sectors not receiving enough energy and capital for their projects. High electricity costs pose a threat to facilitating downstream beneficiation. There is also an additional challenge caused by unreliable power supply to facilitate downstream processing activities (South Africa. Department of the Presidency, 2011).

2.6 Conclusion

This Chapter provides a review of the various concepts pertaining to the research. The mining value chain, linkages and mineral beneficiation are discussed. The Chapter also describes backward, forward and sidestream linkages and their significance in the mining sector, and in a country's economy. The mining and manufacturing sectors are closely related in that they are reliant on one another's output to facilitate their respective activities (Ramdoo, 2013). South Africa has available mining industry inputs such as machinery and equipment, thus strengthening the domestic backward linkages that exist between the mining and the manufacturing sectors (Lydall, 2014). As noted by Hausmann et al., (2008), the successful implementation of mineral beneficiation activity in South Africa depends on the existence of robust ancillary sectors. An effective linkage between the mining and manufacturing sectors makes it easier for beneficiation activity to occur (Baxter, 2005). Having existing regulatory policies that promote localized mineral beneficiation activity, and access to adequate infrastructure determine the success of the implemented beneficiation activities. The South African government has several legislative policies that encourage domestic value addition of its minerals. There are notable opportunities in the regulatory policies which promote localized beneficiation activity at various stages of the value chain.

Only some minerals in South Africa undergo further processing because processing activities require high capital and consume high amounts of electricity (South Africa. Department of the Presidency, 2011). Although mineral beneficiation establishes itself as a potential catalyst for various development initiatives across sectors, the cost of implementing mineral beneficiation activities may outweigh the benefits, thus making it difficult to realize optimum benefits. It is important to consider all factors affecting mineral beneficiation activity such as location advantage and the availability of adequate skills and infrastructure (South Africa. Department of Trade and Industry, 2018). The Chapter contributes to the research by describing how mining industry linkages and mineral beneficiation activities are beneficial to a country's economy. The Chapter also identifies some challenges that hinder the successful implementation of beneficiation activity in a host country.

3 GLOBAL ANALYSIS OF ANTIMONY

3.1 Introduction

To conduct a comparative assessment of South Africa’s current stance in the global antimony market, an analysis of the global antimony market is required. Chapter Three sequentially unpacks the antimony value chain, assessing it at a global scale (Figure 3.1). The geological characteristics of antimony mineralization, antimony production and its uses and applications are discussed.

Chapter Four unpacks the four antimony beneficiation stages separately. The findings thereof are compared to South Africa’s current conditions in Chapter Five. Assessing each aspect of the antimony value chain at a global scale will help identify antimony beneficiation opportunities along the antimony value chain for South Africa.

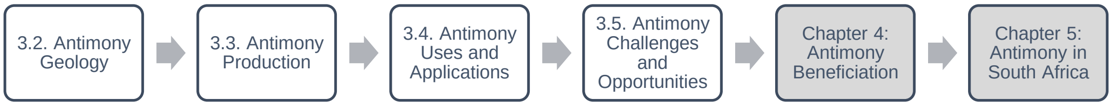


Figure 3.1 Sequential breakdown of global antimony assessment

3.2 Geological Background

Antimony deposits generally form in low-temperature and shallow depth, hydrothermal solutions (United States. Geological Survey, 2004). The deposits occur as either epithermal fissures, joint fillings or replacement nodes. They are also not confined to any specific lithological type or age (United States. Geological Survey, 2004). Graupner et al., (2014) define five different types of antimony deposits. These are namely, hydrothermal-type deposits hosted in quartz-carbonate veins, polymetallic base vein deposits, carbonate replacement type deposits, tin-base metal deposits associated with granite and lastly, antimony deposits generated as a precipitate from hot springs. These are described further below:

- The geological deposition environment for hydrothermal-type antimony deposits is possibly a subduction zone and island arc setting. Hydrothermal type antimony deposits are hosted in greenstone belts and characterized by large stockworks of quartz stibnite veins. The stibnite occurs as veinlets or disseminations. Other associated elements such as copper, zinc and lead are miniscule compared to the antimony found in such deposits. Lithologies along the belt comprise shales, limestone, quartzite, granite and volcanic lithologies. Some examples of such deposits are found along the Antimony Line in South Africa and the Olimpiada antimony deposit in Russia (Graupner et al., 2014). In Deloitte et al., (2017), greenstone-hosted antimony deposits are noted to be significant because they are large and have grades ranging from 1.5% and 25% stibnite content.

- Polymetallic base vein type deposits are hosted in post-collisional zones of metasedimentary or magmatic terranes. The mineralization is structurally controlled and thus occurs within vein breccia. Antimony is hosted in stibnite and other antimony-bearing minerals. The deposits also contain base metals and silver. The Bolivian antimony belt is an example of this deposit type (Graupner et al., 2014).

- Carbonate replacement type deposits indicate syn-to-post collisional tectonic environments. Quartz and stibnite mineralization is hosted in sedimentary or metasedimentary lithologies such as limestone. The mineralization occurs as numerous high-grade stockwork veinlets of almost pure stibnite. The large Xiguanshan antimony deposit in China is an example of a carbonate replacement type of antimony deposit (Graupner et al., 2014).

- Granite-related tin base metal deposits are found in post-collisional extension zones. They commonly occur behind continental margins. The antimony mineralization is found in quartz-carbonate veins which also contain arsenic and gold. These types of antimony deposits are found in Australia and the USA (Graupner et al., 2014).

- Hot spring precipitate deposits are generated in shallow marine, volcanic and hot spring environments. The antimony mineralization occurs with elements such as arsenic and silver. These types of deposits are found in Indonesia and Russia (Graupner et al., 2014).

Antimony is commonly found in association with other elements (Seal et al., 2017). Antimony ores are considered chalcophiles as they are commonly associated with sulphides and oxides (United States. Geological Survey, 2004). Copper, lead and silver may also be found in association with antimony ores (United States. Geological Survey, 2004; Anderson, 2012; Seal et al., 2017). Other elements include gold and mercury (Anderson, 2012; Krenev et al., 2015). Table 3.1 lists some common antimony-bearing minerals.

Table 3.1 Common antimony-bearing minerals (United States. Geological Survey, 2004)

Name	**Composition**
Stibnite	Sb_2S_3
Jamesonite	$PbSb_2S_5$
Senarmontite, Valentinite	Sb_2O_3
Stibiconite	$H_2Sb_2O_5$
Bindheimite	$Pb_2Sb_2O_7.nH_2O$
Kermesite	Sb_2S_2O
Tetrahedrite	$Cu_8Sb_2S_7$

Antimony is found in over a hundred minerals, however, the most common ore mineral from which antimony is derived is stibnite (Sb_2S_3) (Anderson, 2012; Seal et al., 2017). Stibnite occurs in quartz veins (Anderson, 2012), and it has about 71% native antimony content (Krenev et al., 2015).

3.3 Global Antimony Production and Reserves

Antimony reserves are unevenly distributed throughout the world (United States. Geological Survey, 2006; Seal et al., 2017). Prominent antimony deposits are found in China, Bolivia, Russia, South Africa and Australia, to name a few (Graupner et al., 2014). As of 2020, China hosts a sizeable portion of global antimony reserves, followed by Russia and Bolivia (Figure 3.2). Prior to halted antimony production in 2014, South Africa was reported to have over 25 000t of underground antimony reserves (Village Main Reef, 2013).

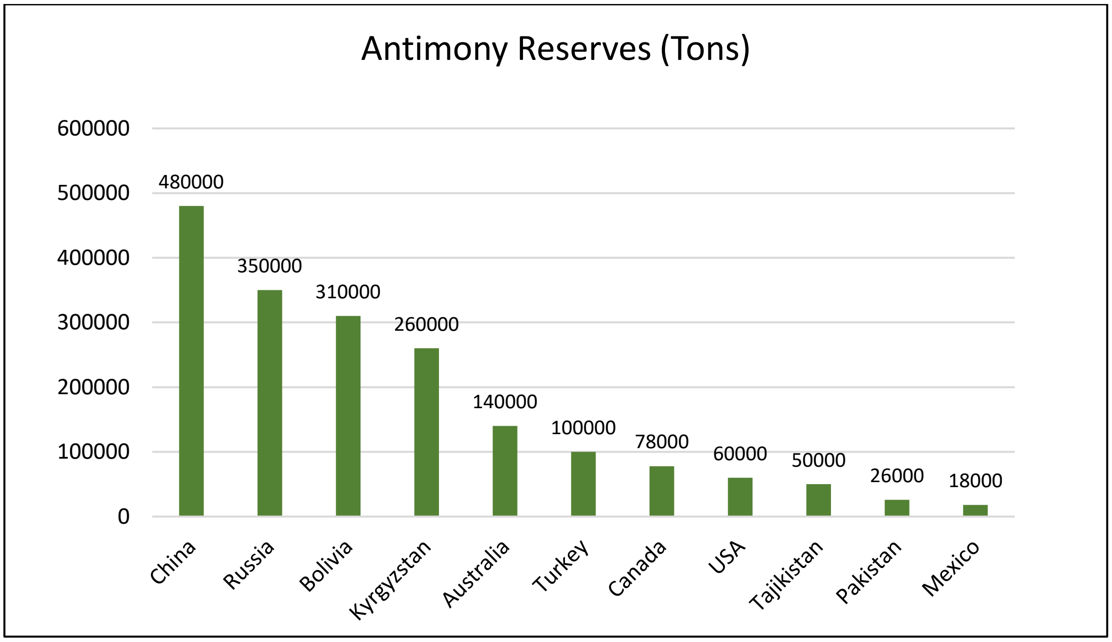


Figure 3.2 Global antimony reserves in 2020 (United States. Geological Survey, 2021)

Antimony production is also unevenly distributed across the world (Seal et al., 2017). Countries such as China, Russia, Tajikistan and Turkey are prominent global antimony producers (Anderson, 2012; Anderson, 2019). China is the world's largest producer of antimony and it hosts the largest antimony reserves (Anderson, 2019). It has globally dominated antimony production for decades, but over recent years, antimony production from China has been declining. China dominates both antimony production and processing capacity because of the country's large antimony reserves and high number of smelters.

Countries in Europe and the United States rely on imported antimony metal from China to produce high end antimony products (Dupont et al., 2016). In 2017, China produced 66% of global antimony and Russia had significantly increased its antimony production (The Crucible, 2018); and Russia has recently become the world’s second-largest antimony producer (Roskill, 2018a). Figure 3.3 below depicts the gradual decline of antimony production output from China and Russia’s evident increase in antimony production output. Global antimony production has gradually increased from just over 137 000t in 2017 to 162 000t in 2019.

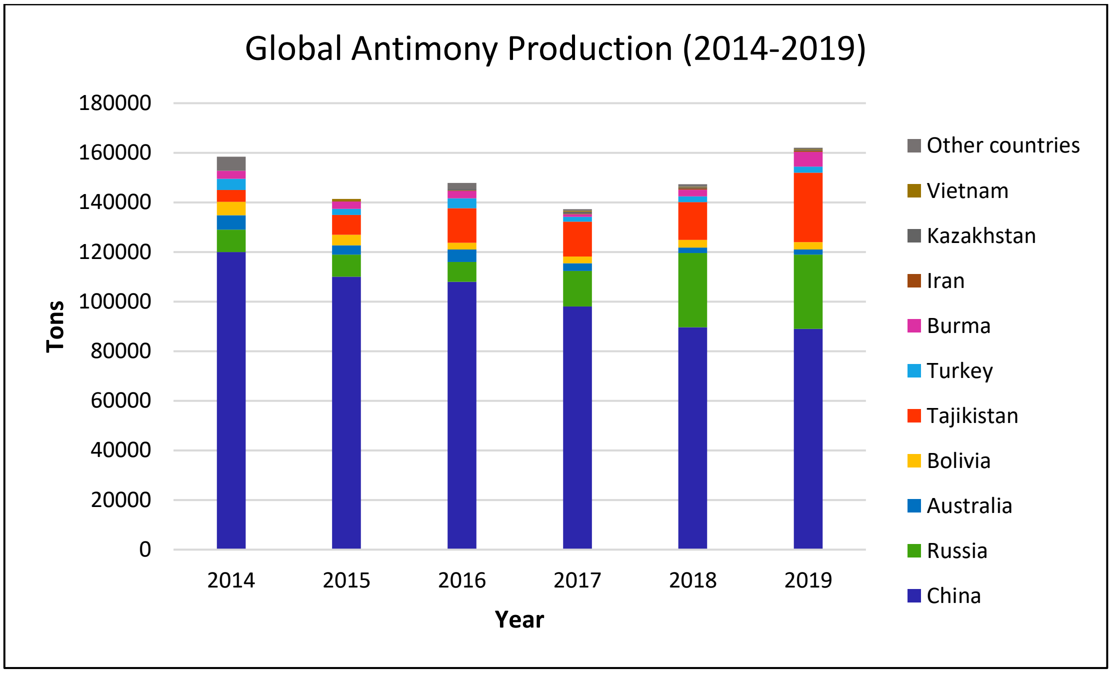


Figure 3.3 Visual representation of global antimony production over recent years (Data retrieved from United States. Geological Survey, 2016 – United States. Geological Survey, 2020)

Antimony is commonly mined as a primary commodity or as a by-product when found in association with other commodities (United States. Geological Survey, 2004; Seal et al., 2017). Mines that primarily mine antimony are typically smaller than those that extract antimony as a by-product (United States. Geological Survey, 2004). Antimony orebodies are mined using either open pit or underground mining methods. Small antimony orebodies are generally mined on a small scale and may use open pit methods. Antimony orebodies located at greater depth are accessed by an adit or vertical shaft. The applied mining method primarily involves stoping of the orebodies and developing underground tunnels along the vein that hosts the antimony (United States. Geological Survey, 2004).

In South Africa, antimony production ceased in 2014 (Roskill, 2018a; South Africa. Department of Mineral Resources, 2019). This was due to liquidation of the country's sole antimony mine (South Africa. Department of Mineral Resources, 2019); whilst the Canadian mine, Beaver Brooke ceased antimony production in 2012 due to falling antimony prices at the time (Roskill, 2019a). Seal et al., (2017) note that the current market climate favours bulk antimony production from large antimony deposits. Countries in Europe and the United States do not have large, lone antimony deposits that are economically favourable to mine (Seal et al., 2017). It is advantageous to extract antimony from deposits that contain antimony and other precious metals that can be mined as by-products (Seal et al., 2017). In the USA, antimony was historically mined as a by-product at the Sunshine Silver Mine in Idaho. The mine eventually shut down and was placed under care and maintenance in 2001 (United States. Geological Survey, 2004).

3.3.1 Antimony Recycling

Antimony recycling has existed since the 1920s (Davis et al., 1986; United States. Geological Survey, 2006). The secondary production of antimony is achieved by recycling metallurgical antimony-bearing products. Lead-acid batteries are recycled to recover secondary antimony (The Crucible, 2018). The recovered antimony is largely consumed by the battery manufacturing industry (Anderson, 2019). Antimony alloys are commonly recycled and produce antimony scrap metal whilst no antimony is recovered from flame-retardant products (United States. Geological Survey, 2006; Deloitte et al., 2017). Antimony found in flame retardant products is not recoverable because the antimony content is much less than in metallurgical applications (Anderson, 2019): and the antimony in flame retardant products is less concentrated than that found in metal products (Deloitte et al., 2017). Antimony-bearing manufacturing scrap is obtained from fabrication plants that produce antimony-based metal alloys. 'New scrap' are metals that were not manufactured correctly because of manufacturing faults and human errors. It can also refer to metals that did not meet customer specifications (United States. Geological Survey, 2006).

Secondary antimonial lead is recovered from antimonial lead scrap found in used lead-acid batteries (United States. Geological Survey, 2004; Indian Bureau of Mines, 2019). In 2010, recycled antimony contributed about 20% of global antimony supply (Figure 3.4). The United States. Geological Survey (2006) notes that lead-acid batteries are likely to remain the leading source of recycled antimony going into the future; however, the projected increase usage of antimony substitutes in lead-acid battery manufacturing will result in a decline in the consumption of secondary antimony (European Commission, 2020).

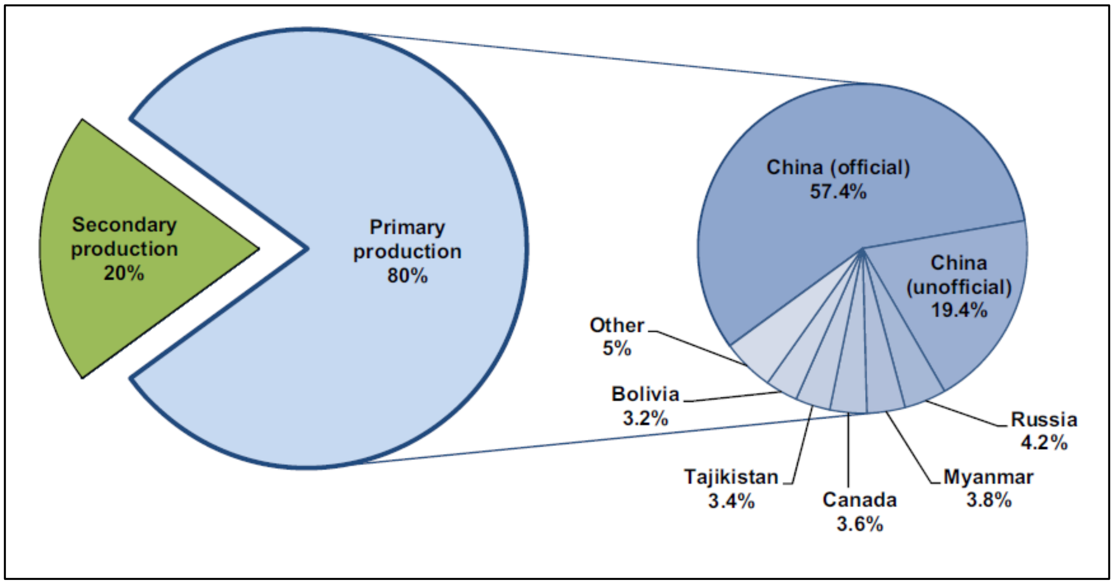


Figure 3.4 Antimony production distribution in 2010 (Dupont et al., 2016)

Secondary antimony is also recoverable from the smelting of lead-based alloys, mine tailings, process residues and antimony-bearing plastics (United States. Geological Survey, 2004; Dupont et al., 2016). Due to the various potential recycling sources, antimony recycling is a realistic option for countries that are interested in obtaining alternative supply sources of the commodity (Dupont et al., 2016). This, coupled with environmental concerns, has driven the interest in antimony recycling (United States. Geological Survey, 2004). Antimony recycling is also advantageous because it leads to the declined consumption of natural resources (United States. Geological Survey, 2006).

Due to the limited life of lead-acid batteries, the supply of 'old' scrap (i.e., form used lead-acid batteries) has always surpassed that of 'newer' antimonial-lead scrap (Figure 3.5). There is a high reliance on old lead-acid batteries for antimonial lead recovery. However, introducing antimony-free batteries in the 1970s led to a gradual decline in the supply of antimony-bearing scrap metal (United States. Geological Survey, 2004).

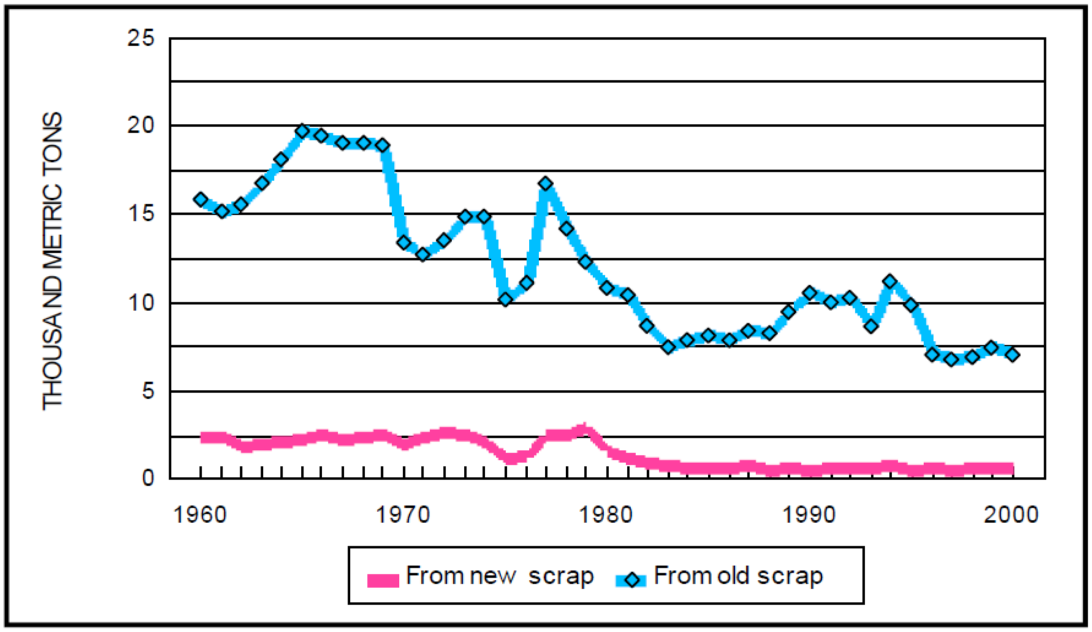


Figure 3.5 Source of antimony scrap in the United States from 1960 to 2000 (United States. Geological Survey, 2004)

The geopolitical risk associated with the high dependence of antimony supply from dominant antimony-producing countries such as China, and the insufficient local supply of antimony for processing in the United States of America and countries across Europe, has caused increased interest in finding alternative sources of antimony (Dupont et al., 2016). Countries in the European Union, the United States of America, Japan and Canada rely on secondary antimony obtained through recycling activity. No antimony is recoverable from non-metallurgical antimony-bearing products (Deloitte et al., 2017).

3.4 Antimony Uses and Applications

Antimony has been used in various applications for many years. From as early as 3100 B.C. stibnite was used by Hindus and ancient Egyptians for their dark eye makeup (Davis et al., 1986; United States. Geological Survey, 2004; Seal et al., 2017). Antimony was also used as a plating on various copper products. In the 16th century, antimony was used in the production of mirrors, ceramics, paints and in some medications to treat ulcers. In the 19th century, antimony was used more in metallic applications. Antimony was commonly alloyed with elements such as tin and lead. Alloying antimony with tin was used in the production of Brittania dinnerware, candlesticks and eating utensils. Alloying antimony with lead proved useful in the manufacture of tin-copper-antimony metal alloys (United States. Geological Survey, 2004). In the mid-19th century, the lead-acid battery was developed. Antimony applications in the manufacture of lead battery plates proved favourable as battery plates lasted longer in service compared to pure lead plates. Antimony was also alloyed with lead to manufacture spherical bullets to be used in the military sector. Most of the antimony recovered from lead-acid battery recycling is used in the manufacture of new lead-acid batteries (United States. Geological Survey, 2004).

Antimony has two distinct supply chains (Figure 3.6) – these generate either non-metallurgical (powder) or metallurgical antimony products (Dupont et al., 2016; Roskill, 2018a). The first antimony supply chain involves the production of primary antimony from the mine. Antimony is extracted and processed into a powdered concentrate or trioxide (i.e., non-metallurgical antimony) and then used to create flame retardants, plastics, and glass to name a few. The second antimony supply chain converts the mined ore into metal by alloying antimony with other metals. This is metallurgical antimony, and it is used in the production of lead-acid batteries (Roskill, 2018a).

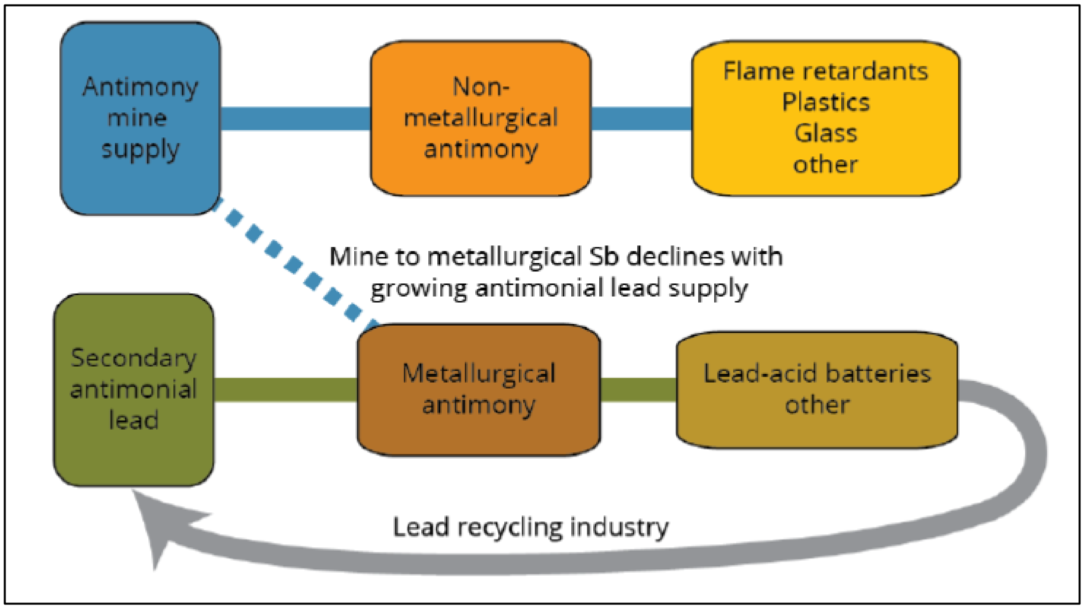


Figure 3.6 Simplified schematic representation of metallurgical and non-metallurgical antimony supply chain (Roskill, 2018a)

Nearly three quarters of the antimony produced (72%) is converted to antimony trioxide and used to manufacture flame-retardant products (Figure 3.7). A smaller portion of antimony is used in the manufacture of batteries and glass (Sait, 2013; Indian Bureau of Mines, 2019). In 2017, over 80% of antimony demand was driven by its application in flame retardants and lead-acid batteries (Anderson, 2019).

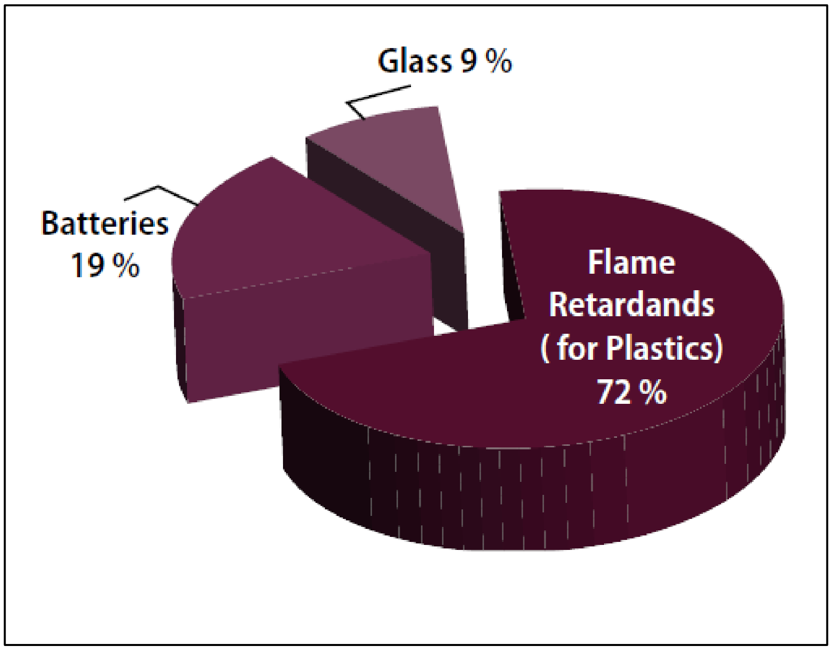


Figure 3.7 Representation of most common antimony uses (Sait, 2013)

3.4.1 Non-metallurgical Antimony Uses and Applications

The non-metallurgical application of antimony primarily involves the use of antimony in the production of flame-retardant products (Roskill, 2018a). Variants of non-metallurgical antimony include antimony compounds such as antimony trioxide (‘oxide’) (Sb_2O_3), sodium antimonite (NaO_3Sb) and antimony sulphide (Seal et al., 2017). Different variants of antimony compounds have slightly different uses. There are up to five types of flame retardants and antimony oxide is classified as an inorganic flame retardant (SGS, 2016).

Antimony trioxide and sodium antimonate are two common types of non-metallurgical antimony. Antimony trioxide's most prominent characteristic is its ability to combine with a halogen to impart flame retardant properties (Davis et al., 1986). Antimony trioxide is used in the manufacturing of flame-retardant products whilst sodium antimonate is used to manufacture specialty glasses (Davis et al., 1986; United States. Geological Survey, 2004).

The USA uses 62% of antimony for non-metallurgical applications, of which 40% is used for flame retardant applications (United States. Geological Survey, 2021). The EU uses over 40% of its antimony for flame-retardant applications (Deloitte et al., 2017; European Commission, 2020). Using antimony in the production of flame retardants became prominent in the early 1970s. Products that comprise antimony-based flame retardants include plastics, car and aircraft seat covers, children's toys, clothing and fluorescent lamps (United States. Geological Survey, 2006). Antimony is also used in paints, ceramics and as a fining agent in the production of transparent glass (United States. Geological Survey, 2004).

3.4.2 Metallurgical Antimony Uses and Applications

Due to its hard and brittle nature, antimony has limited use as a metal on its own, and it is commonly alloyed with either lead or tin-based alloys to harden the various manufactured products (United States. Geological Survey, 2004). Metallurgical antimony is mainly sourced from recycled material such as metallurgical scrap and used batteries. The use of antimony metal depends on the quality of the antimony metal produced. Very high-quality antimony metal is used to create semi-conductors (Seal et al., 2017; Anderson, 2019).

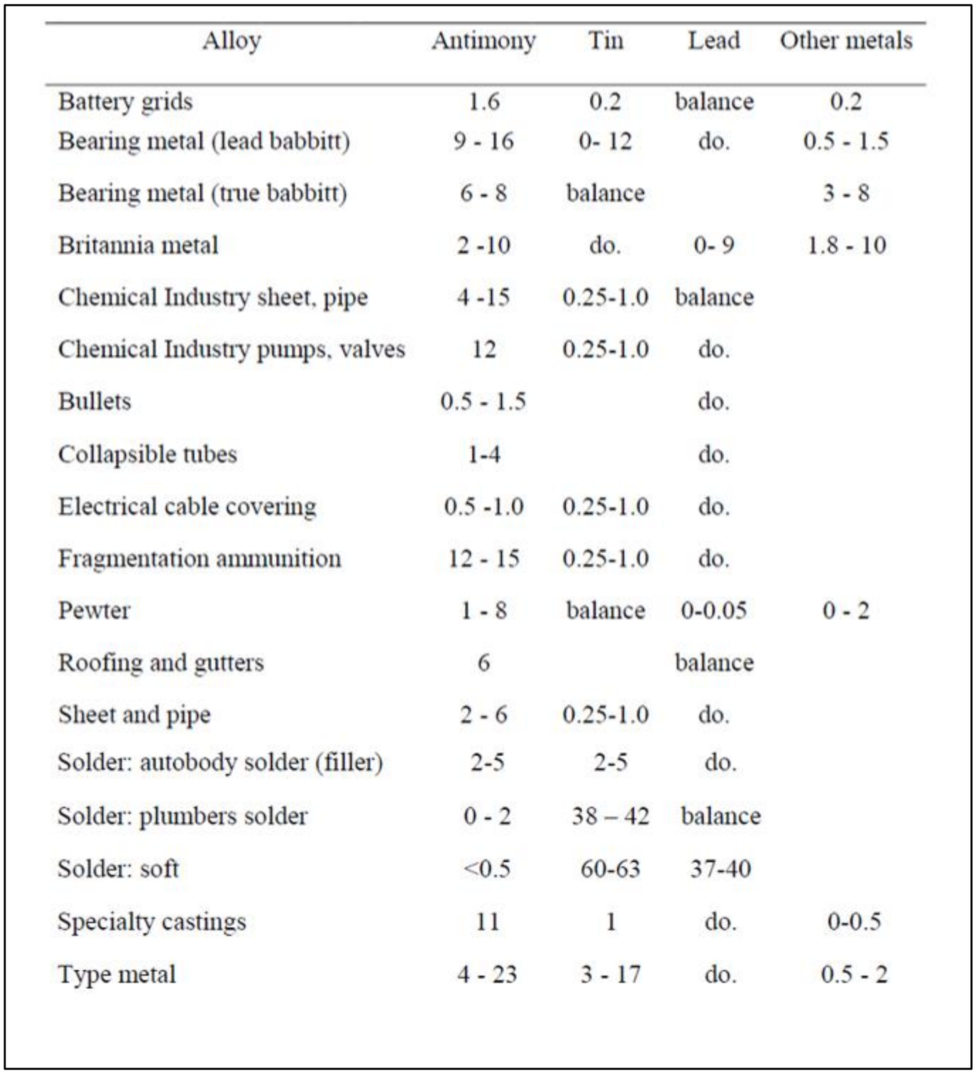
Metallurgical antimony is primarily used in the production of lead alloys for lead-acid battery production in the automotive industry (Sait, 2013; Roskill, 2018a; Anderson, 2019). Lead-acid batteries account for over 65% of the use of metallurgical antimony. Lead-acid batteries are used in the transportation sector and for backup power (Seal et al., 2017). Antimony is an important component in the production of lead-acid batteries because it inhibits the corrosion of the metal (United States. Geological Survey, 2006). It is also used in small amounts for ornamental castings, in semi-conductor devices and in the production of other antimony-based metal parts such as bearings and solders (United States. Geological Survey, 2004). Table 3.2 lists the key market drivers of both non-metallurgical and metallurgical antimony consumption.

Table 3.2 Prominent antimony consumption and end-uses in 2000 and 2010 (Sait, 2013)

	2000	**2010**	**Compound Annual Growth Rate (%)**	**Main Market Driver**	**2000**	**2010**
Non Metallurgical						
Flame Retardants	70,000.0	103,500.0	4	Polymer Demand	72.46%	83.78%
Plastic Catalyst	6,000.0	11,400.0	6.6	PET Demand	6.21%	9.22%
Heat Stabilizer	1,400.0	2,600.0	6.4	PVC Demand	1.40%	2.10%
Glass	16,000.0	1,700.0	-20.1	CRT and Solar Glass	16.60%	1.38%
Ceramics	1,700.0	2,500.0	3.9	Construction	1.80%	2.02%
Others	1,500.0	1,840.0	2.1	General Economic	1.55%	1.49%
Sub Total	**96,600.0**	**123,540.0**	**2.5**			
Metallurgical						
Lead-Acid Batteries	40,000.0	53,000.0	2.9	Automotive Production, replacement	78.43%	69.74%
Lead Alloys	11,000.0	23,000.0	7.7	Construction	21.57%	30.26%
Sub Total	51,000.0	76,000.0	4.1			
Total	**147,600.0**	**199,540.0**	**3.1**			

Antimony-based metal alloys are also used to create acid-resistant tools and apparatuses used in chemical engineering pipes for the transportation of harmful chemical fluids and lead-acid batteries (Krenev et al., 2015). A table of common antimony alloys is found below (Table 3.3). Other smaller uses of metallurgical antimony include the hardening of lead in ammunition, pipes and roofing (United States. Geological Survey, 2004).

Table 3.3 Table of common antimony alloys, their associated content (wt. %) and uses (United States. Geological Survey, 2004)



Alloy	Antimony	Tin	Lead	Other metals
Battery grids	1.6	0.2	balance	0.2
Bearing metal (lead babbitt)	9 - 16	0- 12	do.	0.5 - 1.5
Bearing metal (true babbitt)	6 - 8	balance		3 - 8
Britannia metal	2 -10	do.	0- 9	1.8 - 10
Chemical Industry sheet, pipe	4 -15	0.25-1.0	balance	
Chemical Industry pumps, valves	12	0.25-1.0	do.	
Bullets	0.5 - 1.5		do.	
Collapsible tubes	1-4		do.	
Electrical cable covering	0.5 -1.0	0.25-1.0	do.	
Fragmentation ammunition	12 - 15	0.25-1.0	do.	
Pewter	1 - 8	balance	0-0.05	0 - 2
Roofing and gutters	6		balance	
Sheet and pipe	2 - 6	0.25-1.0	do.	
Solder: autobody solder (filler)	2-5	2-5	do.	
Solder: plumbers solder	0 - 2	38 – 42	balance	
Solder: soft	<0.5	60-63	37-40	
Specialty castings	11	1	do.	0-0.5
Type metal	4 - 23	3 - 17	do.	0.5 - 2

3.5 Antimony in the Environment and its Health Effects

Antimony naturally occurs in the earth’s surface in small quantities (less than 1ppm) (Cooper and Harrison, 2009; European Commission, 2020; Dupont et al., 2016) and it is also found in water (United States. Agency for Toxic Substances and Disease Registry, 2019). Antimony is emitted into the environment throughout the various stages of the antimony mining value chain. It is emitted during mining activity, processing of antimony ores (Dupont et al., 2016); and during the production of antimony-bearing products and through waste disposal (United States. Agency for Toxic Substances and Disease Registry, 2019). Very high concentrations (up to 2550ppm) of antimony in soil have been reported at antimony waste sites which cause antimony absorption by plants (Cooper and Harrison, 2009). Antimony found in soils does not tend to seep further below its region of deposition and it is unreactive (Cooper and Harrison, 2009). Antimony can also be released into the air through coal-burning power plants (Cooper and Harrison, 2009; United States. Agency for Toxic Substances and Disease Registry, 2019). Humans are generally exposed to low levels of antimony in the air and can consume some antimony when ingesting food and water. Antimony-bearing drugs have been used in fields of medicine to treat various illnesses for many years (United States. Agency for Toxic Substances and Disease Registry, 2019). Some of the resultant effects of exposure of humans to antimony compounds such as antimony trioxide and antimony potassium tartrate may lead to respiratory, cardiovascular and gastrointestinal tract effects, to name a few (United States. Agency for Toxic Substances and Disease Registry, 2019). Animals also experience some side effects from exposure to certain levels of antimony (United States. Agency for Toxic Substances and Disease Registry, 2019).

3.6 Current Antimony Market Climate

Global antimony demand is projected to increase because of the forecasted reduction of antimony supply from China. China is forecast to decrease its antimony output because of stricter environmental regulations (Anderson, 2019; South Africa. Department of Mineral Resources, 2019). The projected decline in supply has led to amplified interest in secondary antimony that is sourced from antimony-bearing products (Dupont et al., 2016). There is a sustained projected usage of antimony in flame-retardant products, plastics and lead-acid batteries manufacturing (South Africa. Department of Mineral Resources, 2019). A high industrial demand for antimony metal in the USA is also noted. China has one of the largest antimony smelting facilities available and thus has a competitive advantage over other countries that mine and process antimony (Dupont et al., 2016). Antimony has since been dubbed a strategic and critical element by the European Commission. The element was included as part of its 2011 and 2014 lists as it was projected to have a large supply and demand gap in the years leading up to 2020 (European Commission, 2020). Antimony was again included in the EU's most recent 2020 report on critical raw materials (European Commission, 2020). This is largely because antimony production is concentrated in China with smaller quantities produced in various other operations around the world (Anderson, 2012).

Antimony prices are affected by supply and demand factors, and this has driven the antimony metal price to decline below US$10 000/t from 2013 (Figure 3.8).

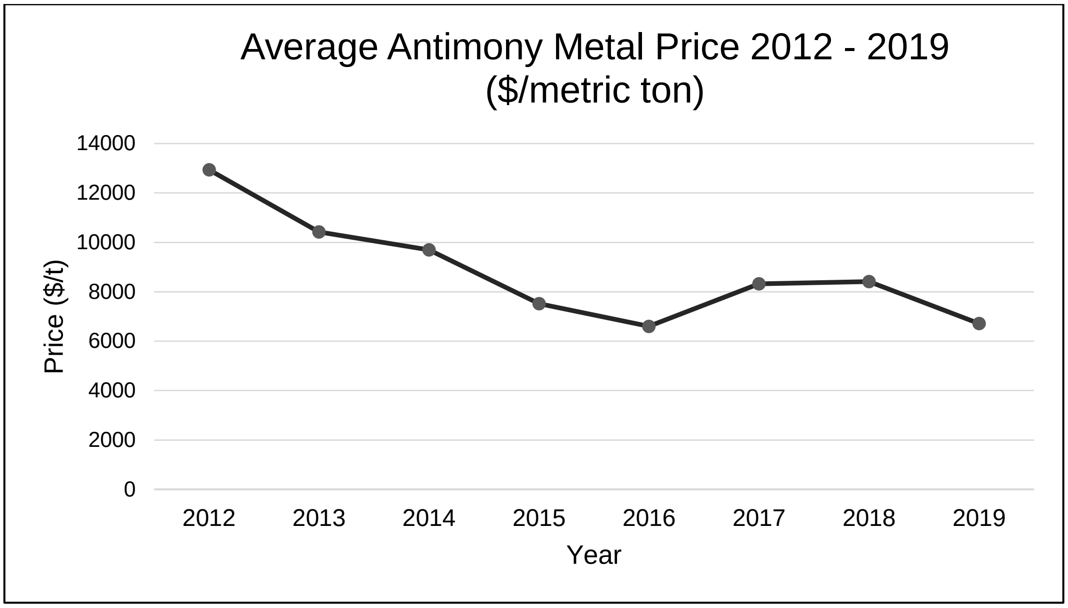


Figure 3.8 Average antimony metal price from 2012 to 2019 (United States Antimony Corporation, 2020)

Weakened antimony demand since 2010, and declining antimony output from China have affected the antimony price (Deloitte et al., 2017; The Crucible, 2018). The price has also declined because of increased usage of antimony substitutes (Deloitte et al., 2017). The antimony price had progressively declined from 2012 to 2015. Antimony prices subsequently increased from 2016 to 2017 due to decreased supply, however the price has continuously remained under US$10 000/t. An increase in price was projected in 2019 due to the persistent restricted supply of the commodity in China (South Africa. Department of Mineral Resources, 2019), however, recently strained trade relations between China and the United States have led to a further decrement of the antimony price. In 2018, the USA had stocked up on imported antimony anticipating an increase in import tariffs on the commodity. The expected tariffs were not implemented, and this led to an oversupply of the commodity in the USA. The trade tensions between the two countries have led to global antimony demand uncertainty, and this has negatively affected the antimony price (Belda and Lv, 2019).

3.7 Antimony Demand and Supply

Antimony demand and supply trends have evolved over time. Trends largely depend on geo-political stability, economics and the forecasted consumption plans of the commodity. The consumption of both metallurgical and non-metallurgical antimony has declined over recent years due to the increased usage of substitutes and antimony recycling activity (The Crucible, 2018). However, antimony demand is projected to outweigh supply in the future because antimony-bearing end products are continuously demanded. An increase in demand can be managed through increased mine output or by introducing new suppliers in the antimony market. Alternatively, metallurgical innovations could be developed to identify ways to effectively use secondary antimony in the production of desired end-products (Anderson, 2019).

Antimony applications in lead-acid battery manufacturing, lead alloys and plastics will also remain prevalent in the future (European Commission, 2014). Antimony demand is highly driven by the plastics, transportation, and construction industries. The use of substitutes will undoubtedly affect the overall demand trends for the commodity heading into the future (South Africa. Department of Mineral Resources, 2017).

The non-metallurgical use of antimony as a flame retardant in plastics is forecast to remain as its primary use (Figure 3.9) (European Commission, 2014; Krenev et al., 2015). The demand for non-metallurgical antimony applications in flame retardants will continue to exist (Anderson, 2019; The Crucible, 2018) however, the demand will be greatly influenced by price. High antimony prices and legislative factors that have caused changes in the production formula of flame-retardant products, have led to an increased interest in finding suitable substitutes for non-metallurgical antimony within the market (Anderson, 2019). These include antimony substitutes in the production of paints, pigments and enamels include chromium, tin, titanium, zirconium and zinc compounds (Seal et al., 2017). Non-metallurgical antimony demand will continue to drive the mining output required to sustain demand (The Crucible, 2018).

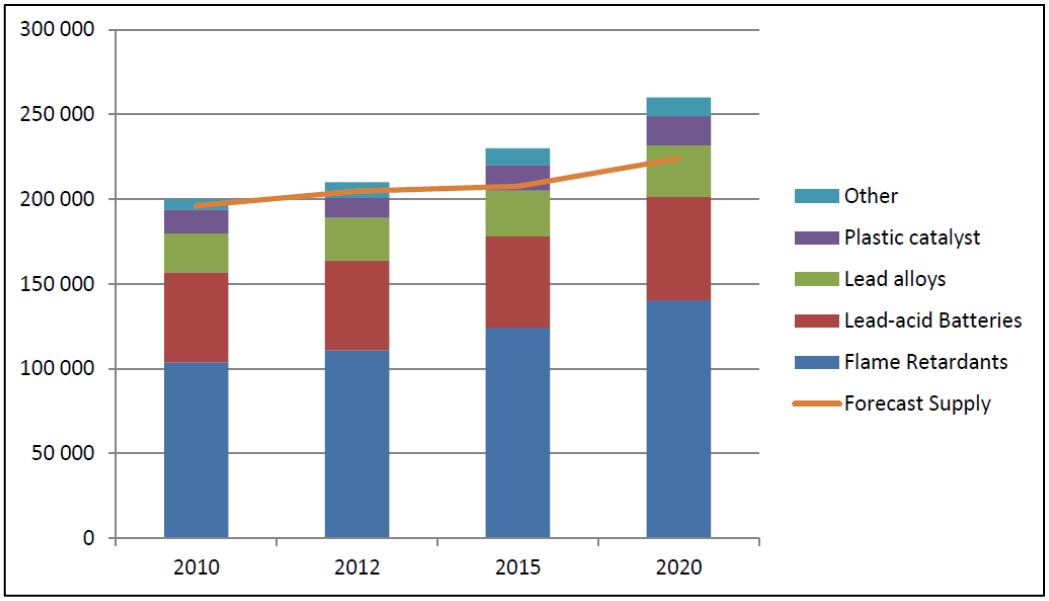


Figure 3.9 Global antimony supply (in tons) and end-use projections (European Commission, 2014)

Antimony consumption has decreased annually since 2010 (Anderson, 2019); because of increased consumption of recycled antimony (Deloitte et al., 2017). However, the consumption of recycled antimony is forecast to decrease as countries increase the application of metallurgical antimony substitutes in lead-acid battery manufacturing (European Commission, 2020). Substitutes such as calcium in lead-acid battery production (Lager and Forssberg, 1989) and tin (Anderson, 2019) negatively affect metallurgical antimony demand. Antimony in lead-acid batteries that are used in the automotive industry are increasingly being replaced by lead-calcium-tin alloys (Anderson, 2019). Batteries that have lead-calcium-tin alloys require less maintenance and are more durable than those that have antimony (European Commission, 2014; Anderson, 2019). The demand for metallurgical antimony is thus projected to decline (Roskill, 2018a; The Crucible, 2018). There is also a noted increase in the supply of recycled antimony (United States. Geological Survey, 2006; The Crucible, 2018). Secondary antimony that is obtained through recycling activity, is forecasted to be equivalent to that of mine production and is therefore noted to be self-sustaining by the mid-2020s (The Crucible, 2018; Anderson, 2019). These two conditions have resulted in a stagnated demand for metallurgical antimony.

3.8 Conclusion

This Chapter provides a global overview of antimony regarding its occurrence, geology, production and uses. Five different antimony deposit types are noted and described. Global antimony reserves and producers are also presented, and China is distinguished as the world’s leading antimony producer. Two different supply chains of antimony are noted. These are namely non-metallurgical and metallurgical antimony. Non-metallurgical antimony is primarily used for flame retardant purposes whilst metallurgical antimony is predominantly used in the production of lead-acid batteries. Non-metallurgical antimony is noted to have a sustained forecasted demand due to its continued application in the production of flame-retardant products. The threat of antimony substitutes in the flame retardant sector continues to exist. Metallurgical antimony demand is likely to decline because of increased antimony recycling activity and the threat of substitutes in the market. Potential opportunities that exist within the antimony market are also outlined in this Chapter. This Chapter contributes to the research by providing a summary of the antimony sector and its significance in the global market. The Chapter has also recognized the strategic importance of antimony in many countries that are reliant on the commodity.

4 UNPACKING THE ANTIMONY VALUE CHAIN

4.1 Introduction

This Chapter aims to unpack the stages of antimony beneficiation and highlights the various inputs, support services and outputs that exist at each stage. The antimony value chain encompasses a series of stages that increase the value of antimony as it advances from one stage of activity to the next. Emphasis is placed on the metallurgical antimony value chain.

4.2 The Antimony Value Chain Process

The antimony value chain process involves the extraction of antimony from stibnite ore, and it is subsequently processed into metal or a white powder (antimony oxide). The antimony is then traded as ore, concentrate or metal (Figure 4.1).

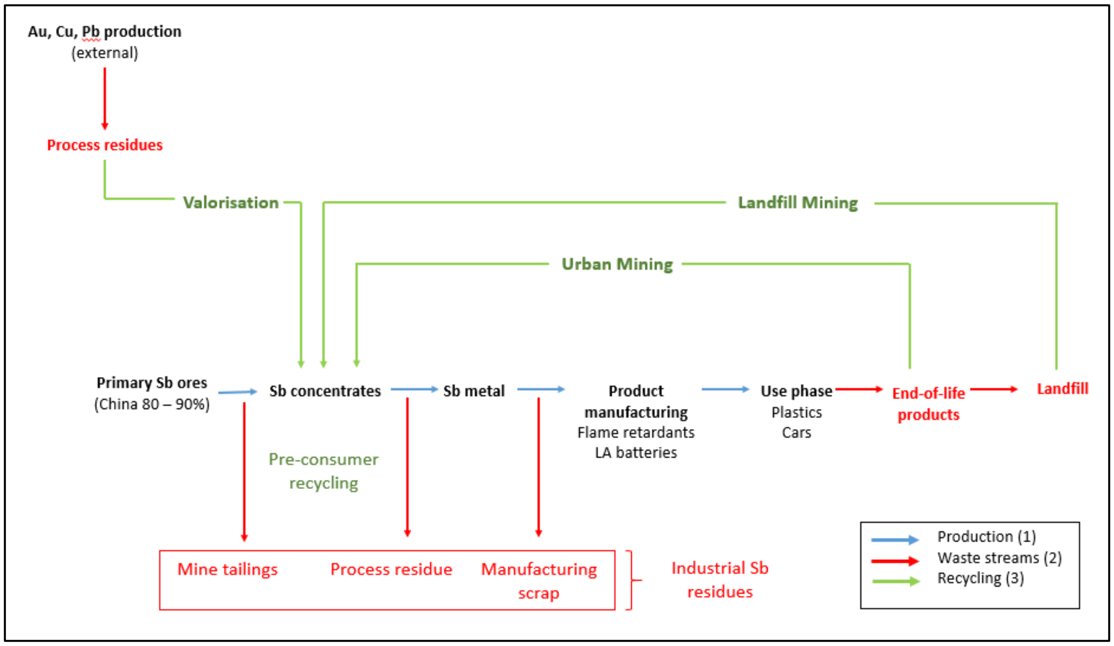


Figure 4.1 Schematic representation of the antimony value chain and its recycling stages (after Dupont et al., 2016)

The antimony beneficiation process progresses over four separate stages of activity. The process transforms an antimony-bearing mineral commodity into a product of much higher value that is sold and used by a consumer (Figure 4.2) (European Commission, 2014). Past trends have displayed a decline in the movement of raw antimony material, and an increase in the trade of processed antimony metal and associated antimony-bearing goods. This has largely been attributed to the rise in China’s antimony processing abilities and its production of antimony-based metal and oxides (United States. Geological Survey, 2004).

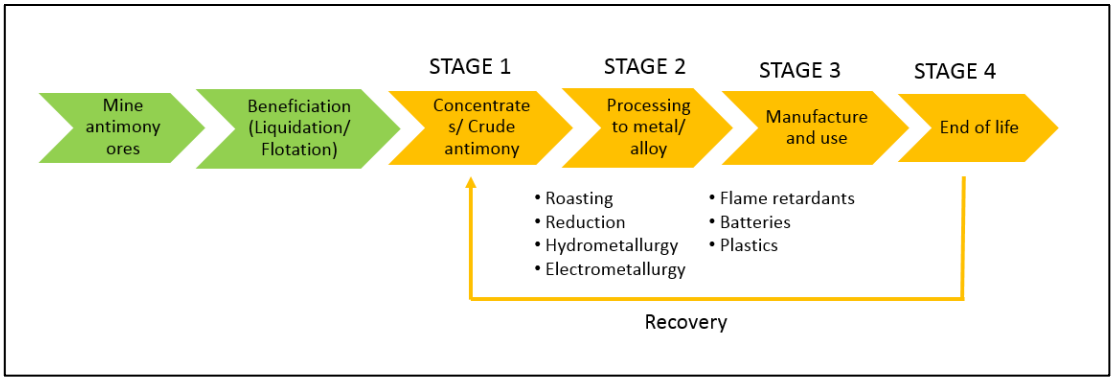


Figure 4.2 Schematic flow diagram of antimony beneficiation stages along the value chain (after European Commission, 2014)

Different countries partake in the global antimony value chain at various stages, and they produce antimony of varying grades and types. Table 4.1 lists the various countries that refine antimony. China has the highest combined plant capacity in the world and produces antimony trioxide, metal, sodium antimonate and pentoxide. Other countries produce either one or two forms of antimony in fewer quantities (Anderson, 2012).

Table 4.1 Table of global refined antimony producers and their estimated plant capacities (Anderson, 2019)

Company	**Location**	**Total Capacity and Products (Sb tonne/year)**
Hsikwangshan Mining Administration	China	30 000 (metal, trioxide, pentoxide, sodium antimonite)
Kadamjaisk Antimony Combine	Kyrgyzstan	20 000 (metal, trioxide)
Amspec Chemical Corp	USA	15 000 (trioxide)
Laurel Industries Inc.	USA	12 500 (trioxide)
Societe Industrielle et Chimique de L'Aisne	France	12 000 (metal, trioxide)
Campine	Belgium	10 000 (trioxide)
Dachang Mining Administration	China	10 000 (metal)
Mines de la Lucette	France	9 500 (metal)
Enal	Bolivia	9 300 (trioxide)
Great Lakes Chemical (Anzon)	USA	6 000 (trioxide)
Union Miniere	Belgium	6 000 (sodium antimonate)
Guzhou Dushan Dongfeng	China	4 000 (metal, trioxide)
Hubei Chongyang	China	4 000 (metal, trioxide)
US Antimony Corporation	Mexico & USA	1 500 (trioxide, sodium antimonate, metal)
Sunshine Mining and Refining	USA	1 500 (metal, sodium antimonate)
Listed Plant Total		**140 500 tonne/year as Sb (estimated)**

Antimony metal is produced in the US, France and Kyrgyzstan. Outside of China, sodium antimonate is produced in Belgium and the US (Anderson, 2012). The antimony beneficiation stages are sequentially unpacked below.

4.2.1 Stage One: Exploration, ore extraction and concentrate production

The first stage of the antimony value chain produces non-metallurgical antimony. This step begins with exploration activity to identify antimony resources and geological expertise is required to facilitate this (Rajagopalan, 2015). Once located, the mineral resource is evaluated for its economic potential, extracted and processed to produce a concentrate (Baxter, 2005; Lundall et al., 2008). Mineral extraction is reliant on inputs such as machinery, equipment and skilled labour. Skilled personnel such as mining engineers and metallurgists are also required at this stage (Napier-Munn, 1997). The amount of labour required to facilitate first stage activity is high (Baxter, 2005; Lydall, 2014). Ore is transported via roads, railways and sea. The viability and mode of transportation is highly dependent on costs (Davis et al., 1986).

An accessible processing plant is required to process the mined antimony ore into concentrate (Davis et al., 1986). Further mineral processing activity may also occur in a separate location, away from the mine premises (Rajagopalan, 2015). Extracting antimony from the mineral involves crushing, milling, flotation and gravity concentration (Dupont et al., 2016). Antimony processing methods depend on the antimony ore quality and the antimony ore type (Deloitte et al., 2017). Antimony ore types are determined by the minerals that are found in association with the antimony ore (Lager and Forssberg, 1989; United States.

Geological Survey, 2004). Ore extraction processes the native ore into the most basic form of saleable concentrate. The concentrate is used in the production of various products of higher value (Deloitte, 2011; Rajagopalan, 2015).

Antimony sulphide ores are processed into concentrate using the froth flotation process. Concentrate which contains 1.5% - 25% antimony is then roasted to produce oxides (United States. Geological Survey, 2004). Antimony oxide is produced in China, Thailand, (United States. Geological Survey, 2019); Belgium, France, Germany, Greece, Italy, Netherlands and the United Kingdom (European Commission, 2014). China has dominated global antimony oxide production (50%-60%) and it is also the largest importer of antimony ores and concentrate. China is also the leading global exporter of antimony oxide (Figure 4.3). There is no antimony oxide production in Africa or Australia (Roskill, 2018a).

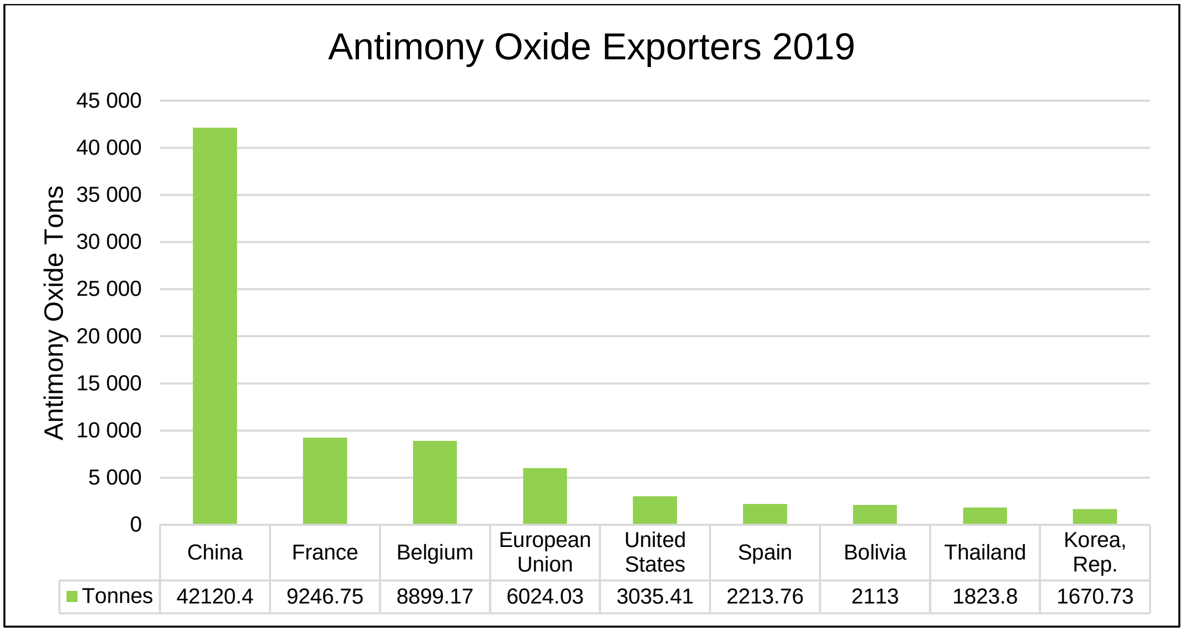


Figure 4.3 Highest antimony oxide exporters in 2019 (World Integrated Trade Solution, 2021)

Non-metallurgical antimony is mainly used for flame retardants in various sectors (Figure 4.4). Antimony trioxide is the most common form of antimony used primarily in flame-retardant applications. Antimony trioxide also acts as a catalyst in the production of plastics and synthetic textiles and is also used to manufacture glass and ceramics (European Commission, 2014). The electronic and plastic sectors are major markets for flame retardants (Seal et al., 2017).

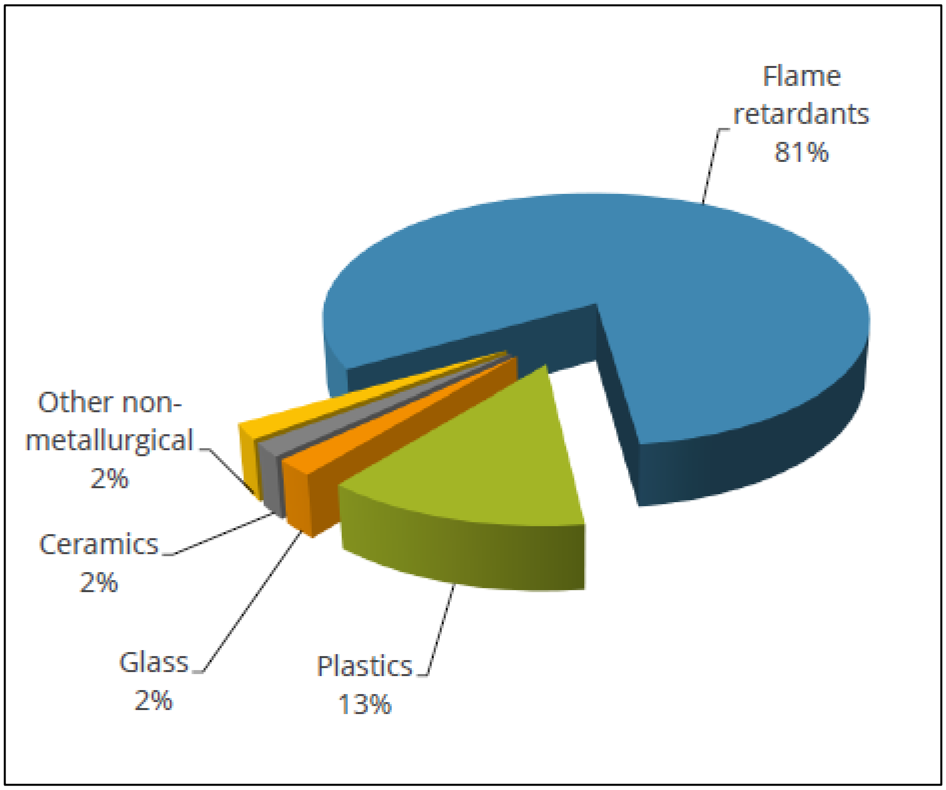


Figure 4.4 Consumption percentage of non-metallurgical antimony end-uses (Roskill, 2018a)

The antimony ore and concentrate trade involves various countries. India imports more antimony ore and concentrate than it exports (Indian Bureau of Mines, 2019). Antimony ore and concentrate exported from India is very minimal compared to countries such as Russia, Australia, Turkey, and China to name a few (World Integrated Trade Solution, 2021). India imports its antimony ore and concentrate from Tajikistan, Russia, and Italy (Indian Bureau of Mines, 2019), and it is listed as the 11th top global exporter of antimony oxide (World Integrated Trade Solution, 2021). The EU produces antimony trioxide from imported, unprocessed antimony metal. This implies that it is highly reliant on external supplies of antimony ores and metal (Deloitte et al., 2017). From 2008 to 2012 the US has imported a large portion of antimony ores, concentrates and oxide from China (67%); with much smaller quantities obtained from Mexico, Belgium, and Bolivia to name a few (Seal et al., 2017). Turkey is a major exporter of antimonial ores and concentrates to the EU (European Commission, 2014). Over 60% of the EU's imported antimonial ores and concentrates are sourced from Turkey (European Commission, 2020). Europe also obtains smaller quantities of antimonial ore and concentrate from countries such as Bolivia and Guatemala (European Commission, 2014). This stage produces mine tailings that contain some antimony content (Dupont et al., 2016).

4.2.2 Stage Two: Process concentrate into metal alloy

The second stage involves the conversion of the concentrate into an intermediate product such as a metal or alloy (Baxter, 2005; Lundall et al., 2008). The brittle nature of antimony makes it difficult to be used on its own. Antimony is thus combined with other metals to form metal alloys and compounds (Anderson, 2012; Krenev et al., 2015). High capital and high energy refineries and smelters are required to process the mineral into metal alloys (Lundall et al., 2008; South Africa. Department of the Presidency, 2011). Incorporating antimony in metal compound production increases the resistance, strength and hardness of the metal alloy produced (Sait, 2013; Krenev et al., 2015). Metal alloys are an intermediate product in the value chain (Lundall et al., 2008). Antimony alloys are created with lead and tin (European Commission, 2014). Compared to the first stage of antimony beneficiation, the labour required to facilitate the activities of the second stage of beneficiation is low (Baxter, 2005; Lydall, 2014). Access to assaying services and adequate supply of chemicals and electricity is important to facilitate the activity at this stage (Ritchken, 2017).

Antimony oxide that contains 25% -45% antimony is smelted in blast furnaces to produce crude metal. Crude antimony contains over 90% antimony (United States. Geological Survey, 2004). Antimony-based metals are produced through reduction smelting of antimony oxides with carbon, or through the smelting of sulphides and antimony ores in furnaces (Davis et al., 1986). Antimony metal is further refined to make it commercially viable by removing impurities such as lead, copper, iron, and arsenic (United States. Geological Survey, 2004). Scrap metal is also generated at this stage (United States. Geological Survey, 2006). China produces the bulk of global antimony-based metal alloys. The country has several refineries and smelters (Krenev et al., 2015; Dupont et al., 2016). The European Union imports very large amounts of antimony metal for various applications. Antimony metal is noted to have some effects on the environment and human health (Deloitte et al., 2017).

4.2.3 Stage Three: Enhancement of antimony metals into products

This stage focuses on the overall quality of the product, market access and ensuring that optimum value is obtained at the lowest cost (Baxter, 2005). This stage of the beneficiation process converts the intermediate good into a refined, semi-fabricated product (Baxter, 2005; Lundall et al., 2008). The resultant product is of much higher value compared to the products of the first two stages of the value chain (Lundall et al., 2008). At this stage, the metal undergoes further heating in blast furnaces and foundries (Lundall et al., 2008). The activities at this stage require high capital input (Baxter, 2005), because of the high costs associated with refining equipment and electricity (South Africa. Department of the Presidency, 2011; Ritchken, 2017). Skills from the manufacturing sector are required, and the labour intensity is relatively low (Baxter, 2005). This stage encapsulates the use of high skills and technology, thus increasing the value of the product considerably (Lundall et al., 2008). The refined products are used by enterprises to manufacture a final product, or the parts may be sold to smaller businesses for direct use (Baxter, 2005; Lundall et al., 2008).

Antimony-based metal alloys are consumed in the construction and automotive industries (Sait, 2013). Antimony alloys are used to produce metal parts for various products such as posts and cell connectors for various types of lead-acid batteries (United States. Geological Survey, 2004; Anderson, 2019).

Smaller amounts of antimony alloys are used to produce bearings and solders (United States. Geological Survey, 2004; United States. Geological Survey, 2006). Other uses of antimony metal include ammunition (Anderson, 2019), cable coverings and in pipes and roofing (United States. Geological Survey, 2004; Anderson, 2019). Antimony sulphides are used to manufacture ammunition used in military services (Seal et al., 2017). Antimony metal is produced in countries such as the United Kingdom, Greece, Italy and Germany to name a few (European Commission, 2014).

4.2.4 Stage Four: Fabrication and distribution of product to consumer

The last stage of processing involves the incorporation of the metal into a range of products that are used by the consumer (Lundall et al., 2008). Medium to high capital is required to facilitate the activities at this stage. Manufacturing equipment and assembling machinery are required to produce a final product for sale (Baxter, 2005; Ritchken, 2017). The labour intensity at this stage ranges from medium to high (Baxter 2005). Final products such as lead-acid batteries are manufactured and distributed to the automation sector (Sait, 2013). Antimony-based metal alloys are also used to produce acid-resistant tools and apparatuses used in chemical engineering applications (United States. Geological Survey, 2004; Krenev et al., 2015). The final product is sold to the consumer at a higher price because the product has undergone value-adding processes (Deloitte, 2011; Rajagopalan, 2015). This stage incorporates functions such as marketing of the saleable product, design, and distribution services (Vorster, 2001; Ritchken, 2017). Various countries across Europe manufacture flame retardant products, batteries, and plastics (European Commission, 2014). The above-mentioned stages and their respective inputs are summarized in Table 4.2 below.

Table 4.2 Summary of metallurgical antimony value chain stages and support services/input requirements

	Stage One	**Stage Two**	**Stage Three**	**Stage Four**
	Ore Extraction and concentrate production	Metal Alloy formation	Alloys used to create saleable products	Fabrication and distribution
Labour	High	Low-High (Labour intensive)	Low	Medium-High
Skilled Human Capital	Geologists, Mining Engineers, Metallurgists	Metallurgists	Engineers	Skilled personnel in the manufacturing industry
Equipment/ Machinery	Mining machinery, Processing plant	Refinery and smelters	Blast furnaces and foundries	Moulding and assembling machinery required
Financial Services	High capital investment	High capital required for infrastructure/ machinery, chemical reagents	High capital required for the creation of saleable end products	Medium–high capital required
Infrastructure	Offices, Transportation modes	Transportation modes	Transportation modes	Transportation modes
Other	Research and Development, Chemical reagents	Adherence to environmental standards and regulatory policy. Electricity supply	Research and Development; Technology; Electricity supply	Trade agreements and guaranteed supply

4.3 Antimony Value Chain Opportunities

This section identifies the potential opportunities that may exist for partakers in the antimony industry. China is a globally dominant antimony producer of both refined and unrefined antimony. Opportunities for new entrants in the antimony production supply market have become increasingly important. Declining antimony production from China in recent years has emphasized the importance of identifying alternative sources of antimony globally.

Major opportunities exist for non-metallurgical antimony suppliers as the demand for flame retardant products is projected to increase. Additional antimony ore or concentrate may be obtained by increasing production capabilities at existing mines, reopening non-operating mines or by opening new mines where antimony resources occur. Countries such as Australia, South Africa, Burma, Turkey and Tajikistan all have antimony reserves that could generate antimony production when their respective restraints are mitigated (Seal et al., 2017). With the successful recovery of antimonial-lead from lead-acid batteries, the demand for new metallurgical antimony suppliers in the lead-acid battery industry is trivial because of the self-sufficiency of the antimony recycling industry. However, for minor uses such as the production of antimony-based alloys used in the chemical engineering, construction and the arms sectors, metallurgical antimony is still in demand.

China’s antimony production levels have declined, and the country partially relies on external supplies of raw antimony to feed its smelters. Opportunities exist for other countries to become antimony producers, as there is a need for additional antimony suppliers in the market. Oman has recently equipped itself to become a new entrant in the antimony market as a producer of refined antimony (The Crucible, 2018). Oman recently commissioned the construction of the second-largest antimony smelter outside of China (Indian Bureau of Mines, 2019). The new antimony-gold processing plant can process about 20 000t of antimony oxide and metal; and 50 000oz of gold annually. Oman is reliant on external supplies of antimony concentrate to feed its smelter to its optimum capacity (The Crucible, 2018; Roskill 2019b). The antimony supplied to the Oman roaster plant is sourced globally (Strategic and Precious Metals Processing, 2020); from countries such as Tajikistan and Russia, to name a few (Roskill, 2018b). The country has secured its antimony concentrate supply through an agreement made with Traxys Europe SA (Roskill, 2019b). Luxembourg-based Traxys Europe will facilitate antimony ore and concentrate supply logistics for the roaster plant (Technical Review Middle East, 2017).

Other countries may also participate in the antimony market. Potential entrants can identify the stages along the antimony value chain that can be implemented domestically. Identifying the sectors that could benefit from activities and a good understanding of the target market are important aspects to consider. Countries in Europe and the United States of America are largely involved in manufacturing end-use products (European Commission, 2014). The end-use products manufactured contain antimony-based products combined with other parts. The knowledge and skills used in Europe to manufacture antimony-based products may be replicated in countries that have access to antimony-based alloys. This would create a basis for knowledge and skills spillovers in countries that have accessible antimony resources. Other factors considered include the availability of labour, machines and equipment required to manufacture certain goods as indicated in Table 4.2.

There are also opportunities for antimony refiners to enter the market just as Oman has done. Manufacturers that use different antimony compounds could also become potential players in the global antimony market. Opportunities exist for subsequent linkage development for downstream beneficiation of antimony within host countries such as South Africa, provided that the country has the skills, infrastructure, resources, and an enabling environment with robust policy structures to facilitate this. Through effective linkages, the host country could address a broad range of socio-economic issues through localized antimony beneficiation activities.

4.4 Conclusion

This Chapter outlines the four beneficiation stages for metallurgical antimony. The antimony beneficiation stages outlined above represent the downstream linkage between the mining and manufacturing sectors. An overview of the various inputs required to facilitate antimony beneficiation processes up to the final stage are discussed. Factors such as adequate skills, equipment and machinery, adequate power supply and policies that support the beneficiation process are critical factors required for the successful implementation of antimony beneficiation activities. The Chapter also identifies current opportunities that exist in the global antimony market. Countries such as China and Oman are currently seeking suppliers of antimony ore to feed their smelters. This presents an opportunity for new entrants to participate in the antimony market. There are also opportunities for other market entrants to produce various types of antimony products depending on the stage of antimony beneficiation activity that one partakes in.

5 THE ANTIMONY VALUE CHAIN IN SOUTH AFRICA

5.1 Introduction and Background

The preceding Chapters have provided some insight on the global antimony industry. This section of the research explores South Africa's antimony value chain by unpacking the antimony beneficiation stages in South Africa. The assessment provides a clear indication of the country's potential in the global antimony market.

Antimony in South Africa was formerly mined at the Consolidated Murchison Mine (now re-named Stibium Mopani Mine) in the Limpopo Province (Figure 5.1).

Figure 5.1 Locality map of the Stibium Mining operations in Gravelotte, Limpopo (Google Earth, 2019)

The gold and antimony mine has had several owners over the last few decades (Table 5.1). Large-scale production at the mine began in 1934 and the mine was named Consolidated Murchison in 1972 (Nex, 2013). Gold was the initial commodity mined and antimony mining was introduced a few years later (Davis et al., 1986). Antimony was mined as the primary commodity, and gold was mined as a by-product throughout various periods in the mine’s operational existence. The Johannesburg Consolidated Investment Company acquired the mine in 1991 and operated it for six years until Meteorex took ownership in 1997. To the Point Growth Specialists gained interest in the mine in 2009 and renamed the mine 'Cons Murch Mine'. This was just before Village Main Reef acquired the mine in 2011 (Nex, 2013).

Table 5.1 Sequential summary of exploration and mining history at Consolidated Murchison Mine up to 2011 (Graupner et al., 2014)

Year	Detail
1870	Two prospectors report having found gold in what was later named the Murchison Range.
1886	Start of a gold rush led by French Bob and the area was soon proclaimed a public digging.
1890	A township is laid out around French Bob's camp, given the name of Leydsdorp.
1890–1928	Numerous small mines are worked for gold. All encounter metallurgical difficulties, with the refractory ore extracted from a certain depth below surface and are forced to close down
1914–1918	Antimony ore first produced for export from the Murchison area. The deposit at Union Jack is treated for gold trying both cyanidation and other leaching processes. These are not successful and production soon ceased.
1928	Exploitation of antimony as a by-product of gold is considered worthwhile and the revival of the area begins.
1934	Consolidated Murchison (Transvaal) Goldfields and Development Company Limited merged with Anglovaal. The purpose of this company is to prospect and exploit the mineralised area to the east of Leydsdorp on the Murchison Range.
1972	The company name is changed to Consolidated Murchison.
1940–1946	Mercury mined is at Harrington Kop east of Monarch Shaft, by a company known as Monarch Cinnabar (Pty) Ltd which is purchased by Consolidated Murchison Limited in 1956.
1966	Eskom power is made available to the mine.
1972	Antimony Products Limited is formed.
1974	First phase of the plant is commissioned.
1985–1988	The McGeanRohco plant is commissioned in 1985 and ceases production in February 1988.
1988–1996	Johannesburg Consolidated Incorporation (JCI) takes over Cons Murch Mine and sells it in 1996 to METOREX Ltd.
1996–2011	METOREX constructs new parts of the ore processing plant and sells the mine to Village Main Reef in 2011, which formed the company Cons Murch Mine (Pty) Ltd.

In 2015, Cons Murch Mine was liquidated and in that same year, Stibium Mining South Africa successfully took over ownership of the mine. The mine’s underground operations have since been placed under care and maintenance. Since taking over ownership of the mine in mid-2015, Stibium Mining has mined gold resources extracted from near-surface deposits and from the slimes dam on site. No antimony extraction has occurred since then (South Africa. Department of Mineral Resources, 2019).

5.2 Regional Geology

Stibium Mine is geologically situated along the Archean Murchison Greenstone Belt in the northeastern part of the Kaapvaal Craton, in the Limpopo Province of South Africa (Davis et al., 1986; Vearncombe et al., 1992). The Murchison Greenstone Belt (MGB) represents one of the very few greenstone belts in the country (Schwarz-Schampera et al., 2010). The MGB is characterized by volcanic and sedimentary rocks that have been intruded by Archean granites and gneisses (Viljoen et al., 1978). Granitic intrusions appear in the northern, central and southern parts of the Belt (Schwarz-Schampera et al., 2010). The Belt is isoclinally folded and the lithologies are narrow and elongated (Viljoen et al., 1978).

The MGB is flanked by the mafic Rooiwater Igneous Complex to the north and the Mashishimale granites to the south (Viljoen et al., 1978; Schwarz-Schampera et al., 2010). The Rooiwater Igneous Complex comprises gabbroic lithologies and younger hornblende and granites (Viljoen et al., 1978). The granite in the south contains pegmatites that host emerald, beryl, and feldspar, to name a few (Schwarz-Schampera et al., 2010). There are also noted occurrences of banded iron formation sequences in various locations throughout the extension of the Belt. (Viljoen et al., 1978).

The MGB is divided into two prominent units. These are the Rubbervale Formations and a second diverse unit comprising mafic and siliclastic schists hosted in a few formations within the belt (Schwarz-Schampera et al., 2010). The Mafic to Felsic Unit represents the central and prominent portion of the MGB. It comprises volcanic and volcaniclastic sediments. The unit is characterized by chlorite and quartz schists, sericite schists and basic lavas. ChlorItic schists are composed of chlorite, quartz and sericite and represent altered volcaniclastic sediments and tuffs. The presence of quartzitic and sericitic schists within the chlorite schists represents the end of the mafic to felsic volcanic and volcaniclastic cycles. Talc carbonate schists also occur within the mafic to felsic unit; and they usually occur in association with carbonate rocks within the MGB (Viljoen et al., 1978).

5.2.1 Antimony Mineralization

Antimony mineralization occurs at the center of the MGB within the 35km long and 250m wide Antimony Line (Vearncombe et al., 1992; Schwarz-Schampera et al., 2010). Stratigraphically, the Antimony Line occurs within the Weigel Formation (Davis et al., 1986). The Antimony Line comprises various carbonate-bearing lithologies (Viljoen et al., 1978). Antimony in South Africa is described as a simple antimony-type deposit. The ore typically occurs in association with sulphides and may be oxidized in some parts (United States. Geological Survey, 2004). The antimony mineralization is predominantly characterized by carbonate and talc lithologies (Viljoen et al., 1978; Davis et al., 1986). The Antimony Line hosts both gold and antimony deposits that are sporadic in their distribution (Schwarz-Schampera et al., 2010). Some other elements found in the antimony line are copper, zinc and mercury, to name a few (Viljoen et al., 1978; Vearncombe et al., 1992). The mineralization is characterized as a gold-antimony epithermal deposit. The antimony mineralization occurs in veins (Graupner et al., 2014); and it is structurally controlled (Viljoen et al., 1978).

The Antimony Line is hosted in a distinct lithological sequence (Figure 5.2) (Viljoen et al., 1978). Quartzite, carbonates, mafic and ultramafic schists, quartz mica schists and iron formation are found throughout the sequence (Davis et al., 1986).

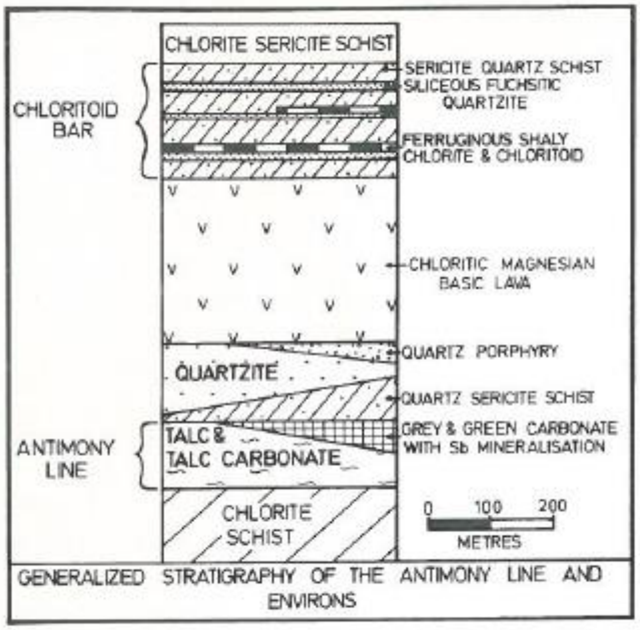


Figure 5.2 Stratigraphic column of antimony line from the north (top) to the south (bottom) (Viljoen et al., 1978)

Below is a description of each of the five lithological sequences that host the antimony line as described by Viljoen et al., (1978).

1. The chloritoid bar is found to the north of the Antimony Line. It is characterized by quartzitic and sericitic schists interlayered with iron formations and carbonaceous shales. Chloritoid usually occurs within the iron formations and fuchsitic alteration commonly occurs in the quartzitic schists. The chloritoid bar generally forms a ridge in the area (Viljoen et al., 1978).

2. The next package comprises chloritic-magnesian basic lava. Both the chloritoid bar and the lava sequences appear to be regular throughout the north-easterly extension (Viljoen et al., 1978).

3. Resistant quartz-sericite schist which grades into quartz porphyry or quartzite (with conglomerate) in some parts, is found adjacent to the lava sequence. This unit creates very prominent ridges on the surface and exhibits a sharp boundary to the Antimony Line (Viljoen et al., 1978). From this unit southwards, the lithologies tend to pinch and swell. The orebodies are elongated and display a sub-vertical dip (Davis et al., 1986).

4. The Antimony Line lies south of the above-mentioned quartz sericite schist package. The Antimony Line comprises talc schist, talcose carbonates, chloritic carbonates, siliceous carbonates, and cherty carbonate lithologies (Viljoen et al., 1978).

5. Chlorite schists are located along the southern margin of the antimony line.

Antimony mineralization is found within resistant quartz-carbonate rocks that are enveloped by less resistant talcose and chloritic carbonates (Davis et al., 1986). This is illustrated in Figure 5.3 below. The transition from talc to carbonate lithologies is gradational. The core of the antimony mineralization is hosted in carbonates that may occur with chloritic and siliceous composition and (sometimes) with fuchsitic alteration. Dolomite, magnesite and quartz are the prominent minerals that occur in the carbonate lithologies (Viljoen et al., 1978). Antimony zoning is common and is characterized by stibnite concentrations that decrease from the carbonate lithology at the center, to the margins (Davis et al., 1986).

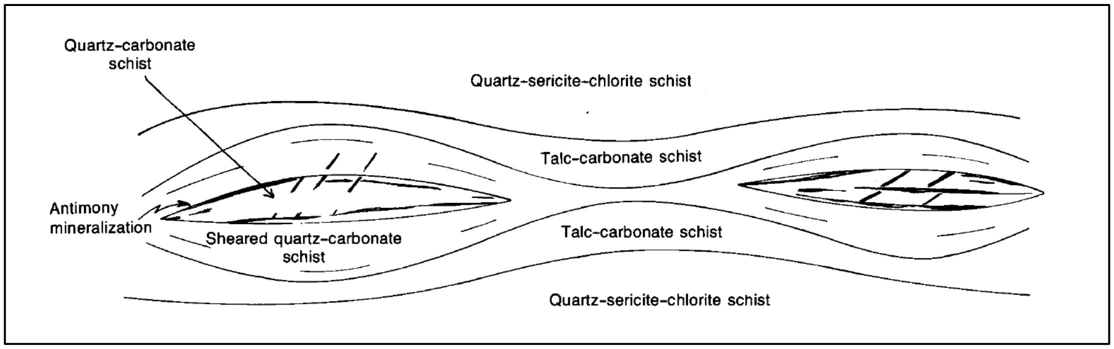


Figure 5.3 Plan view of antimony mineralization in host lithologies (Davis et al., 1986)

The antimony mineralization in the area is described in two distinct ways. The first type is fine crystalline stibnite hosted in veins within the carbonate horizons described above. It appears either massive, as veins or stringers. The second type is coarser and crystalline stibnite. It occurs within fractures that have developed from the main orebodies, veins, and fractures (Viljoen et al., 1978). Various kinds of antimony-based minerals may occur within the ore zone. Stibnite (Sb_2S_3), and berthierite ($FeS.Sb_2S_3$) are common examples whilst sulphides such as pyrite and arsenopyrite also occur in smaller quantities (Viljoen et al., 1978).

5.3 Antimony Production and Reserves

Antimony production in South Africa began in the early 1910s (Graupner et al., 2014). Antimony production was obtained from the antimony deposits along the antimony line in the Murchison Greenstone Belt. Over the years, gold and antimony have been mined interchangeably as either primary commodities or as by-products of one another (Davis et al., 1986). Under the management of Village Main Reef (VMR), Cons Murch Mine operated three vertical shafts and two surface declines (Village Main Reef, 2013). Antimony ore was last extracted from three operating shafts along the Antimony Line. These are namely the Beta Shaft, Athens Shaft and Monarch Shafts. Under Village Main Reef, the Mine produced 500t of antimony and 30kg of gold per month (Village Main Reef, 2013). The sub-level open stoping mining method was used to extract the ore from underground (Davis et al., 1986).

In 2014, antimony production ceased when Cons Murch Mine was liquidated (South Africa. Department of Mineral Resources, 2019). Antimony production in South Africa had progressively declined from 2012 to 2014 (Figure 5.4). Antimony was mined as the primary commodity and gold as a by-product (Village Main Reef, 2013).

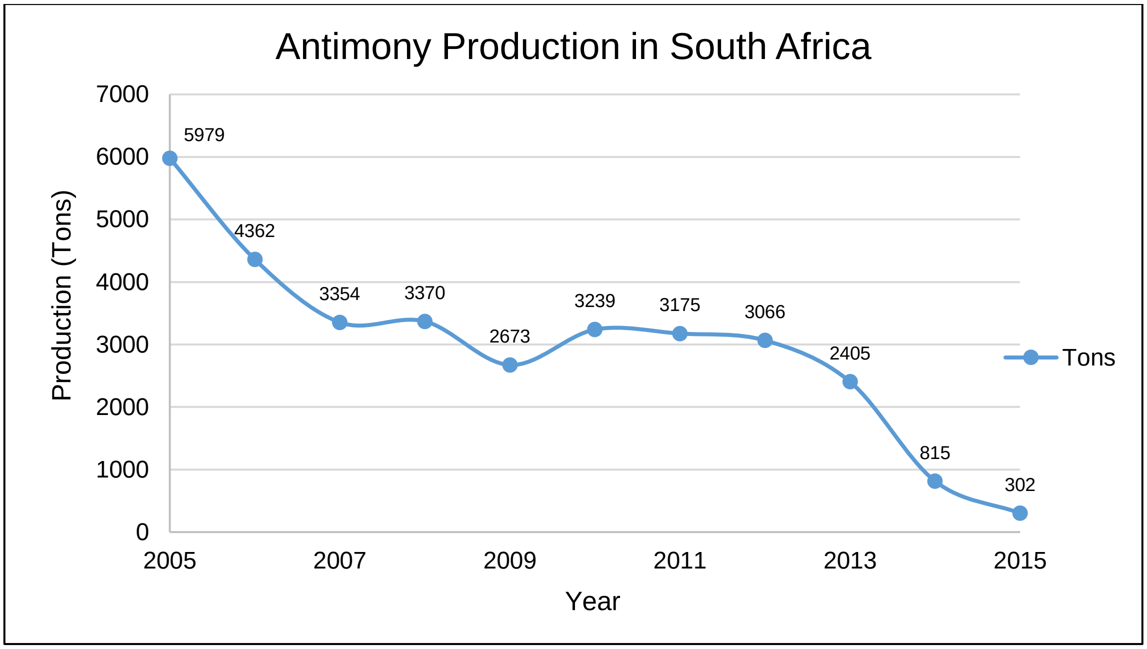


Figure 5.4 Antimony production chart for South Africa (2005 - 2015) in tons (CEICData, 2020a)

South Africa hosts a relatively small portion (2%) of the world's antimony reserves (Table 5.2). For the 2017/2018 period, South Africa's antimony reserves ranked 8th in the world (South Africa. Department of Mineral

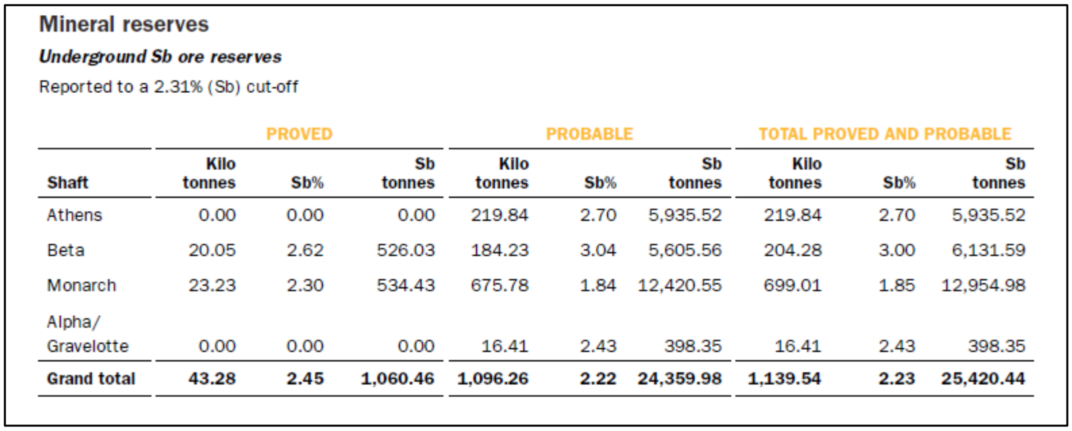
Resources, 2019), compared to 7th in the previous year (2016/2017) under review (South Africa. Department of Mineral Resources, 2018).

Table 5.2 Global antimony reserve rankings 2017-2018 (South Africa. Department of Mineral Resources, 2018; South Africa. Department of Mineral Resources, 2019)

RANK	2017	2018
1	China	China
2	Russia	Russia
3	Bolivia	Bolivia
4	Australia	Australia
5	United States	Turkey
6	Tajikistan	United States
7	South Africa	Tajikistan
8	Mexico	South Africa

As reported in Village Main Reef (2013), proven and probable underground antimony reserves are stated at over 25 000t of antimony at 2.23% Sb. Whilst total measured, indicated and inferred underground resources are stated at just under 205 000t of antimony at 2.18% Sb (Table 5.3) (Village Main Reef, 2013).

Table 5.3 Total calculated underground antimony reserves for Cons Murch Mine as at 2013 (Village Main Reef, 2013)



Mineral reserves

Underground Sb ore reserves

Reported to a 2.31% (Sb) cut-off

	PROVED			PROBABLE			TOTAL PROVED AND PROBABLE		
Shaft	**Kilo tonnes**	**Sb%**	**Sb tonnes**	**Kilo tonnes**	**Sb%**	**Sb tonnes**	**Kilo tonnes**	**Sb%**	**Sb tonnes**
Athens	0.00	0.00	0.00	219.84	2.70	5,935.52	219.84	2.70	5,935.52
Beta	20.05	2.62	526.03	184.23	3.04	5,605.56	204.28	3.00	6,131.59
Monarch	23.23	2.30	534.43	675.78	1.84	12,420.55	699.01	1.85	12,954.98
Alpha/ Gravelotte	0.00	0.00	0.00	16.41	2.43	398.35	16.41	2.43	398.35
Grand total	**43.28**	**2.45**	**1,060.46**	**1,096.26**	**2.22**	**24,359.98**	**1,139.54**	**2.23**	**25,420.44**

A summary of antimony resources per shaft is outlined in Table 5.4 below.

Table 5.4 Total calculated underground antimony resources for Cons Murch Mine (Village Main Reef, 2013)

Underground mineral resources –
Reported to 1% Sb cut off

	MEASURED			**INDICATED**			**TOTAL MEASURED AND INDICATED**		
Shaft	**Million tonnes**	**Sb%**	**Sb tonnes**	**Million tonnes**	**Sb%**	**Sb tonnes**	**Million tonnes**	**Sb%**	**Sb tonnes**
Athens	0.14	0.81	1,106.10	0.75	1.97	14,686.98	0.89	1.79	15,793.08
Beta	0.04	2.65	1,167.88	0.25	2.82	7,107.89	0.29	2.79	8,275.77
Monarch	0.06	1.6	960.90	1.52	1.43	21,777.64	1.58	1.44	22,738.54
Apha/Gravelotte	0.09	3.14	2,838.94	0.47	2.81	13,303.97	0.56	2.87	16,142.91
Grand Total	**0.33**	**1.83**	**6,073.82**	**2.99**	**1.9**	**56,876.49**	**3.32**	**1.89**	**62,950.30**

	INFERRED			**TOTAL MEASURED, INDICATED AND INFERRED**		
Shaft	**Million tonnes**	**Sb%**	**Sb tonnes**	**Million tonnes**	**Sb%**	**Sb tonnes**
Athens	1.15	2.1	24,213.00	2.04	1.97	40,009.55
Beta	1.23	2.51	30,885.30	1.53	2.57	39,153.80
Monarch	1.83	1.9	34,732.00	3.41	1.68	57,478.90
Alpha/Gravelotte	1.84	2.82	51,888.00	2.4	2.83	68,030.91
Grand Total	**6.05**	**2.34**	**141,718.30**	**9.38**	**2.18**	**204,673.16**

An alternative source of antimony is also found in the surface tailings dumps. Tailings Dump 1 and Tailings Dump 2 are located on the mine premises. A summarized resource statement is included below (Table 5.5).

Table 5.5 Total calculated surface tailings resources for Cons Murch Mine in 2012/2013 (Village Main Reef, 2013)

Tailings dump no.1

	DENSITY	CUT OFF	VOLUME AND TONNES		GRADE		
Category	**t/m²**		**km²**	**Mt**	**Au g/t**	**Sb PPM**	**Au EQUIV g/t**
Measured	1.57	0.23	3.94	6.18	0.46	7,518	0.85

Tailings dump no.1 (continued)

	Au CONTENT		Sb CONTENT	Au EQUIV CONTENT	
Category	**t**	**koz**	**t**	**t**	**koz**
Measured	2.84	91.4	46,461	5.25	168.89

Tailings dump no.2

	DENSITY	CUT OFF	VOLUME AND TONNES		GRADE		
Category	**t/m²**		**km²**	**Mt**	**Au g/t**	**Sb PPM**	**Au EQUIV g/t**
Measured	1.57	0	7.47	11.73	0.5	2.37	0.85

Tailings dump no.2 (continued)

	Au CONTENT		Sb CONTENT	Au EQUIV CONTENT	
Category	**t**	**koz**	**t**	**t**	**koz**
Measured	5.87	188.6	27,788	9.97	320.6

Since 2015, surface tailings material has undergone retreatment for its gold content, thus the stated surface tailings resources are likely to differ at this present time.

5.4 The Antimony Value Chain in South Africa

Three forms of antimony-based concentrates of varying grades were historically produced from three separate plants that were constructed at the

Limpopo mine. These are namely antimony sulphide concentrate (Sb_2S_3) (at over 56% Sb and less than 0.25% As), crude antimony trioxide (Sb_2O_3) (at least 81% Sb and less than 0.35% As) and refined antimony trioxide. The mine had also historically produced sodium antimonate (Davis et al., 1986). In recent years, the antimony sulphide concentrate slightly increased (from the above-mentioned 56% Sb concentrate), yet remained below 60% (VMR, 2013).

Since mining commenced in the 1930s, the processing plant located at Stibium Mine was constructed to recover both antimony and gold. The plant has undergone several changes and expansions over the years and thus contains equipment of varying ages and competencies. Thus, certain parts of the processing plant are much older than others, causing varied processing efficiencies in the plant (Davis et al., 1986). New parts were also added onto the mine's plant by Meteorex before the mine was sold to Village Main Reef in 2011 (Graupner et al., 2014). The metallurgical process applied for antimony and gold recovery has undergone many alterations over the years. This is largely attributed to the various antimony-bearing ores that needed to be processed, antimony ore quality and the associated minerals that are found in association with the antimony. Antimony processing on mine premises began in the 1940s after attempts to recover gold proved unprofitable for the mine (Davis et al., 1986). With declining head grades and modified processes, antimony recovery became tricky and consequently, the saleable product was reduced by 50 - 60% of the concentrates produced (Davis et al., 1986).

5.4.1 Stage One: Exploration, ore extraction and concentrate production

Antimony ore was historically mined from the underground operations using the sub-level open stoping mining method (Nex, 2013; Graupner et al., 2014). The antimony extracted from underground usually occurs in association with other mineral commodities such as arsenic, copper and lead. The processing plant found on mine premises was designed to process and recover both antimony and gold. Gravitational methods were used to recover gold whilst antimony recovery was achieved through flotation methods. The mine produced three types of non-metallurgical antimony products. These are namely antimony sulphide concentrate, crude antimony and refined antimony trioxide (Davis et al., 1986).

For this research, the historical metallurgical processes used for antimony recovery from the associated common lithologies/minerals along the antimony line are briefly discussed below. A more detailed historical account is reported in Davis et al., (1986). Antimony ores occur in association with gold, arsenopyrite, talc and carbonate lithologies. The occurrence of arsenic with stibnite had caused problems with the measured purity of the antimony recovered and could potentially affect the quality of the antimony alloys and oxides produced (Davis et al., 1986).

Antimony concentrate formation

Stibnite ores at Stibium Mine are auriferous (gold-bearing) and also occur in association with arsenopyrite. The variance in the density of gold and that of stibnite aids in the separation of the two metals via gravity separation. (Lager and Forssberg, 1989). Davis et al., (1986) simplify the historical antimony and gold recovery process used at the mine as indicated below and in Figure 5.5:

(i) Ore crushing;
(ii) Milling;
(iii) Gravitational gold separation;
(iv) Antimony recovery via flotation;
(v) Concentrate then undergoes low-pH high pressure cyanidation to recover any gold that may have remained behind;
(vi) Filtration; and
(vii) Drying.

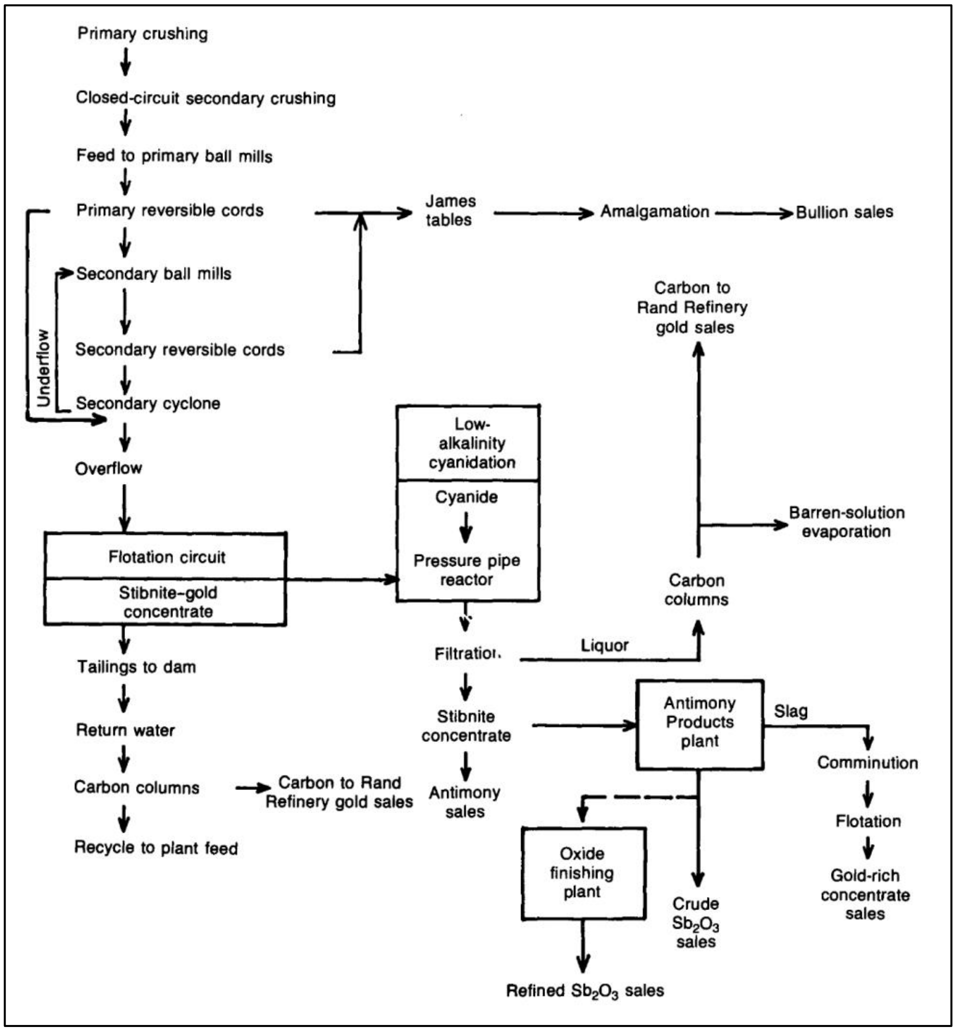


Figure 5.5 Process flow chart of Sb and Au recovery process at Consolidated Murchison Mine as recorded in the 1980s (Davis et al., 1986)

Historically, the antimony concentrate produced had to be at least 56% antimony and less than 0.25% arsenic. Antimony sulphide concentrates produced from the mine had averaged between 57% – 60% antimony in the past. The concentrate produced was securely placed in bulk bags of 1.4 tons each. The bulk of the bagged concentrate was then transported by railway from the mine to Durban for exportation overseas (Davis et al., 1986). VMR (2013) note that antimony concentrate was also exported to India for further processing.

Crude antimony trioxide formation

In the 1970s, the mine began producing antimony trioxide. This was largely the result of rising global demand for this type of antimony. Antimony trioxide was produced at a separate plant known as the Antimony Products (AP) Plant. The plant was also located on mine premises. The AP Plant was commissioned in 1974. Producing crude antimony oxide involves volatizing the antimony sulphide concentrate produced at the initial stages of processing. The crude antimony oxide produced at the mine was historically exported to Europe and the US for further refinement processing (Davis et al., 1986).

Antimony Oxide Formation Process encompasses the following four stages:

(i) Roasting;
(ii) Cooling;
(iii) Bagging; and
(iv) Deslagging.

Refined antimony trioxide formation

Refined antimony trioxide production was conducted through further processing of the crude antimony trioxide produced in the previous stage. The refining process was not reported because of the competitive nature of the antimony oxide industry at the time. Refined antimony trioxide was produced in line with global antimony demand specifications at the time (Davis et al.,1986).

5.4.2 Stage Two: Process concentrate into metal alloy

The bulk of the antimony concentrate produced in South Africa was exported overseas. The presence of impurities in the ore processed in the first stage, affects the quality of the antimony-bearing metal alloys produced. Antimony metal was not historically produced in South Africa (Davis et al., 1986). To facilitate the production of antimony metal alloys in South Africa, blast furnaces (which are highly dependent on power supply to function) are required. This stage also requires skilled personnel such as metallurgists and processing engineers (Lundall et al., 2008). The South African Mining Qualifications Authority does not identify metallurgical and processing engineering skills in its top ten occupational skills in high demand. This implies that the country has a relatively adequate number of personnel in these fields in comparison to other fields (MQA, 2018). Antimony metal is recovered from secondary sources through recycling activity (Davis et al., 1986). Recycled lead-acid batteries are a common source of antimony and lead alloys. Lead-acid battery recycling separates the constituents into lead, plastic and acid components. Lead alloys are subsequently produced by combining the separated lead parts with other materials (First National Battery, 2019).

5.4.3 Stage Three: Enhancement of antimony metals into products

The antimony-bearing metal alloys from the previous stage are used to create low antimony positive plates for the battery manufacturing industry. Low antimony positive plates contain 1.4% Sb (First National Battery, 2019). Requirements at this stage include high capital input and skills from the manufacturing sector (Baxter, 2005). Casting equipment is used to produce the antimony positive plates (First National Battery, 2019); and the labour required to facilitate the activity at this stage is relatively low (Baxter, 2005; Lydall, 2014).

5.4.4 Stage Four: Fabrication and distribution of product to consumer

This stage of the antimony value chain is centered around the manufacturing industry. The process uses the low antimony positive plate to produce lead-acid batteries (First National Battery, 2019). This stage uses assembling machinery and manufacturing equipment (Baxter, 2005). The resultant product is sold to the consumer and is made accessible via existing transport routes. Labour intensity is relatively moderate to high at this stage (Baxter 2005). The skill sets in the last three stages of the beneficiation process tend to overlap (Lundall et al., 2008).

5.5 Antimony Recycling in South Africa

Antimony recycling is an important source of metallurgical antimony. Antimonial-lead alloys are recovered through lead-acid battery recycling. Lead-acid battery recycling is conducted through smelting. Once recovered, the alloys are re-used to manufacture new lead-acid batteries. One lead smelter, developed by First National Battery, is located in Benoni, Johannesburg. The smelter has recycled over 17 000t of lead annually (First National Battery, 2019).

5.6 Antimony Uses and Applications in South Africa

Most of the antimony concentrate produced in South Africa was exported to other countries for further processing (Davis et al., 1986; VMR, 2013). Historical records of antimony tonnages indicate that the difference between locally consumed antimony and exported antimony volumes is vast. The amount of antimony exported was up to fifty times higher than that of locally consumed antimony (Figure 5.6).

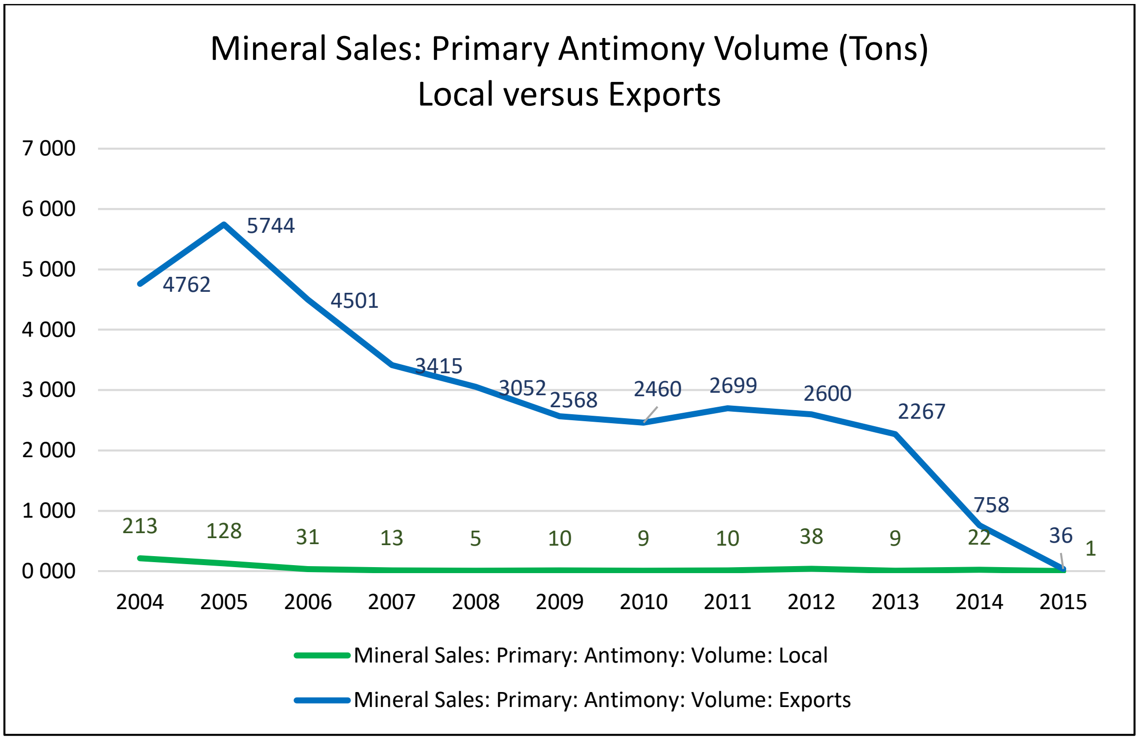


Figure 5.6 Graphs depicting the vast difference between South African antimony volume exports and local antimony consumption from 2004 to 2015 (CEICData, 2020b)

Figure 5.6 confirms that local antimony beneficiation activities have remained limited and antimony applications within South Africa are also minimal. Antimony production volumes in South Africa have declined for reasons such as poor global market conditions, poor antimony recoveries and scaled back production in 2009/2010 period (South Africa. Department of Mineral Resources, 2010). In the 2013/2014 period, antimony production had declined due to the introduction of trackless machinery in the underground operations at Cons Murch Mine and infrastructure and machinery upgrades. Workers at the mine had also embarked on a ten-day strike over dividend payments (South Africa. Department of Mineral Resources, 2015). The lead-acid battery industry only consumes a small fraction of antimony (First National Battery, 2019). Low antimony (1.4% Sb) positive plates are advantageous because the plates lower the required maintenance of the battery, they reduce operating costs and increase the battery's service life. Lead-acid batteries are used in warehousing equipment, mining locomotives, mining cap lamps and railway batteries, to name a few. (First National Battery, 2019). Although South Africa has stopped producing antimony for over five years, the country has maintained lead-acid battery production through recycling activity. Major developments have advanced the battery manufacturing industry in recent years. There are threats of substitutes and an increased interest in the manufacturing of electric motor vehicles. The lead-acid battery industry is progressing from high maintenance antimony batteries to low maintenance hybrid batteries that contain calcium-bearing alloys (Ndlovu, 2019). Non-metallurgical antimony, in the form of antimony trioxide, was historically used for flame retardant products manufactured in the country (Coral Chem, 2011).

5.7 Antimony Value Chain Challenges and Opportunities

Some notable challenges and opportunities pertaining to the implementation of antimony value chain activities in South Africa are identified below.

5.7.1 Access to Antimony Resources

The availability of antimony resources places Stibium Mining South Africa in a good position to re-enter the global antimony market. There is a forecasted demand for non-metallurgical antimony in countries such as Oman and China, where smelters need antimony supply. Some countries in Europe and the USA need antimony to manufacture flame-retardant products. The stated antimony resource and reserve statements for both underground and surface tailings confirm the great potential that still exists at the mine. When the mine was liquidated in 2014, the mine had three operating shafts with indicated ore shoot extensions at depth. There had also been the development of a surface decline in the Gravelotte Shaft area aimed at accessing more antimony reserves (VMR, 2013). The mine can identify ways to extract and process its antimony ore beyond the first stage of processing. There is an opportunity for the mine to partake in the global antimony market as an antimony producer.

5.7.2 Linkage Development

South Africa has an opportunity to use antimony beneficiation activity to facilitate the expansion of the country's linkages with ancillary sectors. Antimony is currently used in lead-acid battery manufacturing and in the production of flame–retardant products. Domestic linkages between local antimony oxide producers and local manufacturers of antimony-bearing products can be established. This would promote the local consumption of antimony oxide by flame-retardant product manufacturers. Government could enhance forward linkages fostered through the extraction of the country's antimony resources. The development of these linkages would generate jobs and increase the shared benefits arising from domestic antimony beneficiation activity.

5.7.3 Government Incentives and Increased Revenue

The MPRRA presents an opportunity for Stibium Mining South Africa to qualify for discounted royalty payments through antimony beneficiation activities. By producing a concentrate containing 65% or more of Sb, the company could benefit from the MPRRA. Processing antimony concentrate to a minimum of 65% not only presents an opportunity for the mining company to save money via a discounted tax rate, but it also increases the value generated from sales of the refined concentrate. The refined antimony concentrate would generate more revenue because it would have undergone further processing. The recent increase in antimony oxide price (Shanghai Metals Market, 2021) could also encourage South Africa's participation in the global antimony industry. The country could explore ways to improve antimony processing capabilities locally to prevent the export of raw antimony concentrate. There is also potential for the country to create metallurgical antimony that can be incorporated into metallic applications that may arise in the future. Having the ability to manufacture and produce antimony-based products domestically, would permit

South Africa to partake in the global market as a supplier of antimony-bearing manufactured products. By becoming a producer of various types of antimony and antimony-bearing products, South Africa has an opportunity to generate additional revenue from antimony beneficiation. The country would require equitable access to international markets, enabling policies and up to date technological expertise to facilitate domestic production of a wider range antimony-bearing products. The costs of beneficiating metallurgical antimony for metal alloy production and manufacturing other metallurgical products besides lead-acid batteries in the country would also need to be considered.

5.7.4 Infrastructure, Machinery and Equipment

To implement domestic antimony beneficiation activities up to the latter stages, effective linkages between the mining company and the manufacturing sector must exist. Robust machinery, equipment and infrastructure are required to facilitate the extraction and processing of antimony. The mine has a processing plant on the mine premises which has only processed gold for the past four years (South Africa. Department of Mineral Resources, 2019). Recapitalization of the plant infrastructure for antimony processing might need to be considered. Skills and knowledge expertise on processing techniques and the equipment required would need to be considered. The manufacturing-centered stages of antimony beneficiation also rely on the availability of reliable machinery and equipment. As Lydall (2014) has noted, South Africa has a relatively excellent base of input supplies to facilitate domestic beneficiation activities. The domestic availability of machinery and equipment is advantageous for local antimony mining activity. The availability of transportation networks within the country also makes domestic antimony beneficiation activities favourable.

5.7.5 Skills for Antimony Beneficiation

Both the mining and manufacturing sectors rely on skilled labour to facilitate antimony beneficiation activities. Industry experts and government can work together to devise tailored skills plans for the local antimony sector. Investment in education, innovation and entrepreneurship is vital for the success of implemented beneficiation practices (Lydall, 2014). Optimum antimony recoveries and an improved quality of the concentrate produced in South Africa, rely on updated knowledge and innovative ideas. Skilled expertise is essential to discovering more innovative antimony recovery processes that can optimize domestic antimony concentrate production. An opportunity exists for South Africa to expand its skills in the manufacturing sector by focusing on antimony-based product manufacturing. The South African Government may consider establishing a skills pool for the beneficiation and manufacturing of antimony-based products. There is an opportunity for South Africa to acquire further skills development through potential knowledge spillovers from countries that have successfully implemented antimony beneficiation activities in their respective countries. The spillovers could expand throughout the stages of the antimony value chain.

5.7.6 Antimony Recycling and Threat of Substitutes

Antimony recycling and substitutes both pose a threat to antimony beneficiation. Non-metallurgical antimony such as ore concentrate and antimony trioxide cannot be recycled and it is sourced through antimony mining activity. However, the non-metallurgical supply chain is threatened by the availability of substitutes. Metallurgical antimony in South Africa is recovered through recycling activity. Lead-acid batteries are recycled and used in the production of new lead-acid batteries. There is also an increased interest in alternative battery types in the automation industry. The threat of substitutes in the lead-acid battery industry has led to a declined demand for metallurgical antimony. Lead-acid battery manufacturing is noted to have sustained production well into the future because of recycling activity.

5.7.7 Limited Electricity Supply

As previously noted, blast furnaces and smelters are required to facilitate stage two of the antimony beneficiation process. Blast furnaces and smelters consume large amounts of electricity. Lundall et al., (2008) note that South Africa’s abundant coal reserves and relatively low electricity prices place the country at a comparative advantage over its peers regarding mineral beneficiation activity. However, low electricity prices, insufficient capital investment in electricity supply expansion projects and electricity demand that far outweighs supply have ultimately led to a deficit of power supply in the country (Jones, 2013).

Many power stations in South Africa were built from the 1960s to the 1980s (Jones, 2013). The country had a surplus of electricity which thus made it inexpensive (Naidoo, 2012; Jones, 2013). Initially, smelters in South Africa were setup around the country's supply of low-cost electricity (Naidoo, 2012). South Africa has a 40 GW power generating capacity; of which an estimated 15% is consumed by the country's mining sector. More than half of this power is used for electric smelting (Jones, 2013). Smelters in South Africa are used to beneficiate aluminium, platinum, titanium, iron ore, copper and manganese (Naidoo, 2012).

Surges in power-supply shortages resulted in load shedding in 2008 (Naidoo, 2012; Jones, 2013). Load shedding was largely attributed to the high consumption of electricity by the country's smelters, and Eskom's arrangements with large companies that processed raw mineral commodities (Naidoo, 2012). In 2012, Eskom introduced measures to decrease the power supplied to smelters, to curb the insufficient availability of power in certain grids. Eskom paid smelters to shut down for up to three months and this led to increased tariffs and economic disorder (Naidoo, 2012). Post-2012, many smelters closed because of their large power consumption (Naidoo, 2012). Several ferro-alloy smelters in the country have closed and others are paid by Eskom to prevent them from consuming electricity. This ensures that adequate power supply is made available to other consumers (Jones, 2013).

Mineral beneficiation requires the use of smelters and blast furnaces, which consume large amounts of electricity. Power shortages and increased tariffs have constrained local beneficiation activity (Jones, 2013). To ease power supply constraints in South Africa, Eskom has since begun the construction of two coal-fire power stations in the country to increase the country's current capacity (Graupner et al., 2014). South Africa also has a long-term plan to address power supply constraints through a combination of varied power-generating methods. The Department of Energy in South Africa released the Integrated Resources Plan in 2019 which outlines the country's long-term plans to address the country's energy needs (South Africa. Department of Energy, 2019). Addressing the country's power supply constraints would make stage 2 antimony beneficiation activity more realistically implementable in the country.

5.8 Conclusion

This Chapter provides some insight on South Africa's antimony industry. The Chapter focuses on the antimony orebodies located in the Limpopo Province. The Chapter describes the regional geology, production trends and uses of antimony in the country. South Africa has contributed to global antimony production since the 1940s, and production ceased in 2014. Since then, the antimony circuit at the mine's plant has remained inactive and only gold production has been generated from the treatment of mine tailings. Non-metallurgical antimony products such as antimony concentrate, crude antimony trioxide and refined crude antimony trioxide were historically produced at the mine. Local consumption of antimony in South Africa was very low in comparison to exported antimony. Metallurgical antimony is recovered through recycling activity. Lead-acid batteries are recycled to recover antimony-based alloys, which are re- used to manufacture new lead-acid batteries. The Chapter concludes by identifying significant challenges and opportunities related to local antimony beneficiation activities.

6 DISCUSSION

South Africa was once considered a reliable antimony producer outside of China. Antimony from South Africa had undergone first stage processing and non-metallurgical antimony was exported to various countries until production ceased in 2014. Lydall (2014) notes that the demand for a mineral commodity encourages the local implementation of mineral beneficiation activities in a country. Identifying alternative sources of antimony and suitable substitutes for the commodity has become increasingly important because of antimony's effect on human health and decreased antimony output from the world's leading antimony producer, China. Additional antimony supplies are sought in countries such as China and Oman to feed their smelters. Strained relations between China and the USA have also created a window of opportunity for global antimony suppliers. Although South Africa hosts smaller known antimony reserves compared to China, the country could use its comparative advantage and re-enter the antimony market as a supplier of antimony and antimony-bearing products. The successful local implementation of activities along the antimony value chain depends on South Africa's current capabilities and the strength of its linkages across sectors.

South Africa has an extensive history of effective backward linkages in the mining sector (Walker and Minnitt, 2006). The country has supplied its mining sector with locally manufactured machinery and equipment to facilitate mining activity over many years (Ghebrihiwet, 2018). Thus, there is guaranteed local supply of mining equipment readily available should Stibium Mining South Africa restart its underground mining operations. Recapitalization costs associated with the startup of underground operations would need to be considered. Antimony may also be recovered by recycling the tailings dams located on the mine premises. Retreating tailings material would provide an alternative source for antimony production.

Stibium Mining South Africa could consider optimal extraction and processing methods to produce a minimum antimony concentrate of 65% to benefit from the discounted Royalty Tax rate as stipulated in the MPRRA. Davis et al., (1986) note that the construction of the mine’s processing plant used various structures of varying ages and competencies, and it was last refurbished when Meteorex had ownership of the mine. Since antimony production ceased in 2014, the mine’s plant circuit for antimony recovery has not been in use. It is expected that capital costs for plant refurbishment would have to be considered should the mine start antimony extraction and processing activities. Skills, research, and development conducted domestically for antimony and antimony-based products is limited; and all are crucial for optimized antimony processing techniques. Obsolete processing research conducted on antimony orebodies found along the MGB restricts the identification and implementation of the best recovery methods. The ideal 65% antimony concentrate is likely achievable through the application of improved processing methods and techniques.

Metallurgical antimony is mainly used to create production cells for lead-acid battery manufacturing. Metallurgical antimony is recovered from recycled lead-acid batteries. The recovered metal is used to manufacture new batteries. This has caused a declined demand for primary metallurgical antimony and the lead-acid battery manufacturing industry is forecast as self-sustaining (Anderson, 2019). In addition, metallurgical antimony production requires the use of smelters and furnaces, which consume large amounts of electricity. South Africa is currently experiencing load shedding due to deficient power supply. The current insufficient supply of electricity poses a threat to the local implementation of antimony beneficiation activities. Although the implementation of stage two metallurgical antimony beneficiation activities would bring forth job opportunities for South African citizens, and an opportunity for the country to access a broader spectrum of the antimony market, the country does not currently have the electrical capacity to do this. There is also no significant demand for metallurgical antimony at this present time. The Department of Minerals and Energy of South Africa has outlined a strategy to address the mid to long term electricity supply in the country's Integrated Resource Plan (South Africa. Department of Minerals and Energy, 2019). By addressing power supply constraints, South Africa could potentially partake in the latter stages of the antimony value chain. There is also potential for the country to create metallurgical antimony for use in other metallic applications that may arise in the future. The ability to manufacture and produce antimony-based products domestically, would permit South Africa to partake in the global market as a supplier of manufactured products. This would also increase the revenue generated from local antimony beneficiation activities. The USA uses metallurgical antimony to produce metal products such as antimonial lead and ammunition (United States. Geological Survey, 2021). South Africa could potentially become an alternative supplier of metallurgical antimony to the USA.

Consideration for all sectors involved in the beneficiation process and their associated challenges creates a realistic plan for the implementation of antimony beneficiation practices in the country. As noted by Baxter (2005), seamless linkage development between the mining and manufacturing sectors is imperative for the successful implementation of antimony beneficiation. With advantages such as increased revenue, job creation opportunities, skills development and an opportunity to become an important global producer of the commodity, domestic antimony beneficiation could positively impact the South African economy.

7 CONCLUSION AND RECOMMENDATIONS

This research report aimed to identify the various opportunities that exist for antimony beneficiation activities in South Africa. This Chapter reflects on the findings of the research and draws the following conclusions and recommendations.

South Africa has significant antimony resources and reserves that present an opportunity for the country's antimony mine to re-enter the global antimony market. The country also boasts a reputable minerals inputs cluster that has supplied inputs to the local and regional mining industry over many years. South Africa is therefore currently well-positioned to extract and beneficiate antimony up to the first stage of processing.

Depending on various factors, South Africa could partake in the global antimony market as a supplier of non-metallurgical antimony or metallurgical antimony products. Metallurgical antimony production is sourced from recycled lead-acid batteries. There is a projected decline in demand for metallurgical antimony in the lead-acid battery industry. This is because of the battery industry's self-sustaining nature, as it consumes recycled antimony, and it also uses substitutes to manufacture batteries. Metallurgical antimony is also used to make metal alloys with lead and tin. South Africa could become an alternative global supplier of antimony-based metal alloys. Smelters and refineries would also require large amounts of power supply. The country's Department of Energy has outlined various projects to mitigate the long-term power supply constraints in the country in the 2019 Integrated Resources Plan. Thus, making it plausible for the country to explore ways of incorporating sustainable antimony beneficiation activities into its plans. Once power supply shortages are mitigated, South Africa could explore the possibility of producing antimony-based metals for consumption outside of the battery manufacturing sector. The country could also enter the global antimony market as a supplier of various metallurgical antimony-bearing products.

Non-metallurgical antimony currently has more favourable opportunities for South Africa. Non-metallurgical antimony may be mined and exported to countries that need the commodity. China and Oman require primary antimony to feed their smelters. Other countries that rely on antimony imports from a dominant supplier may be interested in exploring alternative supplier options, thus decreasing their reliance on one supplier. The USA and countries in the EU rely on imported antimony and South Africa could become a potential supplier antimony to countries such as these. South Africa may also incorporate locally produced non-metallurgical antimony to manufacture flame-retardant products for local consumption and export sales. This could be underpinned by policy frameworks that facilitate the establishment of localized linkages between antimony mining companies and local manufacturers of flame retardant products. The government could draft policies that support localized antimony beneficiation activities. Non-metallurgical antimony is, however, also subject to the threat of substitutes. Antimony oxide substitutes threaten the viability of its use in the flame retardant applications. Nevertheless, the projected demand for flame retardant products presents non-metallurgical antimony with great potential in the global antimony market compared to its metallurgical counterpart. Table 7.1 summarizes the local opportunities and challenges of metallurgical and non-metallurgical antimony beneficiation in South Africa.

Table 7.1 Summary of identified antimony beneficiation opportunities and challenges for South Africa

NON-METALLURGICAL ANTIMONY BENEFICIATION OPPORTUNITIES	**NON-METALLURGICAL ANTIMONY BENEFICIATION CHALLENGES**	**METALLURGICAL ANTIMONY BENEFICIATION OPPORTUNITIES**	**METALLURGICAL ANTIMONY BENEFICIATION CHALLENGES**
• Existing demand for non-metallurgical antimony. • Antimony deposits in SA. • Re-enter the antimony market. • Antimony concentrate production. • Optimize on 65% MPRRA discount. • Export antimony to Oman and China. • Manufacture flame retardant products for export to the EU.	• Plant refurbishment costs. • Invest in R&D to optimize antimony recovery processes. • Threat of substitutes. • Ensure products align with global standards. • Establish new trade agreements.	• Incorporate antimony alloy production into the manufacturing sector. • Manufacture other antimony-based products (i.e., besides LA Batteries) for local consumption and export.	• Dwindling demand for metallurgical antimony due to recycling activity and threat of substitutes. • Power supply constraints. • Invest in R&D to optimize antimony recovery processes. • Restricted use of existing furnaces and smelters. • Limited local antimony-based product manufacture skills and expertise. • Establish new trade agreements.

The following recommendations are made for local non-metallurgical antimony beneficiation:

1. Stibium Mining South Africa may explore processing methods and strategies to achieve antimony concentrate of at least 65% to benefit from the discounted royalty rate as prescribed in the MPRRA. The true benefit can be determined by comparing the saved costs obtained through discounted Royalty Tax payments, compared to the costs associated with the refining process.
2. Investment in the research of advanced antimony processing techniques within South Africa is also recommended. This would help identify ways to optimize antimony recoveries and improve the overall quality of the concentrate produced.
3. An opportunity exists for Stibium Mining South Africa to supply non-metallurgical antimony to local manufacturers of flame retardant products. Alternatively, non-metallurgical antimony could be exported to countries such as the USA, China, and Oman.
4. Locally manufactured flame retardant products (created from locally produced antimony) could be supplied to the local market or sold globally. This creates an opportunity for South Africa to enter the global antimony market as a supplier of flame retardant products. This would translate to increased revenue for the country generated from export sales.

5. To ensure that the flame retardant products manufactured in South Africa are globally competitive, the government, research bodies and manufacturing companies may introduce knowledge and skills training initiatives from expert global manufacturers. This would create a local pool of expertise from which the manufacturing industry can source skilled personnel.
6. South Africa has the potential to conduct stage two antimony beneficiation activities. Government should consider incorporating the expansion of linkages between antimony oxide producers and flame retardant manufacturers into policies that regulate local antimony beneficiation activity.

Demand for metallurgical antimony is limited however, South Africa could still become a potential producer of metallurgical antimony. The following recommendations are noted to encourage the local production of metallurgical antimony for both domestic consumption and international export:

1. Government, manufacturers and research institutions may collaborate and invest in knowledge and skills training initiatives from expert global manufacturers of metallurgical antimony-bearing products. This would create a local pool of expertise from which the manufacturing industry

can source skilled personnel. This would also ensure that manufactured products are globally competitive.

2. Expand on current policies to incorporate domestic antimony metal beneficiation activities. Policies pertaining to local linkages between local antimony producers and local manufacturers of metallurgical antimony products should be established.
3. Identify potential target markets for the export of locally manufactured metallurgical antimony-based products. Trade agreements would need to be established.

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