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# SOUTH AFRICA'S ALUMINIUM VALUE CHAIN AND CLIMATE CHANGE COMPATIBILITY

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## EXECUTIVE SUMMARY

In South Africa, the aluminium value chain consists of primary production, secondary production, semi-fabrication and fabrication, and scrap recovery and recycling. No mining of bauxite, the primary input into aluminium production, takes place. Primary aluminium is produced at the Hillside Aluminium smelter in KwaZulu-Natal. Secondary aluminium is produced by several companies across the country, such as Hulamin and Wispeco.

The South African value chain is highly carbon intensive due to its dependency on fossil fuels, such as coal-powered electricity. The Hillside smelter, the only primary aluminium producer in the country, is 100% reliant on coal-powered electricity from Eskom. Electricity accounts for 88% of the smelter's greenhouse gas (GHG) emissions. Secondary aluminium producers Hulamin and Zimco Metals primarily produce their aluminium from natural gas, liquid fuels and coal-powered electricity.

The carbon intensity of South Africa's aluminium value chain places it at risk. As the world shifts towards a low-carbon economy, countries introduce border carbon taxes, and end-user demand for "green" aluminium increases, the industry could lose its international competitiveness. In a carbon constrained future, the value chain will need to find solutions to reduce its carbon and energy intensity. The aluminium value chain will need to rethink its production processes and energy use.

A number of possible avenues can be considered to foster a climate compatible aluminium value chain in South Africa. Only four could promote the climate change compatibility of the value chain, namely decarbonising the energy input, engineering improvements, disruptive technologies, and recycling. While substitutes would be useful in certain products, the extent to which they can contribute to the climate change compatibility of the South African aluminium value chain is marginal.

The first avenue would be to decarbonise the energy input by increasing utility-scale renewable energy capacity or distributed renewable energy generation through the use of Independent Power Producers (IPPs). Given the high contribution of indirect GHG emissions from coal-powered electricity, addressing indirect emissions is key to ensuring the climate compatibility of the value chain. The decarbonisation of the national power system would require an acceleration of renewable energy capacity and increasing battery storage while reducing the coal-powered generation capacity.

Across the value chain, electricity is sourced from Eskom. Hillside, the primary aluminium smelter is entirely dependent on Eskom, sourcing 100% of its electricity requirements from the national utility. Hillside requires utility-scale renewable energy and battery storage to reduce its GHG emissions. South32 (previously BHP Billiton) has announced that it is looking at options for "greening" Hillside in partnership with Eskom, the government and other relevant stakeholders.

In the other parts of the value chain, electricity is used in conjunction with natural gas and liquid fuels in the production process. Electricity from Eskom accounts for 34%, 33% and 20% of the power mix for Hulamin, Wispeco and Zimco respectively. The secondary aluminium sector is investigating distributed generation renewable energy, biomass and gas-based electric generation as a means to decarbonise and to mitigate the loadshedding risk.

Then, improving energy efficiencies for both primary and secondary aluminium production could contribute to the climate compatibility of the value chain. Reducing direct emissions from both primary and secondary production would require making engineering improvements or/and implementing disruptive technologies. The reduction in GHG emissions would depend on the technology or processes used. In both primary and secondary aluminium production, combinations of various technologies and processes would yield the best results. In the short to medium term, engineering improvements and technologies would be the best options for reducing direct emissions. Most novel or disruptive technologies are not commercially available or cannot be retrofitted in a financially feasible way at this point in time.

While recycling rates are already high for aluminium, more could be done to increase recycling, sorting and collection as well as creating closed loop production. Increasing recycling would reduce GHG emissions by reducing the need to produce primary aluminium. Increasing collection would require increased convenient collection infrastructure, increased consumer awareness, and a close relationship between manufactures and recyclers.

Last, substituting aluminium with other materials or products would require that they satisfy the requirements as well as fit the characteristics of aluminium. Aluminium is a highly versatile metal. It is the most used non-ferrous metal worldwide. Its multiple properties (lightweight, non-corrosive, high thermal and electrical conductivity, low density, non-toxic, non-magnetic) mean that finding suitable materials to substitute aluminium is difficult. Not only do the materials need to fit the characteristics of aluminium but they also need to have a lower carbon footprint than aluminium. In a variety of applications, that has not been possible as of yet.

Looking ahead, the future of the South African aluminium is uncertain. In the current business-as-usual scenario, the shift in energy generation and production/technologies methods continues to be implemented at the current gradual pace. This scenario paints a picture of the future of the value chain if decarbonisation of the energy input and efficiency technologies are not implemented fast enough. This scenario is not viable for the aluminium value chain. In the long run, it would lead to either parts of or the whole value chain shutting down. As the global economy shifts towards a low-carbon trajectory, highly carbon intensive value chains will face significant risks and loose competitiveness.

Achieving long-term sustainability therefore equals decarbonising the value chain. This entails decarbonising the electricity input and reducing direct emissions. From the avenues highlighted above, two pathways emerge for the aluminium value chain: decarbonising electricity and implementing technologies to reduce direct GHG emissions.

Decarbonising electricity would require accelerating utility-scale and distributed renewable energy generation, transforming the distribution and transmission networks, and deploying large-scale energy storage facilities. Direct GHG emissions could be reduced through engineering improvements and disruptive technologies. Increasing recycling would require creating closed loop production and improving collection rates.

The electricity input pathway would have different implications for different stages of the value chain. Primary aluminium producer Hillside is dependent on electricity from Eskom. Greening Hillside would require utility-scale renewable energy and battery storage. Hillside could take three approaches to decarbonising electricity.

- The first option is to decarbonise the Eskom grid. This would mean accelerating Eskom's decarbonisation plan. The key concern is that the glide path would not be fast enough for South32's decarbonisation targets. South32 aims to reduce 50% of its group emissions by 2035. Hillside currently accounts for 58% of the group's total GHG emissions. Another concern is that Eskom cannot earmark renewable energy for Hillside. Last, the renewable energy tariff rates might not be financially feasible for Hillside. While the current tariff under the new pricing contract is publicly unknown, the special pricing contract has historically led to the smelter paying lower than Megaflex rates.

- Second, Hillside could procure electricity independently through IPPs. This would require up to 5 000MW of renewable energy and large-scale battery storage. The smelter could procure the renewable energy in two ways. Block stages, where it procures renewable energy in blocks, or exponentially, where it procures a little at the beginning and more towards the end. The exponential approach would be more suitable as the smelter could take advantage of the declining prices of solar photovoltaic (PV), wind energy and battery storage. However, the scale of the generation capacity to be procured makes it difficult. In addition, this would lead to Eskom losing Hillside as an anchor customer.

- Third, South32 could enter into a public-private partnership (PPP) with Eskom to procure renewable energy and battery capacity for Hillside. A new power purchase agreement (PPA) could be introduced which would require leveraging the long commercial relationship between Eskom and Hillside. This approach could be the most suitable approach for South32 and Eskom to secure low-carbon power for Hillside. This approach would require amendments to and/or a new Negotiated Pricing Agreement contract between Hillside and Eskom and could, for instance, be implemented through the Tubatse hydro-battery project.

Secondary producers, Hulamin, Wispeco and Zimco Metals, could decarbonise their electricity inputs through distributed energy from IPPs. These companies are already investigating solar PV and wind energy as well as biomass as low-carbon alternatives to the grid.

In terms of research and development (R&D), the local value chain players are not involved in technology development. They have to use the technology which exists in the market. The current disruptive or novel technologies, such as inert anodes, are not commercially available. While engineering improvements do improve direct production efficiencies, the gains are marginal compared to decarbonising electricity.

Along the value chain, every opportunity to reduce both direct and indirect emissions should nevertheless be taken. The primary source of carbon intensity in the South African aluminium value chain is electricity. Moving forward, decarbonising electricity inputs should be a primary focus for all stakeholders in the value chain.

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## ABBREVIATIONS

| | |
|---|---|
| ACD | Anode-to-Cathode Distance |
| APDP | Automotive Production and Development Programme |
| BESS | Battery Energy Storage System |
| CBAM | Carbon Border Adjustment Mechanism |
| CCS | Carbon Capture and Storage |
| DRS | Deposit-Return Systems |
| EU | European Union |
| EGA | Emirates Global Aluminium |
| EPR | Extended Producer Responsibility |
| EV | Electric Vehicle |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| IAI | International Aluminium Institute |
| IPP | Independent Power Producer |
| IRP | Integrated Resource Plan |
| LTE | Low-Temperature Electrolysis |
| MIDP | Motor Industry Development Plan |
| NASA | National Aeronautics and Space Administration |
| NERSA | National Energy Regulator of South Africa |
| NPA | Negotiated Pricing Agreement |
| NPC | National Planning Commission |
| PPA | Power Purchase Agreement |
| PPS | Price Preference System |
| PPP | Public-Private Partnership |
| PV | Photovoltaic |
| PFC | Perfluorinated Compounds |
| R&D | Research and Development |
| REIPPPP | Renewable Energy Independent Power Producer Procurement Programme |
| SPA | Special Pricing Agreement |
| SPS | Spark Plasma Sintering |
| UBCs | Used Beverage Cans |
| VSDs | Variable Speed Drives |
| XRT | X-Ray Transmission |

# 1. INTRODUCTION

Aluminium is the most used non-ferrous metal worldwide. Its multiple properties (lightweight, non-corrosive, high thermal and electrical conductivity, low density, non-toxic, non-magnetic) make it a versatile multiuse metal (Plunkert et al., 1991). Aluminium is used in various sectors, most prominently in transport, construction, consumer goods, packaging and machinery and equipment.

The production of primary aluminium is, however, extremely energy-intensive. Globally, the industry is responsible for 2% of human-caused GHG emissions (IEA, 2020a). The production of aluminium requires large amounts of electricity and as such relies on the availability of an affordable, reliable electricity supply. Depending on the energy sources used to power aluminium smelters, this comes with high environmental impacts, notably GHG emissions (Khare et al., 2007).

As countries around the world, including South Africa, shift to low-carbon development trajectories, as part of broader sustainable development pathways, the production of aluminium is set to experience material changes (United Nations, 2015). Countries are progressively implementing climate change mitigation measures, such as carbon pricing and carbon border taxes to curb GHG emissions. South Africa is no exception, as exemplified by the implementation of a carbon tax and carbon budgets. In addition, consumer preferences are shifting away from carbon-intensive products, with impacts on entire value chains.

Within this trend, carbon-intensive and/or hard-to-decarbonise industries are particularly at risk and need to rethink their operations and business models. This is notably the case of the South African aluminium value chain. While South Africa does not have any bauxite deposits, the mineral at the foundation of aluminium, it does host primary aluminium smelting as well as downstream industries. Within the global context, South Africa is a minor player, contributing 1.2% to global aluminium production. And, unlike in most countries, where hydropower plays a large role, the domestic industry primarily relies on coal-fired power generation. However, the premise of abundant, cheap electricity, on which the industry was historically established in the country, does not hold anymore (Montmasson-Clair et al., 2014).

At the same time, the aluminium industry is critical to industrial and economic development. Due to its properties, it also has many applications that can assist other industries to decarbonise and improve sustainability. For instance, aluminium is critical to reducing the GHG emissions of the transport sector by enabling the production of lightweight motor vehicles. The construction sector uses aluminium to improve energy efficiency and to increase the lifespan of buildings. Aluminium also plays a critical role in the energy sector, particularly in solar energy and battery storage (International Aluminium Institute, 2021).

Aluminium production and its usages require thinking about the role and shape of the aluminium value chain in a carbon-constrained world, and its future within the South African context. This paper aims to assess the climate compatibility of the aluminium value chain. It discusses the key issues of the aluminium value chain from a climate change perspective. It explores avenues towards the climate compatibility of aluminium in South Africa as well as looking at the future of aluminium in a carbon-constrained future.

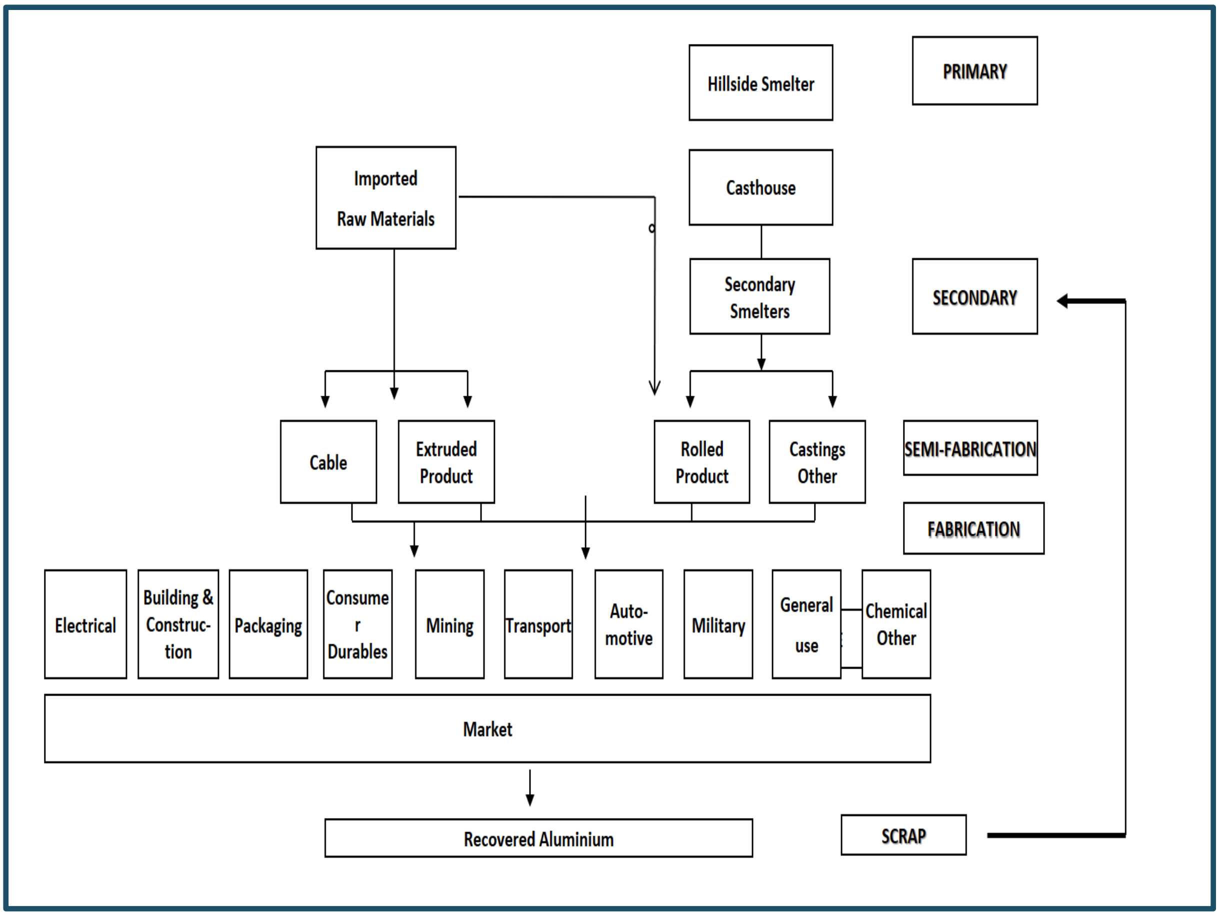
The paper is structured as follows: Section 2 provides an overview of the South African aluminium value chain. It covers the socio-economic and environmental contributions of the industry and outlines its performance in GHG emissions, energy efficiency and carbon intensity. Section 3 provides the avenues for moving towards climate change compatibility. Section 4 presents the potential future of aluminium in South Africa. Section 5 details the conclusions of the paper and policy recommendations.

## 2. THE SOUTH AFRICAN ALUMINIUM VALUE CHAIN

The aluminium value chain is considered one of the industrial pillars of the South African economy. In 2019, it directly contributed 0.7% to South Africa's gross domestic product (GDP) and accounted for about 2% South Africa's total exports (Hulamin, 2020). In 2017, the industry employed 11 600 people directly and 28 900 people indirectly. These employees are estimated to support over 55 700 dependents. Large numbers of informal workers also benefit from aluminium scrap collection (Department of Science and Technology and CSIR, 2017).

The South African value chain is shown in Figure 1. It consists of primary and secondary production, semi-fabrication and fabrication, aluminium scrap recovery and recycling. Aluminium-related mining is non-existent in South Africa, as South Africa has no known bauxite[1] reserves, the basic mineral at the foundation of aluminium production.

**Figure 1: South African aluminium value chain**




*Source:* AFSA, 2017.

### 2.1 Primary aluminium

The South African aluminium value chain begins with the production of primary aluminium. South32's Hillside smelter is the only producer of primary aluminium in South Africa. Hillside uses the Hall-Héroult process (the primary industrial production process) and Pechiney Technology to produce aluminium through electrolysis/smelting. The process involves dissolving alumina in a

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[1] Bauxite is transformed into alumina through a process known as the Bayer Process. Alumina is then used for the production of aluminium metal. South Africa imports almost all of its alumina from Worsley Alumina, an Australian subsidiary of South32.

molten cryolite bath and electrolysing the molten salt bath, typically in a large carbon or graphite lined steel container called a reduction pot (Mandin et al., 2009). The electrolysing process is the most energy-intensive part of the production process. During the process, carbon dioxide and other[2] GHG emissions are produced.

**Box 1: South African primary aluminium and Eskom**

Production of primary aluminium began at the BHP Billiton (now South32) owned Bayside smelter in the 1980s in Richards Bay in KwaZulu-Natal. Bayside Aluminium was the first major industry established in Richards Bay. The smelter was the only aluminium producer until the Hillside smelter was commissioned in 1995 (South32, 2016).

South Africa has no known bauxite reserves. As such, industry was established to promote industrial development, support the growth of Richards Bay, and absorb excess power generation capacity following the construction of several power stations in the late 1980s. In the early 1990s, the South African power utility Eskom had excess capacity, with about 40% reserve margin. Given the cost of storing surplus electricity, Eskom entered into 25-year Special/ Negotiated Pricing Agreements (SPAs/NPAs) with BHP Billiton (Montmasson-Clair et al., 2014). Industrial policy at the time advocated investment in large, energy-intensive sectors and was seen effectively as a coal-beneficiation strategy.

The original NPAs ran from 1995 to 2020 and included SPAs that linked electricity prices to an international US$-based aluminium price at the prevailing exchange rate and not Eskom's cost of producing electricity (Yelland, 2013). The contracts were struck to stimulate investment in aluminium refining in South Africa. BHP Billiton's multi-billion rand investment in the smelters was made in direct response to incentives and encouragement by the governments of South Africa and Mozambique (with the Mozal facility). The contracts also aimed to develop a downstream aluminium industry, create jobs, substitute the imports of aluminium by domestic producers and contribute towards the balance of payments (Montmasson-Clair et al., 2014).

In 2008, commodity prices fell and, since the NPAs were linked to aluminium prices, the price of electricity paid by BHP Billiton fell. Yet, the constrained electricity supply and other factors placed BHP Billiton in a position where it had to reduce 120 000 tonnes of production to cut its electricity consumption. In 2014, the Bayside smelter was decommissioned due to "significant and ongoing financial pressure" and government's requirement that the industry reduces electricity demand by 10% (Moorcroft, 2014). The Hillside Aluminium smelter remains the only operating smelter in South Africa.

The original NPAs were criticised for the length and the embedded derivative risk. The NPAs were favourable to BHP Billiton. They provided the smelter with a discounted tariff methodology, which fluctuated with the performance of aluminium prices and the rand dollar exchange. This resulted in the heaviest user of electricity paying some of the lowest prices for it. It is estimated that the cost of supplying the smelters at the special price rather than at Megaflex rates was R11.5 billion (for 2013) (Levin, 2014). In 2020, the original contracts expired for Hillside Aluminium's Potlines 1 and 2, the contract for Potline 3 was extended to 2028 (De Klerk, 2019).

In December 2020, Eskom submitted a new NPA agreement to the National Energy Regulator of South Africa (NERSA).

[2] Aluminium production also releases other high global warming GHGs such as perfluorinated compounds (PFC), tetrafluoromethane, and hexafluoroethane.

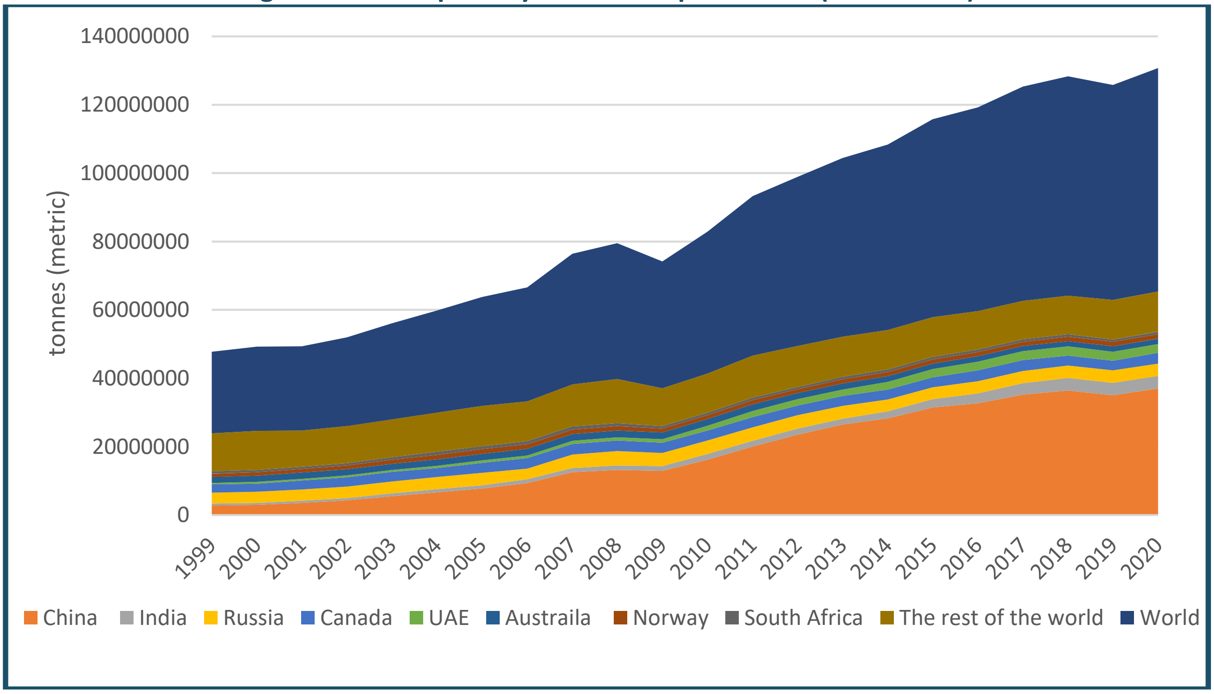
The new agreement, valid for 10 years, has removed the embedded derivative by excluding the commodity price or rand dollar exchange link. While the exact details of the contract remain confidential, it includes real yearly price increases linked to South African producer price inflation (Eskom, 2021a). The NPA does, however, include a surcharge paid by Hillside once the aluminium commodity price and exchange rate is in its favour.

The submission to NERSA by Eskom stated that the new agreement aimed to sustain the production of aluminium at Hillside, maintain the 1 800 direct employees and thousands of indirect jobs. Hillside is a critical commercial customer of Eskom. In 2019, it accounted for 5% of Eskom's sales. Hillside also plays an important role in Eskom's grid stability. The smelter provides flexible interruptible loads, which is used by the National System Operator to manage electricity supply to the country as a whole. Hillside offers 2 000MW of instantaneous reserve and supplemental reserve to supply the demand during periods of electricity shortage (loadshedding). After stakeholder comments, NERSA approved the NPA in July 2021 (Myeni, 2021).

### 2.1.1 Production

South Africa is a small player in global aluminium production. Figure 2 shows primary aluminium production from the seven largest aluminium producing countries, South Africa and the rest of the world. Global aluminium production has been mainly driven by China, which accounted for 54% of global production in 2017. The seven largest aluminium-producing countries collectively supply approximately 80% of global aluminium production. In 2017, South African production only contributed 1.2 % to global aluminium production. The country ranked 13th in global aluminium production and 8th in exports (Department of Mineral Resources, 2018).

**Figure 2: Global primary aluminium production (metric tons)**

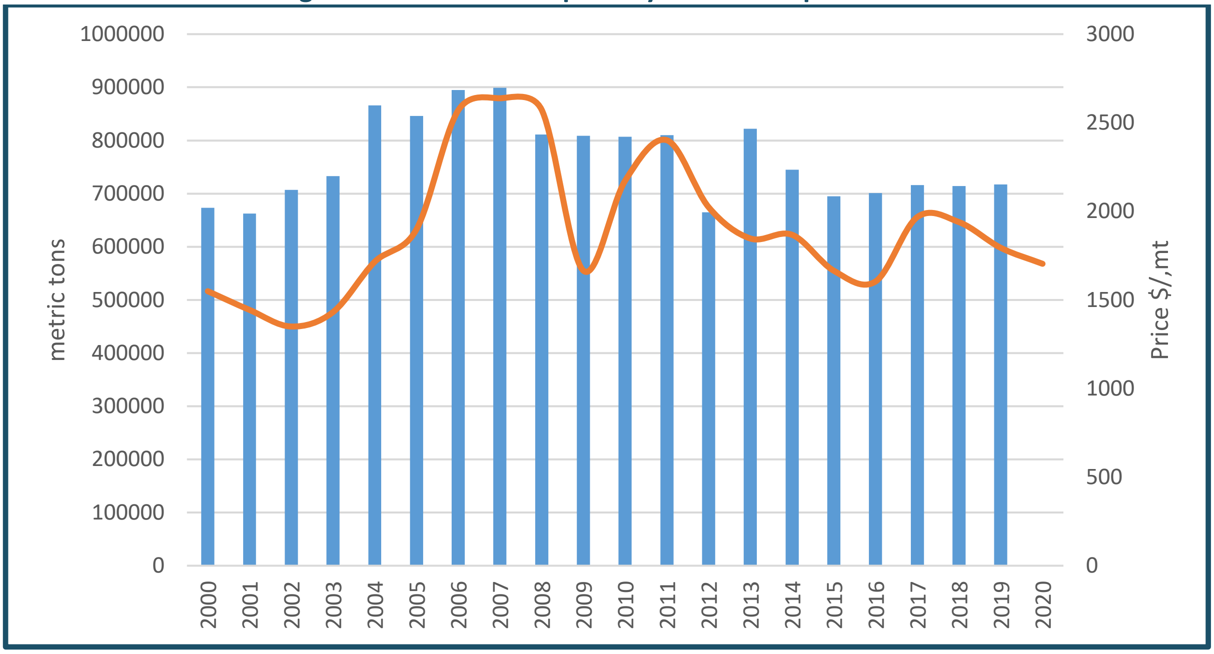



*Source:* Authors, based on data from the British Geological Survey, Series on Global Primary Aluminium Production, 2020 downloaded on minerals statistics in September 2022.

Aluminium production is relatively inflexible, owing to the production capacity of smelters. Figure 3 depicts South Africa's aluminium production from 1999. Since 2015 (and the closure of the Bayside smelter in 2014), aluminium production has remained relatively flat in South Africa, at approximately

700kt per annum. While prices have fluctuated over the past 20 years, since 2019 the price of aluminium has shown a downward trend.

**Figure 3: South African primary aluminium production**




*Source:* Authors, based on data from the British Geological Survey, Series on Global Primary Aluminium Production, downloaded on mineralsuk statistics and World Bank, Series on Commodity prices, 2020 downloaded on CMO Pink-Sheet March-2022 in September 2022.

South32 produces aluminium for both domestic and export markets. Export sales significantly outweigh domestic sale. Over 70% of South Africa's aluminium production is for export markets. South Africa mainly exports aluminium to the Netherlands, the United States, Thailand and Japan. The high export volumes have led to calls for more beneficiation or downstream activities of the aluminium sold to the domestic markets. Of the 30% of aluminium produced for the domestic market, about 60% is exported only after limited value-addition, while 10% is exported after downstream value addition.

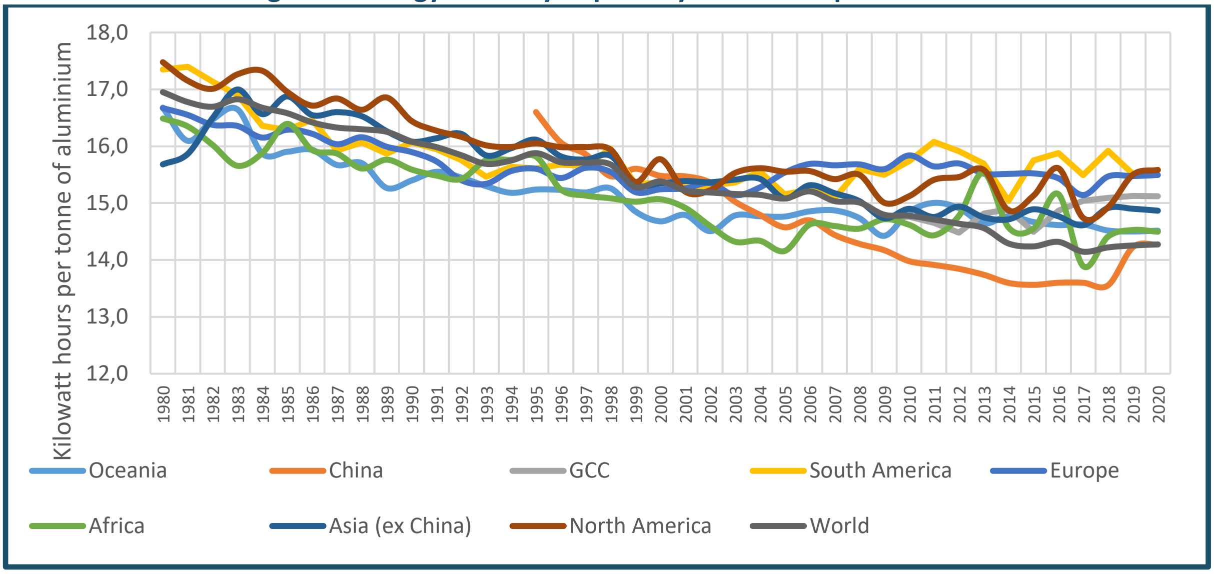
### 2.1.2 Energy and GHG emissions

The most energy-intensive stage of aluminium production is the smelting process – about 14MWh per tonne of aluminium is required in the smelting process. The second is alumina refining, with approximately 10 000MJ or 3MWh per tonne of alumina. As South Africa does not have bauxite deposits, the country does not have alumina refining facilities.

Figure 4 outlines global aluminium energy intensity from 1980 to 2019. Since the 1980s, globally, there have been significant improvements in the energy intensity of the smelting process. Between 2010 and 2017, global primary production energy intensity decreased on average 0.6% per year. In 2019, global energy intensity of overall aluminium production[3] fell by 1.2%. The decline in energy intensity is primarily as a result of developments in China. Since 2014, China's production capacity has expanded significantly, which enabled robust energy intensity declines as China increasingly used best-available technologies. Africa's energy intensity has followed the trend of the rest of the world, declining from 16.5kWh per tonne in 1980 to 13.9kWh per tonne in 2017 and increased to 14.5kWh per tonne in 2019.

[3] Including bauxite mining, refining and secondary aluminum.

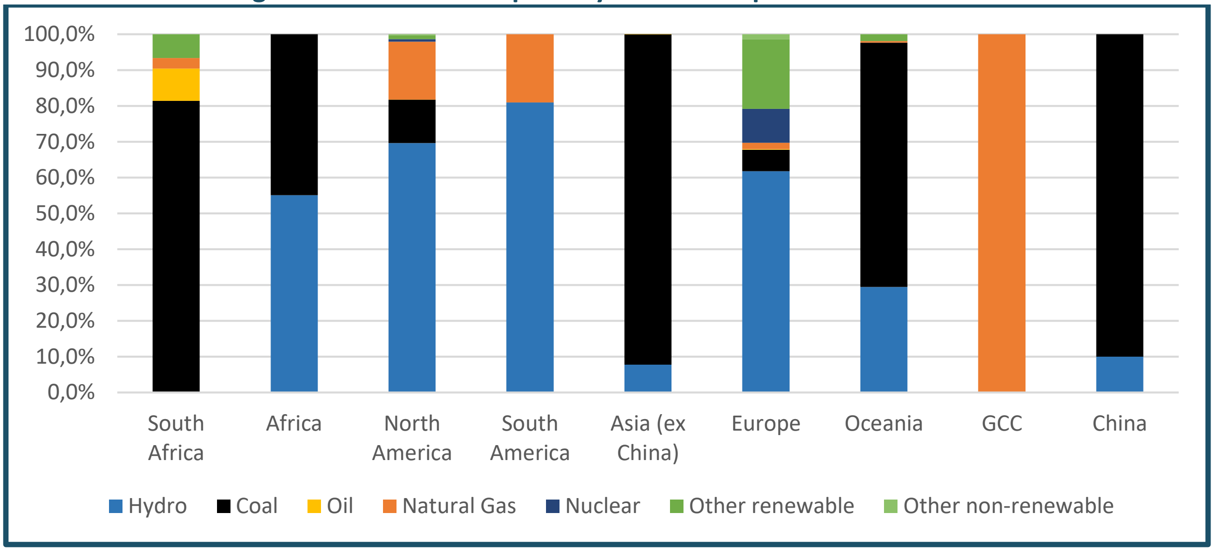
**Figure 4: Energy intensity of primary aluminium production**




*Source:* Authors, based on data from the IEA, Series on Energy Intensity of primarily aluminium, downloaded in January 2021. *Note:* GCC = Gulf Cooperation Council.

Aluminium is referred to as "molten electricity" as the production process requires significant amounts of electricity. Production is usually located where there is abundant and relatively inexpensive electricity. Traditionally, this has been close to hydroelectric power plants or sources of natural gas. Roughly 3.5% of global electricity is consumed by the aluminium industry. Electricity costs represent between 30% and 40% of aluminium production expenses.

**Figure 5: Power mix of primary aluminium production in 2017**




*Source:* Authors, based on data from the International Aluminium data base on Primary Aluminium Smelting Power Consumption primary aluminium smelting power consumption in September 2022; DFFE, 2017 GHG Inventory, and South32, 2021 Sustainability briefing. *Note:* GCC = Gulf Cooperation Council.

Hillside is entirely reliant on Eskom's largely coal-based grid, at a base load of 99.9%. Over 44% of Africa's energy for primary aluminium is from coal. This is largely attributed to the Hillside and Mozal smelters. Mozal sources about 47% of its electricity from Eskom. Mozambique exports hydropower generated from the Cahora Bassa hydropower to South Africa, which is then bought back by Mozal (Manuel, 2013). Ghana and Cameroon mainly produce their primary aluminium using hydroelectric power from the Akosombo and Edea dams respectively. Egypt primarily sources it energy from natural gas and oil (Africa Intelligence, 2003; EJatlas, n.d.; Moamar, 2022).

Primary production for Asia (excluding China) and China are also largely coal-driven, with 92% and 90% of energy requirement respectively. In Europe, North America and South America, smelters predominantly use hydropower, with the largest hydropower use being in South America where it contributes 81% to the energy requirements. Countries of the Gulf Cooperation Council use oil as their primary energy input for aluminium smelting.

Table 1 shows global GHG emissions from aluminium production in 2019. The majority of GHG emissions generated from primary aluminium production are from smelting (about 78%). GHG emissions from electricity accounted for 65% of total primary aluminium GHG emissions, the largest contribution (10,4 $tCO_2e$ per tonne primary aluminium) coming from the electricity input into the smelting processes.

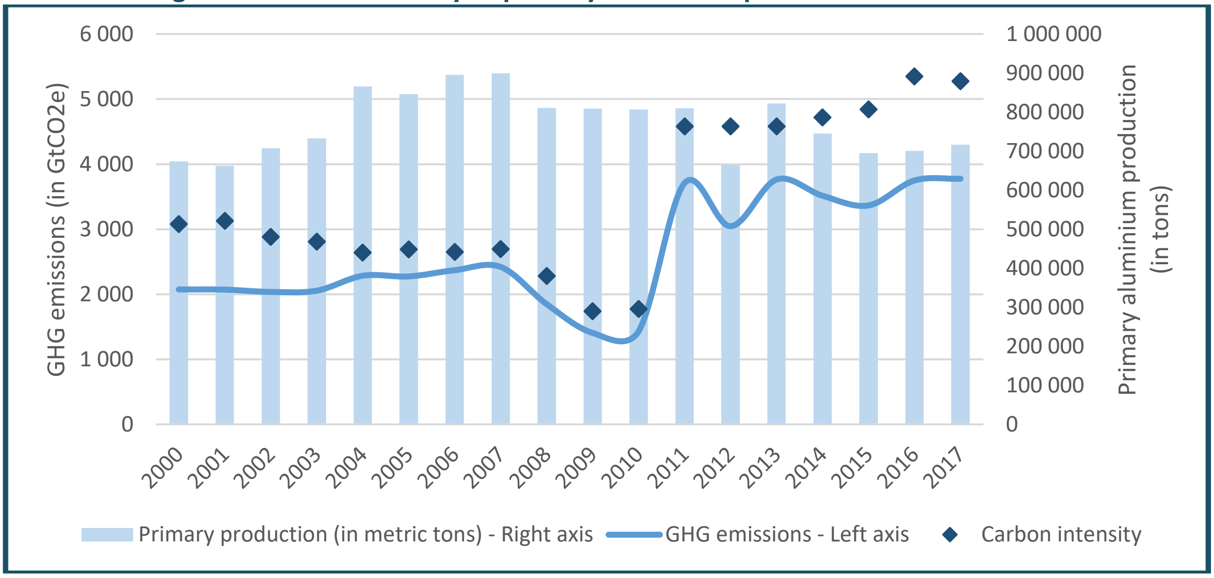
**Table 1: GHG emissions for primary aluminium in 2019**

| GLOBAL (TONNES CO2E PER TONNE PRIMARY ALUMINIUM) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2019** | Bauxite | Alumina | Anode | Smelting | Casting | Total | % |
| Electricity | 0,01 | 0,3 | | 10,4 | | 10,7 | 65% |
| Non $CO_2$ GHG | | 0,5 | | 0,6 | | 1,1 | 6% |
| Direct Process ($CO_2$) | | | 0,1 | 1,4 | | 1,5 | 9% |
| Ancillary Materials | | 0,2 | 0,3 | 0,1 | | 0,6 | 4% |
| Thermal Energy | 0,04 | 1,8 | 0,1 | | 0,1 | 2,1 | 12% |
| Transport | | 0,2 | | 0,3 | | 0,5 | 3% |
| Total | 0,05 | 3,1 | 0,5 | 12,8 | 0,1 | 16,5 | 100% |
| % | 0% | 18% | 3% | 78% | 1% | 100% | |

*Source:* World Aluminium, series GHG Emission Data for Aluminium Sector World Aluminium, series GHG Emission Data for Aluminium Sector, downloaded from greenhouse gas emissions aluminium sector in September 2022.

South Africa's primary aluminium production is highly carbon-intensive due to its use of coal-powered electricity. Figure 6 shows the carbon intensity of primary aluminium production from 2000 to 2017. Between 2000 and 2007, GHG emissions followed production output. A 41% decline in GHG emissions occurred from 2008 to 2010. This was attributed to reduced production caused by electricity supply challenges and decreased demand following the economic crisis that occurred during 2008/2009.

**Figure 6: Carbon intensity of primary aluminium production in South Africa**

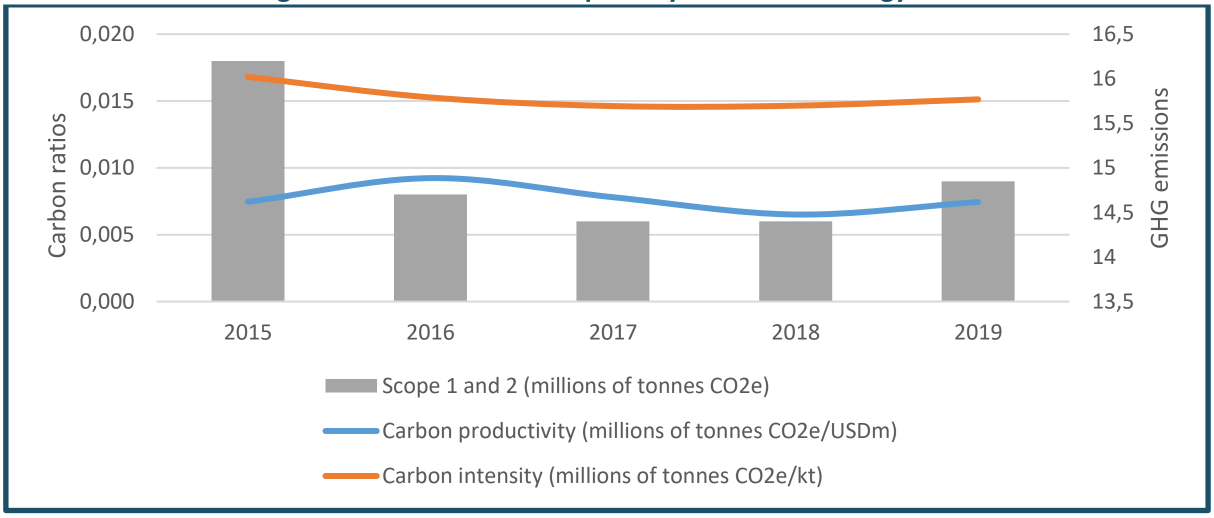



Source: Authors, based on data from the National Greenhouse Gas Inventory 2000 to 2017 and BGS, 2018, downloaded from GHG inventory in June 2021.

The sharp increase in GHG emissions and carbon intensity from 2011 has been due to inefficient operations from aluminium plants. The Hillside smelter assisted with the rotational electricity blackouts in the country at the time, which necessitated switching on and off at short notice leading to large emissions of PFCs. In 2000, about 47% of GHG emissions linked to aluminium production in South Africa were PFCs. Between 2011 and 2012, this increased to about 65% (2453Gg$CO_2$e) (DEFF, 2017).

South32's Hillside smelter is the only primary aluminium producer in South Africa. Figure 6 and Figure 7 show South32's Southern Africa's GHG emissions, energy and carbon ratios, and energy and carbon intensity and productivity.

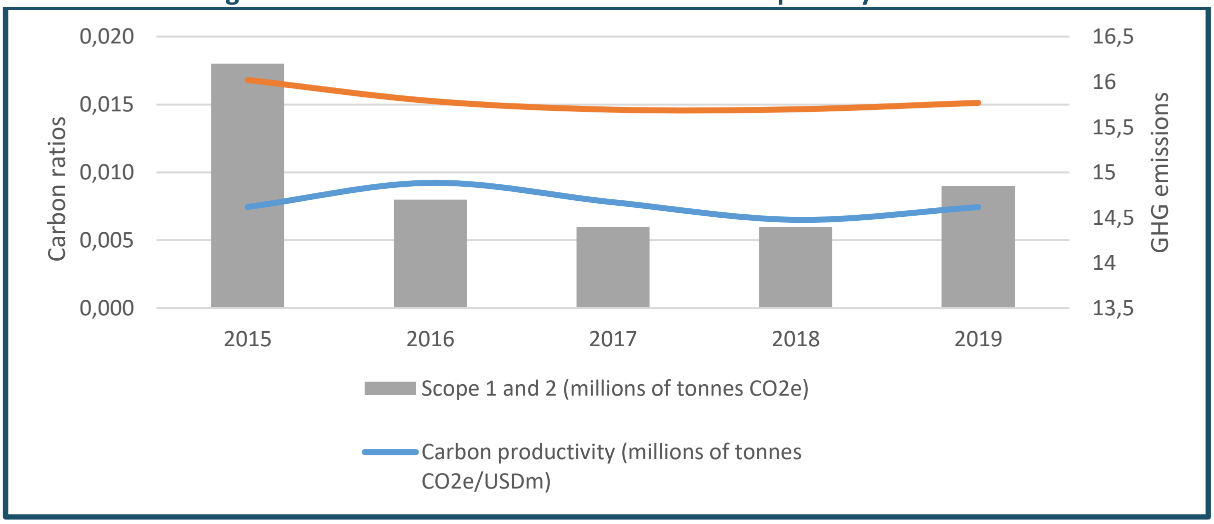
**Figure 7: Southern Africa's primary aluminium energy use**




*Source:* South32 sustainability data tables 2016-2019. *Note:* South32 does not disaggregate between Africa and other operations. Data includes the Mozal smelter in Mozambique.

South32's Southern African energy consumption has remained relatively constant since 2016. In 2019, total energy use increased, due to instability of hydroelectricity supply at Mozal and the Hillside smelter reaching maximum capacity. Energy intensity improved from 2015 and remained flat from 2016 to 2019. Energy productivity was highest in 2016 improved between 2017 and 2018 and worsened slightly in 2019. This can be attributed to the testing of maximum capacity, where production reached a record high (South32, 2021).

**Figure 8: Carbon emissions for Southern Africa primary aluminium**




*Source*: South 32 sustainability data tables 2016-2019. Note: South 32 does not disaggregate between Africa and other operations. Data include the Mozal smelter in Mozambique.

Figure 8 shows that improvements were made in reducing GHG emissions between 2015 and 2016 with a decline in Scope 1 and Scope 2 emissions[4] from 16.2 $MtCO_2e$ to 14.4$MtCO_2e$. This reduction in GHG emissions was part of South32's five-year emissions reductions targets across its business operations. Approximately 85% of South32's total Scope 1 and Scope 2 emissions come from four operations, namely Hillside Aluminium, Worsley Alumina, Illawarra Metallurgical Coal and Mozal Aluminium. Hillside alone contributed 58% of Scope 1 and Scope 2 emissions in 2021 while Mozal contributed 6%. Scope 1 emissions account for 12% of the smelter's Scope 1 and Scope 2 emissions while Scope 2 accounts for 88% of Scope 1 and Scope 2 emissions. Hillside's Scope 1 carbon intensity is 1.9 $tCO_2e$/t aluminium, which is far below the global average of 8.5$tCO_2e$/t aluminium (South32, 2021). The smelter's Scope 2 intensity stands at 14.9tCO2e/t aluminium while the global average is 1.6 $tCO_2e$/t aluminium (South32, 2021).

## 2.2 Secondary aluminium and foundries

The South African value chain also includes secondary aluminium produced from scrap. Secondary aluminium smelters produce aluminium scrap into various aluminium products of varying grades. Compared to primary aluminium, recycled aluminium consumes only 5% of the energy and releases 5% of the GHG emissions. Recycling aluminium is also a shorter process (about 60 days) than producing primary aluminium (IEA, 2020a).

Globally, in 2019, about 34% of aluminium produced was from new and old scrap[5] aluminium. The share of secondary aluminium has remained relatively constant at 31-33% since 2000. Global aluminium collection rates for new scrap are the highest at 95% while old scrap is about 70% (IEA, 2020b). Collection rates for old scrap are lower as a result of aluminium being locked within products until their lifetime ends as well as contaminated. As such, recycling rates for old aluminium face a lower ceiling than new scrap (Buchner et al., 2015).

South Africa's secondary aluminium sector is well established. Zimco Metals (Zimalco)[6] aluminium is the largest and oldest secondary producer, producing around 50% of secondary aluminium, all from scrap aluminium. Zimco primarily produces aluminium alloys, oxidants, powders and casting ingots. Zimco produces aluminium primarily using natural gas, which accounts for 80% of its energy mix. Electricity from the national grid consists of 20% of the energy mix and is used in the aluminium powder production lines and in non-production activities, such as lights and air conditioning.

Zimco is located in Benoni, near Johannesburg. It has 160 employees and a production capacity of 30 000 tons a year. However, given the small size of the South African market and issues with obtaining quality scrap material, production levels have been at 30% for several years.[7] Since 2012, Zimco's production volumes have shrunk by 50%. This has mainly been driven by shrinkage in the downstream casting sector and the lack of access to quality scrap. Zimco sources its raw materials from aluminium converters, scrap metal recyclers and, when required, from primary producers such as South32. Zimco produces secondary aluminium from both international and domestic markets (BUSA, 2012; Zimalco, n.d.).

Apart from South32 and imports, secondary smelters are the only other sources of aluminium to the South African market. Other major secondary aluminium producers include Metlite Alloys (Insimbi), Future Alloys, and Aluminium Granulated Products and eight smaller producers.

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[4] Scope 1: Direct on-site emissions (mostly from the combustion of fuels). Scope2: Emissions associated with electricity consumption.

[5] New scrap refers to scrap created during product manufacturing while old scrap refers to end-of-life scrap

[6] Zimco Metals has two divisions: aluminium and zinc.

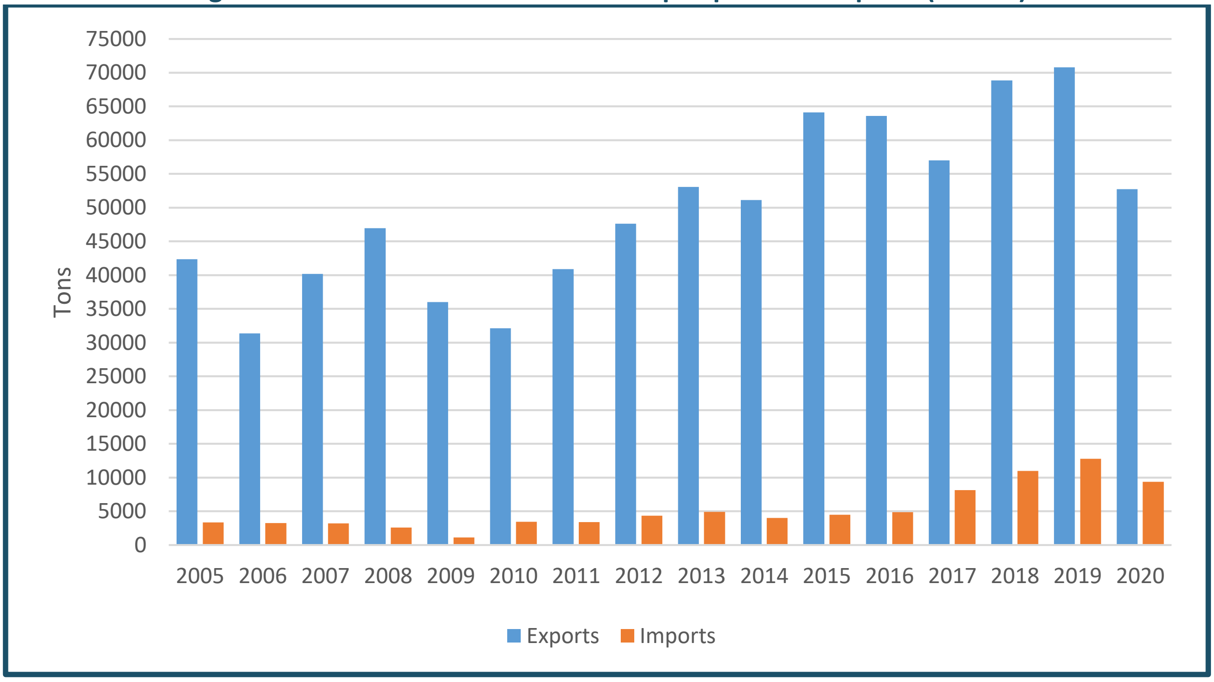
[7] Interview with Zimco.

Foundries are the main consumers of secondary aluminium in South Africa. Aluminium alloys produced from scrap by secondary smelters typically account for between 70% to 80% of the total manufacturing cost of aluminium foundries. The price and availability of quality aluminium scrap greatly impacts the industry (Montmasson-Clair et al., 2014). The foundries industry is relatively small and mainly produces aluminium for the automotive industry. Aluminium foundries use either the die casting (high and low pressure) method or the gravity casting method (dies and sand moulds). The foundry industry also serves the agricultural industry, industrial and consumer needs, mining and electrical and energy sectors.

Almost half of all foundries are in Gauteng, and more than 65% of the foundries in Gauteng are in Ekurhuleni. Although the aluminium foundry industry showed growth between 1990 and 2000, attributed largely to the Motor Industry Development Plan (MIDP),[8] since the early 2000s, a number of foundries have shut down. Currently, there are 130 foundries (all types of foundries) countrywide. Of the remaining foundries in South Africa, about 35% are non-ferrous foundries, almost all of which are aluminium foundries (South African Institute of Foundrymen, 2011).

Globally, on average, non-ferrous scrap metal accounts for less than 10% of the total recycled metal volume in circulation. In South Africa, aluminium consists of 15% of the scrap metal market.[9] Non-ferrous scrap metal value is 10 times that of ferrous scrap.

**Figure 9: South Africa's aluminium scrap export and imports (in tons)**




*Source*: Authors, based on data from the Trade Map, Series on waste and scrap, of aluminium, downloaded from Trade Map scrap aluminium in February 2022.

South Africa is a net exporter of aluminium scrap. As depicted in Figure 9, export volumes have fluctuated since 2005. In 2020, exports decreased to about 52 000 tons due to COVID-19 restrictions and the government's two-month ban on exports of all ferrous and non-ferrous scrap. The ban was introduced as a response to the calls made by South African scrap consumers on the shortage of quality scrap metals despite measures to give domestic suppliers priority. In 2013, export control

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[8] The MIDP has been replaced with the Automotive Production and Development Programme (APDP). The APDP extends support to the South African automotive industry until 2035.

[9] Interview with Hulamin.

guidelines were put in place by the then-Economic Development Department to give preference to local buyers before dealers export. The Price Preference System (PPS) was introduced to improve the availability of domestic scrap. The PPS was renewed in 2018, 2019, 2020 and again in 2021 for a period until July 2023. The PPS requires scrap dealers to offer their product to local buyers first at a discount of 2%%-30% before exporting (Department of Economic Development, 2019).

## 2.3 Fabrication and semi-fabrication

The distinction between secondary smelting and fabrication is somewhat blurred given that foundries can, and do, remelt their recycled material. The key local semi-fabricators include Hulamin and Wispeco. The high energy-intensive process of producing primary aluminium explains why aluminium foundries and fabricators such as Wispeco and Hulamin prefer to do their remelting.

At the fabrication and semi-fabrication level, value is added to aluminium. Primary and secondary aluminium ingots from the smelters and foundries are used to produce slabs, sheets or foil, plates, drawn into cables, ground to powder or cast into shapes/moulds for architecture and building, light engineering, transport and automotive markets (Montmasson-Clair et al., 2014).

Wispeco is one of the largest extruders in South Africa. It produces aluminium extrusion profiles for the domestic and export markets, trading in the transport, construction, agriculture and engineering sectors. Wispeco is vertically integrated at various levels of the aluminium value chain including remelting and casting, extruding and surface finishing, and distribution. The group also owns an extensive nationwide network of wholesale outlets.[10]

Wispeco has a production capacity of 36 000 tons a year, operating at 85% utilisation. The group has 1 200 employees. Natural gas makes up 67% of the power mix, used in the heating of furnaces while electricity is used for the rest of operations. Scope 2 emissions account for 54% (0.763 $tCO_2e/t$) of total emissions while Scope 1 emissions account for 23% (0.333 $tCO_2e/t$) of total emissions, the balance is from Scope 3 (metal supply).[11]

Wispeco uses secondary and primary aluminium for production. Over two-thirds of the aluminium used in manufacturing originates from recycled aluminium. Wispeco purchases post-consumer scrap from bonafide scrap dealers (40%) and also reprocesses its internal manufacturing scrap (60%) (Wispeco, n.d.).

Hulamin has rolling and extruding plants in Johannesburg and Pietermaritzburg. It processes over half of all domestic aluminium at a production capacity of 250 000tpa, which it then rolls into sheets, plates and foils of various thicknesses, which are used by downstream fabricators in a broad range of industries (Hulamin, 2017a). Hulamin is the largest supplier of raw aluminium material for the South African manufacturing industry.

Other semi-fabricators include Autocast South Africa, Borbet SA, HJS Blinds, Nampak, PG Group, Cape Heat Exchange and Mazor Aluminium.

Hulamin’s operations can be used to illustrate the energy and carbon profiles of midstream industries. Its business operations consist of rolled products, extrusions, containers and a casthouse, and a recycling centre. Hulamin’s products are used by downstream fabricators within the packaging, engineering, automotive and construction sectors. A total of 53% of Hulamin’s sales are exported, making it one of the largest mineral beneficiating exporters in South Africa.

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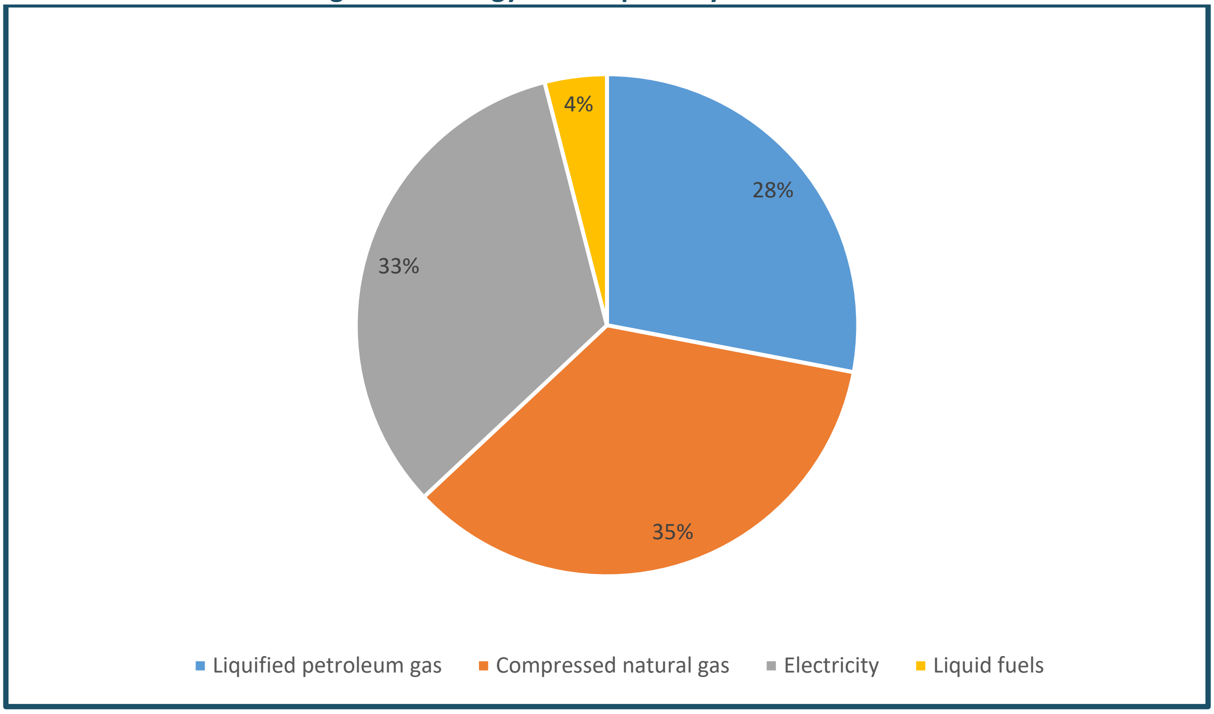
[10] Interview with Wispeco.
[11] Interview with Wispeco.

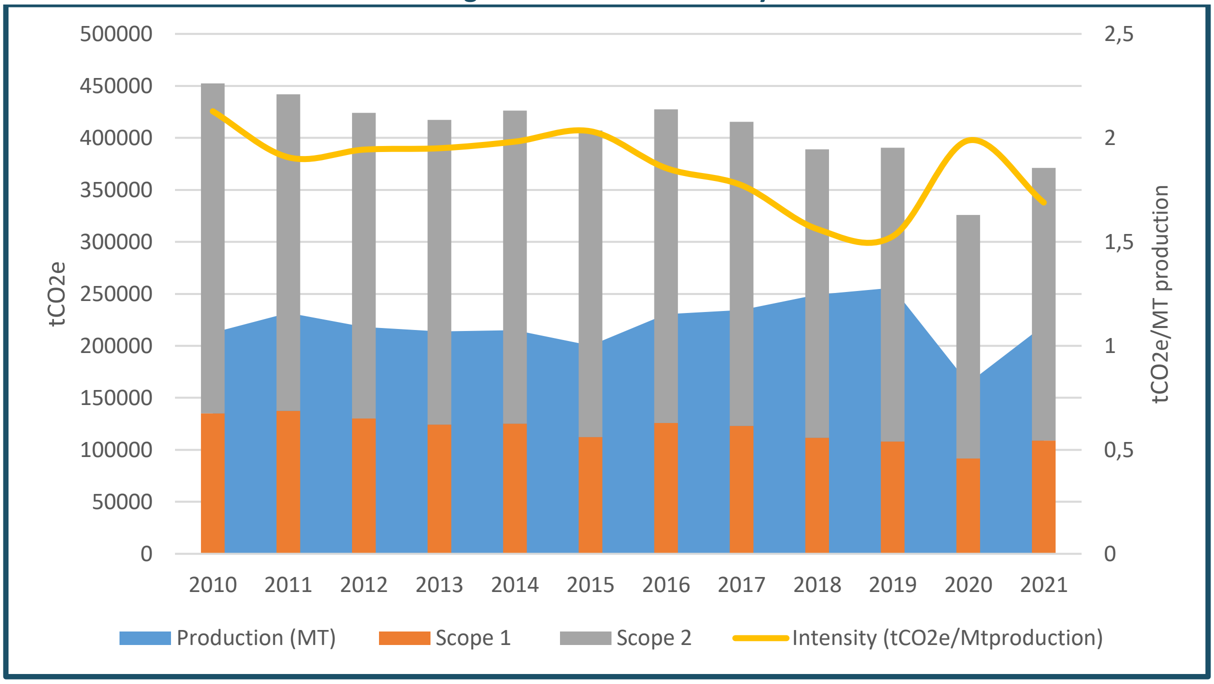
**Figure 10: Energy consumption by source in 2021**




*Source:* Authors, based on Hulamin 2022 sustainability report downloaded from Hulamin Sustainability 2022.

Figure 10 shows Hulamin's energy mix in 2021. Compressed natural gas (35%) is the largest energy input followed by electricity (33%). The Hulamin group has decreased the share of electricity from 39% in 2017-18 through the rollout of variable speed drives (VSDs), which saves energy through adjustments in the speed of machinery (Hulamin, 2020). Hulamin has committed to further decreasing its energy consumption to reduce its carbon footprint (initiatives discussed in section 3.3.1).

**Figure 11: Carbon intensity**



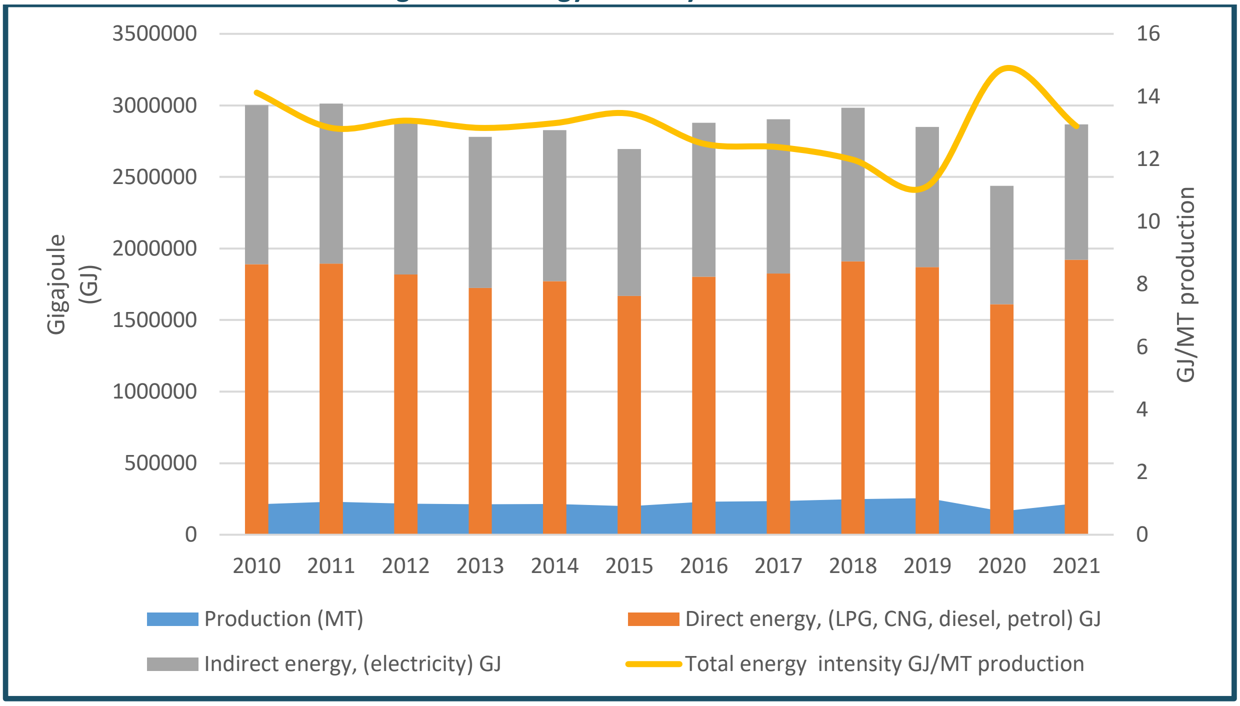

Source: Authors based on Hulamin sustainability 2022 downloaded from Hulamin Sustainability 2022.

As illustrated in Figure 11, Scope 2 emissions are the largest emissions for the group. The bulk of Scope 1 and Scope 2 emissions are related to electricity, which accounted for 71.9% of total GHG emissions in 2020. Hulamin's carbon intensity has declined since 2010 with the most significant improvements after 2015. Carbon intensity increased sharply in 2020 due to unusually low production levels. This was attributed to COVID-19 related restrictions and low-demand (Hulamin, 2021).

Hulamin uses both secondary aluminium and primary in its production process. In 2018, it initiated an assessment of Scope 3 emissions from metal supply. Scope 3 emissions are measured for primary metal, hardeners (alloying metals), scrap metal inputs and recovered metal from aluminium dross. The monitoring system revealed that Scope 3 emissions contributed 91% of Scope 1, Scope 2 and Scope 3 emissions in 2018.[12] The main contributors to Scope 3 emissions were from primary metal supply from Hillside.

Hulamin has committed to reducing Scope 3 emissions by 24% per ton of aluminium produced by 2030, from a 2018 base year. Hulamin understands that increasing scrap volumes and reducing its reliance on primary aluminium would decrease its Scope 3 emission and overall carbon intensity. Quality scrap availability remains a hindering factor to increasing scrap volumes. Hulamin intends to work with South32 to "green" primary aluminium as sourcing primary aluminium from other jurisdictions is not currently feasible (Hulamin, 2021).

**Figure 12: Energy intensity of Hulamin**




Source: Authors based on Hulamin sustainability 2022 downloaded from Hulamin Sustainability 2022,

Direct energy makes the largest contribution to energy inputs (Figure 12). Total energy intensity was on a downward trend until 2019, with the most significant decline occurring from 2016. The increase in energy intensity was due to lower production output (a result of the COVIC-19 pandemic) and frequent interruptions to production during the national lockdown.

[12] Interview with Hulamin.

**Box 2: Environmental impact of aluminium**

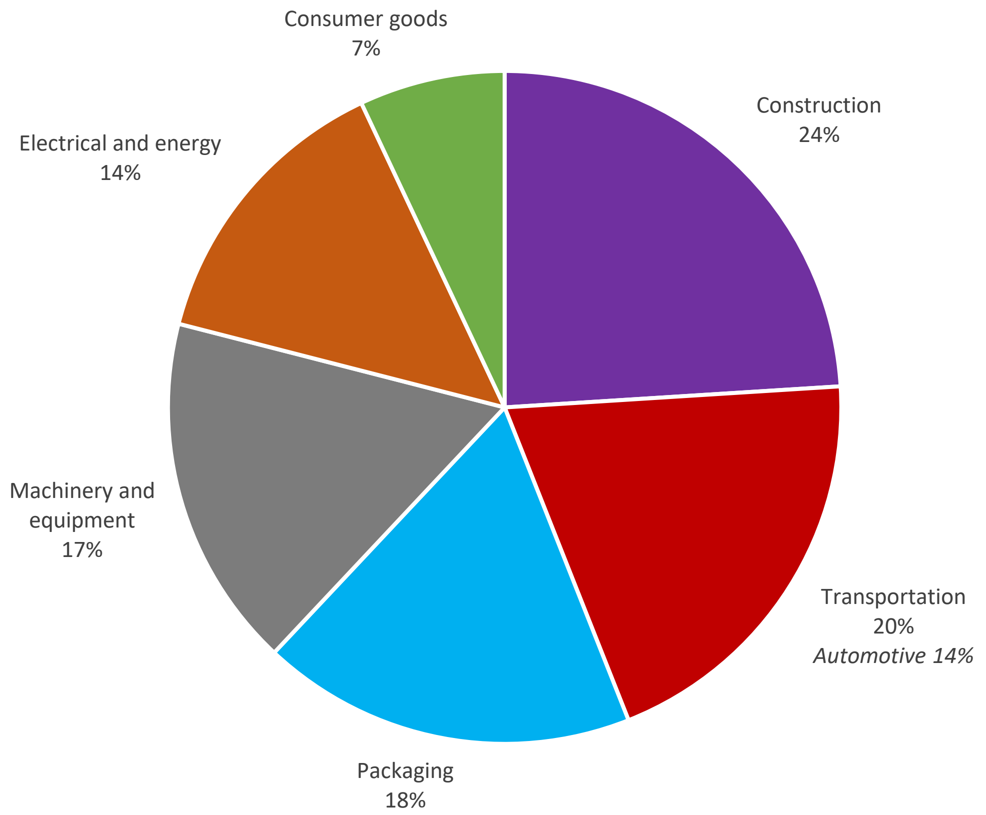
| GHG emissions | Air pollution | Land | Water |
|---|---|---|---|
| Aluminium production is responsible for 3% of global GHG emissions.<br><br>The primary source of emissions is aluminium's highly energy-intensive refining and smelting stages. GHG emissions result from both the electrical consumption of smelters and the processing of by-products. | The mining and refining process releases gasses and particles known to compromise air quality. These include caustic aerosols, sodium, limestone, charred lime and dust from bauxite.<br><br>Atmospheric pollutants released from the refining process can also produce acid rain when mixed with water vapour. | Bauxite mining results in significant land degradation consisting of:<br>- Topsoil removal<br>- soil erosion<br>- loss of native vegetation<br>- destruction of ecosystems<br>- loss of habitat and food for wildlife<br>- the release of toxic metals and naturally occurring radioactive materials. | Aluminium production requires significant amounts of water.<br><br>The average global primary aluminium water used in plants is 2.1m3 H2Oe per tonne of primary aluminium.<br><br>The use of hydropower to smelt aluminium uses significant volumes of freshwater.<br><br>Hydropower plants have a high contribution to the indirect water scarcity footprint of primary aluminium, contributing to 79% of the global value.<br><br>Red mud is a by-product of aluminium production that contaminates water sources. It contains trace heavy metals which damage marine ecosystems |

*Source:* Khare et al., 2007; United States EPA, 1998; Buxmann et al., 2016.

## 2.4 Aluminium users and waste management

Aluminium’s characteristics make its use attractive in several industrial applications. The demand for aluminium in South Africa is driven by the transport (20%) and construction sectors (24%). Seventy percent of the transport market is derived from the automotive industry (Figure 13). The electrical and energy sector and the machinery and equipment sector combined contribute 31% of total consumption. The remaining 25% come from the consumer durables sector and the packaging sector.

**Figure 13: Consumers of aluminium by sector in South Africa in 2017**




*Source:* AFSA, 2017.

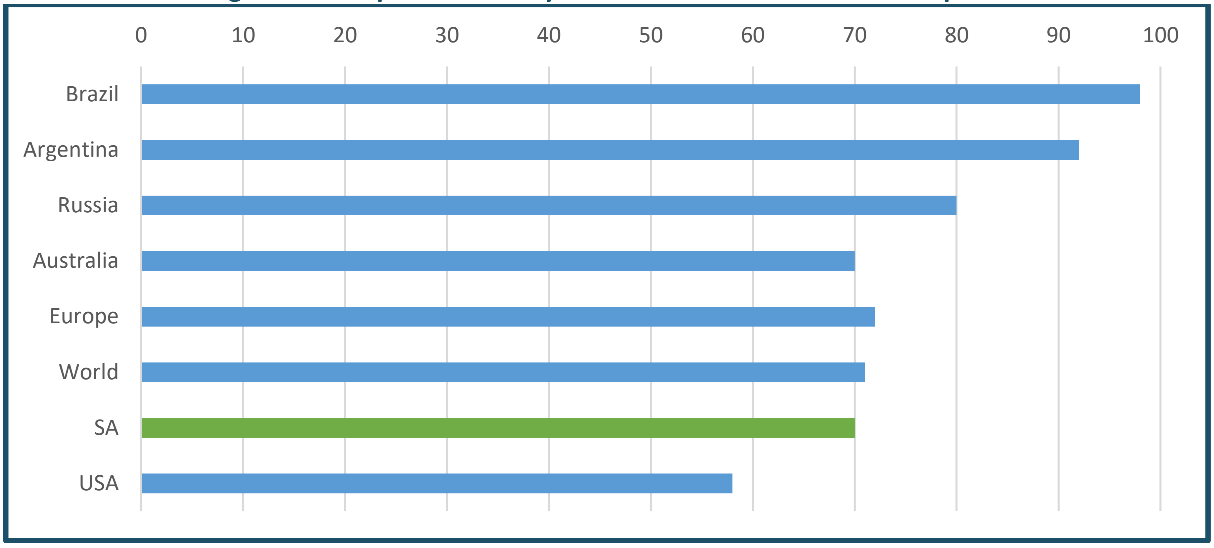
Aluminium is infinitely recyclable, meaning it can be recycled without any loss in quality. Aluminium's product lifecycle shows that there are district advantages to recycling aluminium. To date, over than 75% of aluminium ever produced is still in use.

Global aluminium recycling rates are relatively high: 90% of aluminium used in transportation and construction is recovered and over 60% of aluminium-based used beverage cans (UBCs) is in a recycling loop. In 2017, the total recycling rate of aluminium containers and packaging was 32%; about half of this was from UBC.

South Africa has a well-developed metal packaging recycling sector. Over 75% of all metal packaging is recovered. The metals packaging industry aims to increase collection rates to 81% by 2023. The domestic aluminium recycling sector is also well developed. The most common sources of aluminium scrap are UBCs, automobile parts, building materials, and appliances and consumer durable goods.

As shown in Figure 14, about 70% of South Africa's aluminium consumption of aluminium beverage cans is met from recycled aluminium which is on par with the global average (Hulamin, 2017b). Brazil is the global leader in aluminium beverage can recycling, with approximately 98% of UBCs consumed coming from recycled aluminium (Hulamin 2017b).

**Figure 14: Proportion of recycled aluminium to total consumption**




Source: Hulamin, Integrated Report 2017a.

South Africa has launched various campaigns directed at increasing UBC recycling rates.[13] One such campaign is Collect-a-Can. Since the start of the Collect-a-Can campaign in 1993, South Africa's UBC recovery rate has improved from 18% in 1993 to approximately 70% in 2017. Beverage cans form the basis of the recycling system for aluminium packaging and are collected in almost every recycling programme in South Africa. Can litter has also seen a reduction from 8% of total South African litter to less than 1% between 1993 to 2017 (Collect a Can, n.d.).

In 2013, South African key players made the conversion from steel beverage cans to aluminium. Nampak, AB Inbev, Coca-Cola South Africa and Hulamin believed that used aluminium cans are more valuable than steel cans as they are infinitely recyclable and lightweight. These players made a R1.2 billion capital investments to convert steel cans to aluminium cans (Nampak, 2013).

The scrap metal and recycling industry is a crucial source of income for informal waste collectors. According to Collect a Can, waste collection and the sale of used cans provide income to between 100 000 and 160 000 people. More than R20 million is paid to collectors on average a year (Collect a Can, n.d.; Hulamin, 2021).

**Box 3: Aluminium and decarbonising industries**

Aluminium has been described as a metal of the future. Its durability and multitude of uses means that it can play an important role in decarbonising and increasing the climate resilience of other sectors.

Aluminium is playing a key role in decarbonising the power sector. Aluminium is replacing copper in long-distance electricity grids. Due to its non-corrosive durable nature, aluminium contributes to long-run emissions reduction in the electricity supply sector as it is more resistant to the elements than copper (Djukanovic, 2016). Aluminium is also playing a key role in lithium-ion and vanadium batteries, which are contributing to increasing the sustainability of the energy sector. Aluminium is furthermore one of the key materials in renewable energy technologies, such as solar PV systems (Bödeker et al., 2010).

[13] Since 2021, the industry has the legal obligation to comply with Extended Producer Responsibility regulations. This is discussed in Section 3.4.2.2.

In the automotive and aerospace industries, aluminium's light weight makes it an attractive metal. Aluminium weighs almost a third of steel. Substituting steel for aluminium can decrease a vehicles' weight by up to 30%. Reduced weight reduces fuel consumption and GHG emissions. Aluminium also reduces the demand for raw materials since a high proportion of end-of-life products are recycled (International Aluminium Institute, 2018). Aluminium lightweight and durability characteristic make it an excellent metal for the production of electric vehicles (EVs). The amount of aluminium used in an EV is 40%-50% higher than in a conventional internal combustion engine.

In the construction sector, aluminium's thermal conductivity and durability make it ideal for increasing the energy efficiency of buildings and their long-term sustainability. Aluminium window frames and doors can help reduce heating bills by up to 20% a year as they can ensure that about 40% more heat is retained in buildings that could have been lost (European Aluminium, n.d.).

Aluminium can positively contribute to a circular closed-loop system. It is considered a substitute for steel and plastic in certain packing products. Aluminium is non-toxic, has excellent heat conductivity, is temperature stable, odourless and moisture resistant (Hulamin, 2017a). These characteristics make it ideal for various applications within the food and beverage industries.

## 2.5 Summary

The South African aluminium value chain consists of primary and secondary production, semi-fabrication and fabrication, and scrap recovery and recycling. The South African value chain is highly carbon intensive due to the use of fossil fuels such as natural gas and coal-powered electricity. The industry is dependent on primary producer Hillside and secondary producers such as Zimalco and Hulamin for aluminium. Hillside is highly dependent on coal-powered electricity from Eskom. Coal-powered electricity consists of 100% of the energy input to producing primary aluminium, contributing to 88% of the smelter's carbon emissions. Secondary aluminium producers Hulamin and Zimco mainly produce their aluminium from natural gas, liquid fuels and coal-powered electricity.

There are benefits to producing secondary aluminium. Secondary aluminium is produced from scrap aluminium which consumes 95% less energy and only produces 5% of the carbon emissions compared to primary aluminium. Aluminium recycling rates are about 90% for construction and transport sectors and between 70%-75% for consumer goods and packaging. Although South Africa's secondary aluminium production is well developed, efforts to increase and create closed-loop products can reduce total industry emissions.

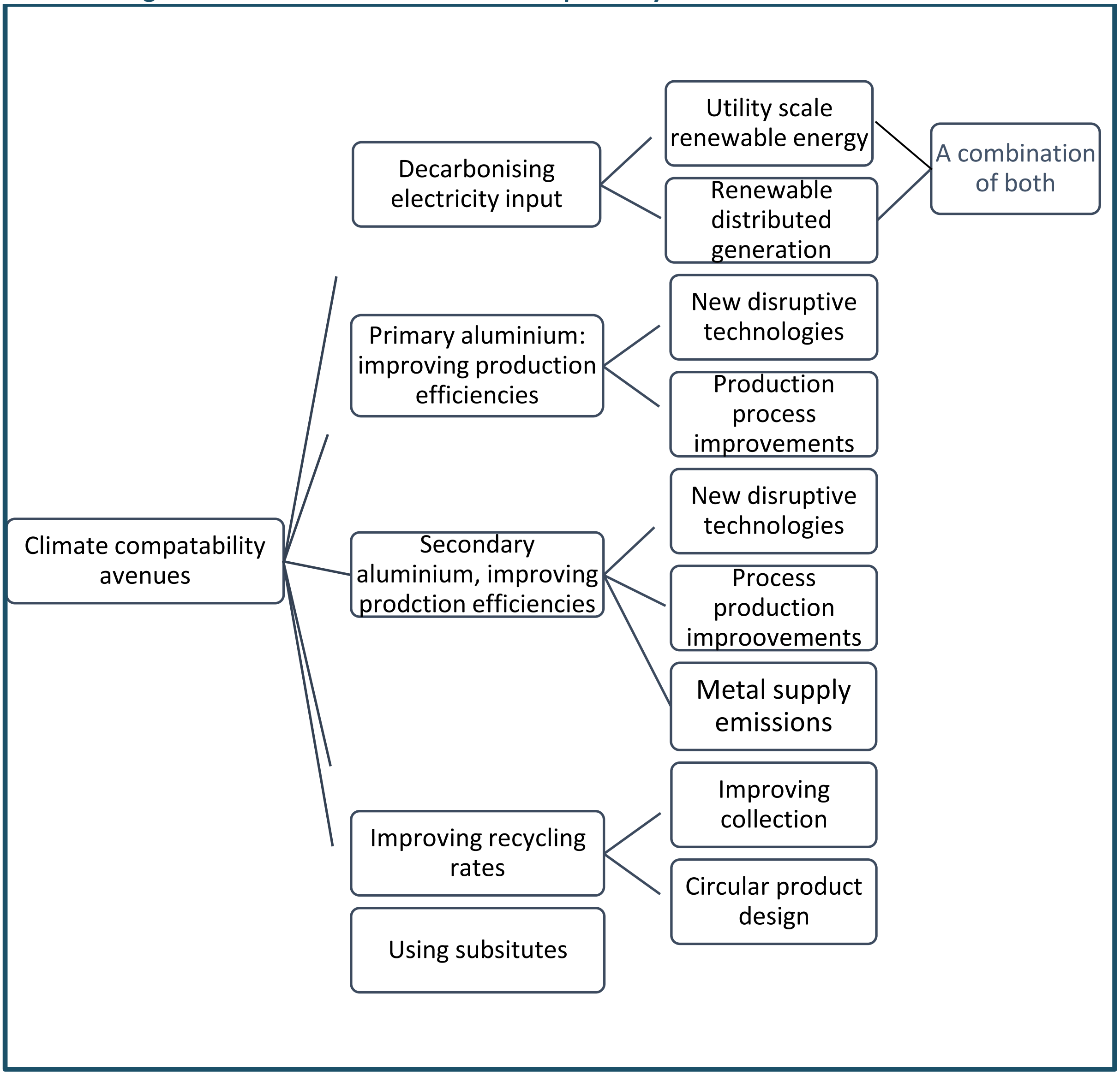
Zimalco, Wispeco and Hulamin produce aluminium from primary aluminium and scrap aluminium. The main consumers of secondary aluminium are foundries. Aluminium alloys produced from scrap account for 70% to 80% of total manufacturing costs for foundries. Foundries produce aluminium alloys for the automotive industry, among others. The key issue in secondary aluminium production is the availability of good quality scrap aluminium.

The carbon intensity of South Africa's aluminium value chain places the industry at risk. As the world is shifting towards a low-carbon economy, countries introduce carbon border taxes, and end-user demand for "green" aluminium is increasing, the industry could lose its international competitiveness. In a carbon-constrained future, the value chain would need to find solutions to reduce its carbon and energy intensity. In other words, the aluminium value chain would need to rethink its production processes and energy use.

# 3. AVENUES FOR A CLIMATE-COMPATIBLE VALUE CHAIN

The overreliance on fossil fuels has made the South Africa's aluminium value chain highly carbon intensive. In a carbon-constrained world, the current state of the value chain would be unsustainable. Avenues need to be explored to transition the value chain into a low-carbon development pathway. Figure 15 shows the potential avenues that could ensure the climate compatibility of the South African aluminium value chain. These avenues include: decarbonising the electricity input; improving production efficiencies through ground-breaking technologies and process improvements across the value chain; and increasing recycling rates. Last, replacing aluminium with viable alternatives is also explored.

**Figure 15: Avenues for the climate compatibility of the aluminium value chain**




## 3.1 Decarbonising electricity input

The International Aluminium Institute (IAI) recommends that the sector needs to reduce emissions from electricity by 45% from 2010 levels by 2030 to achieve net-zero emissions by 2050. This is required to avoid a +1.5°C increase in global temperature (compared to the pre-industrial era (International Aluminium Institute, 2021). Regions that depend on coal-powered electricity would have to drastically reduce their GHG emissions by including renewable energy in their power mix. (Merchant, 2018).

Across the value chain, electricity is provided by Eskom's coal-powered grid. Primary aluminium producer Hillside is completely reliant on Eskom's grid (Moyo, 2020). In 2019, electricity accounted for 34%, 33% and 20% of Hulamin, Wispeco and Zimalco energy mix respectively. Hulamin, Wispeco and Zimlaco primarily use liquid fuels and natural gas in their production process (BUSA, 2012; Hulamin, 2020).

Scope 2 emissions make up a significant proportion of production emissions, across the value chain. Decarbonising the electricity input would reduce total value chain GHG emissions. This can be achieved through decarbonising of Eskom's coal-power grid, renewable energy-based distributed generation capacity or some combination of both (Reuters, 2021).

### 3.1.1 Decarbonising the national grid

Decarbonising the national grid would require accelerating installing renewable energy and battery storage capacity. In 2020, less than 6% of South Africa's power was generated from renewable energy (IEA, 2020c). South Africa is well-placed to increase its renewable energy capacity. South Africa has wind and solar resources that are among the best resources in the world and it has vast amounts of unused land (Bischof-Niemz, 2020).

Global reliance on renewable energy has increased threefold from 2000 to 2019, from a very low base (World Economic Forum, 2020). The average net present cost of generating electricity from an asset over its lifetime (US$/kWh) for renewable energy has become competitive with fossil fuel-based energy. A study by the CSIR revealed that new solar PV and onshore wind energy are 40% cheaper than new coal baseload electricity in South Africa. According to the study, in 2016, solar PV and wind cost R0.61/kWh (US$.04/kWh) while coal was priced at R1.03/kWh (US$0.07/kWh). The cost of renewable energy-based generation has further declined since then. The price of solar PV and wind are projected to be as low as R0.46/kWh and R0.56/kWh respectively by 2030 (GreenCape, 2020).

According to (NBI, BUSA and BCG. 2021), transitioning South Africa's power system to net-zero would require the deployment of about 150GW of wind and solar capacity by 2050, requiring an investment of about R3 trillion over the next 30 years. South Africa would need to install at least 4GW of renewable energy a year, which is roughly 10 times the current pace of new-build. It would also require utility-scale battery storage and the expansion and upgrade of the transmission and distribution infrastructure.

Through the Integrated Resource Plan (IRP) 2019, the government has committed to increasing renewable energy capacity and reducing the country's reliance on coal-powered electricity. The IRP 2019 aims to increase renewable energy capacity from the 2019/20 level of 6% to about 41% by 2030. The additional renewable energy-based capacity would be achieved through installing 17 742MW of wind, 8 288MW of solar PV, 4 600MW of hydropower (largely imported from Mozambique) and 600MW of concentrated solar power by 2030 (Department of Mineral Resources and Energy, 2020).

The plan also aims to reduce the share of coal-powered electricity from more than 70% of generation capacity to about 44% by 2030. According to the IRP 2019, 5 400MW of coal-powered generation will be decommissioned by 2022. This is projected to increase to 10 500MW by 2030 and 35 000MW by 2050 (IRP).

Despite some delays and haphazard developments, there has been progress in increasing renewable energy generation in South Africa. The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has increased renewable energy capacity by 6.4GW since 2011. Through Bid Window 5, the programme aimed to procure an additional 2 600MW of renewable power by 2022 (GreenCape, 2020). In 2022, the procurement of wind- and solar-based generation capacity in Bid Window 6 has been increased from 2 600MW to 4 200MW (Global Infrastructure Hub, 2021).

Eskom has announced its commitment to decarbonise the grid and become carbon neutral by 2050. The utility envisions spending R61.75 billion on wind power and R44.25 billion on solar energy by 2030. The decarbonisation plan would be financed through concessional finance from partner countries and financial institutions. At COP26, US$8.5 billion was pledged by partner countries to facilitate South Africa's just transition to a low-carbon economy, including the utility's decarbonisation plan (Eskom, 2022). Eskom needs significant support to decarbonise while addressing a 4 000MW-6 000MW generation capacity shortage, a R392 million debt and an ongoing unbundling process (Eskom, 2021b).

The power utility plans to add 6 800MW of renewable capacity from 2022 to cater for the 22 000MW of coal capacity that will be retired by 2035. The plan has three phases, the first spanning from 2022 to 2023 when 246MW of solar PV could be built at the Arnot, Duvha, Lethabo, Majuba and Tutuka coal-fired power plants. An additional 100MW of solar generation capacity could be built at the Komati plant and 19.5MW of solar power at the Sere Wind Farm. In the second phase, Eskom plans to build 300MW of wind power at Kleinzee and 200MW at Aberdeen and, in the third phase, 2 950MW of solar PV and 3 100 MW of wind power between 2025 and 2030 (Department of Public Enterprise, 2019).

Eskom would also need to increase long-duration storage capacity. The power utility is in pre-contract discussions for the first phase of the battery energy storage system (BESS) project. The BESS project will deploy 360MW of storage capacity at various Eskom distribution sites in several provinces. The project will be implemented in two phases when 800MWh and 640MWh will be installed respectively. The financing for Phase 1 and Phase 2 amounts to US$320 million and US$400 million (African Development Bank, 2021). Eskom also plans to upgrade its transmission and distribution infrastructure. It plans to build 8 000km of new transmission lines, up to 12 substations and 110 transformers. The upgrades will require an estimated R120 billion for distribution and R45 billion for transmission (Eskom, 2021b).

While the country has started to decarbonise the grid, the decarbonisation process may not be fast enough to ensure the survival of the aluminium value chain. This is particularly the case for primary aluminium smelter Hillside. The decarbonisation of the national grid should be part of a long-run solution for the sustainability of not only the aluminium value chain but the entire economy, but does not appear to be a short-term solution to maintain the competitiveness of the smelter.

### 3.1.2 Combination of distributed generation and utility scale

In 2021, the Minister of Mineral Resources and Energy amended Schedule 2 of the Electricity Regulation Act No. 4 of 2006 to increase the licensing exemption threshold for distributed generation capacity from 1MW to 100MW – in other words, projects below 100MW of generation capacity need to be registered with NERSA but do not need to obtain a generation licence (Department of Mineral Resources and Energy, 2021). In July 2022, the President announced the lifting of the 100MW cap altogether (although regulations are yet to be promulgated at the time of writing). The amendments make it easier for (energy-intensive) industries to enter into PPAs with private entities to launch their own power projects, thus reducing their reliance on Eskom. The President also announced that "special legislation" would be placed before Parliament to address remaining legal and regulatory obstacles to the urgent introduction of new generation capacity (Sguazzin, 2022).

#### 3.1.2.1 Primary aluminium

Hillside's power demand is 1 205MW of electricity at a baseload factor of 99.9%. Operating the smelter on renewable energy alone would require about 5 000MW of solar and wind energy supplemented by a large battery storage capacity.

Hillside could follow many other companies, such as Sasol and ArcelorMittal,[14] and source the renewable energy-based self-generation capacity by contracting IPPs (Spaes, 2020). Decarbonising primary aluminium through distributed generation would need several large renewable energy generation projects. Once the 100MW threshold is officially lifted, Hillside could procure as much renewable energy and battery storage capacity it required.

South32 has announced that it has been working on options to secure low-carbon energy sources for Hillside. The company, publicly, supports Eskom's efforts to decarbonise and will work with government, Eskom and relevant stakeholders to secure renewable energy and storage capacity for Hillside (Creamer, 2022a). Hillside is running feasibility options, investigating low-carbon energy options and energy yield mapping.

Hillside could procure the renewable energy and storage from IPPs. As Hillside would be unable to build the required renewable energy generation capacity on or near its smelter, it would be required to wheel it through Eskom's and municipalities' distribution and transmission networks (Creamer, 2022b; Mallinson, 2020).

The scale of renewable energy required by Hillside would make this avenue challenging. In addition to financing the project, issues around wheeling and land use for construction of renewable energy and battery would need to be addressed (Creamer, 2022b). This approach would have serious implications for Eskom as it would mean losing its largest industrial customer and the revenues associated with it as well as losing Hillside as a grid stabiliser.

Hillside could also enter into a partnership with Eskom to secure renewable energy through a PPP. Hillside and Eskom could use their long-standing commercial relationship to establish a PPP to secure renewable energy and storage options for Hillside. This relationship would be mutually beneficial as Eskom would retain its largest industrial customer, while Hillside would secure its much-needed low-carbon power supply.

The De Hoop dam Tubatse hydro-battery project could enable Hillside's use of renewable energy sources from 2030 to beyond 2050. The hydro-battery project is proposed as a private-public partnership that could provide 12 000MWh of battery storage for Eskom and Hillside. The project would be accompanied by 1 000MW of solar PV and wind power, which would be wheeled over to Eskom's grid to power Hillside and an additional 1 000MW of solar PV and wind power to recharge the battery. This project would need Eskom and South32 to leverage their long commercial relationship and mutual interest in the survival of the smelter (Creamer, 2022b). Hydro storage

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[14] Sasol and Air Liquide have begun to seek partners to potentially deploy renewable energy projects. Sasol intends to procure 600MW of renewable electricity. ArcelorMittal has entered into small scale 10MW PPAs for six of its sites.

options are expensive, have long lead times to develop, and require approvals to implement. Tubatse should be accompanied with other options, but could be a long-term solution to decarbonising Hillside. At the time of writing, the hydro storage avenue has not been formally pursued by Hillside and Eskom.

Hillside is one of Eskom's key industrial customers. It accounts for 5% of Eskom's sales and is important to the stabilisation of the national grid during loadshedding. The smelter plans to initiate its transition to low-carbon energy sources by 2026. Hillside has established a working group with Eskom to chart solutions to the carbon intensity issue.

If South32 was unable to secure affordable low-carbon electricity, Hillside would become uncompetitive. Accordingly, South32 has started planning to support a just transition through the closure of the smelter if the energy transition is not commercially viable.

#### 3.1.2.2 Secondary aluminium semi-fabricators and foundries

Zimalco, Hulamin and Wispeco use natural gas and electricity in their production processes, however, electricity accounts for the majority of GHG emissions for these companies.

In 2020, Hulamin announced it would pursue renewable or low-carbon energy sources. The company has built a multi-disciplinary Environmental Sustainability team to ensure that all environmental sustainability aspects are translated into business support and action. The team is in the process of assessing efficiency technologies and low-carbon energy projects (Hulamin, 2021). Since electricity makes up most of its carbon footprint, the focus of the company is to decarbonise its electricity input. Hulamin plans to replace coal-powered electricity with solar, wind and biomass while it keeps a close eye on developments in the hydrogen market for substituting natural gas.

Hulamin is engaging with the Msunduzi Municipality to get a municipal agreement to get PPAs for solar and wind powered electricity.[15] The first round of PPAs would generate about 15% of the electricity needs, while subsequent rounds would secure more low-carbon electricity and battery storage. The request for quotation process was planned to be released in 2022 and, at the time of writing. the renewable energy generation capacity expected to be connected by the end of 2023.

Hulamin is also investigating biomass to generate electricity. In a collaboration with the municipality, sawmills and forestry companies, it plans to convert the municipality's waste disposal site to generate biomass electricity. The project is still at conceptual stage. It is projected the project would have a two year lead time at minimum.[16]

Zimalco uses electricity for aluminium powder production. In 2020, the company investigated the use of gas generators to generate electricity, however, the cost was not financially feasible for the company. The company intends to pursue this avenue as its financial outlook improves. Solar rooftop PV was investigated; however, the production site generates excessive dust which would make solar rooftop installations costly to maintain.[17]

Wispeco has integrated renewable energy-based distributed generation into their production processes by installing solar rooftop panels and are entering into a PPA with an IPP to procure electricity from renewable energy sources.[18]

[15] Interview with Hulamin.
[16] Interview with Hulamin.
[17] Interview with Zimalco.
[18] Interview with Wispeco.

A combination of both utility scale and distributed generation for secondary foundries would mean accruing renewable energy through PPAs while maintaining the access to the grid during periods of low distributed generation capacity.

**Box 4: Aluminium produced from renewable energy**

Hydro, a Norwegian company, produces 70% of its aluminium using hydropower and wind power. It sources renewable energy through well-established renewable energy PPAs in Norway and Sweden. In addition to the power agreements, Hydro operates 20 hydropower facilities throughout Norway and produces about 20TWh of renewable energy. Hydro offers its low-carbon aluminium at a premium of US$14/ton through the Hydro CIRCAL and Hydro REDUXA brands (Bloomberg, 2021). To further decrease its carbon footprint, Hydro is also testing next-generation technology with the potential to reduce the electricity required for smelting by 10%-14% at its Karmoy technology plant in Norway (Hydro, 2021).

Emirates Global Aluminium (EGA), based in Abu Dhabi, became the first company to use solar-based electricity for commercial aluminium production in 2021. The United Arab Emirates is the largest producer of premium aluminium in the world. EGA sources its solar energy from the Mohammed bin Rashid Al Maktoum Solar Park project in Dubai. The solar park is operated by the Dubai Electricity and Water Authority, and the electricity is certified by third parties for transparency. The solar park provided EGA's aluminium smelter with 1 013MW of power, to produce 40 000 tonnes of aluminium in the first year with the potential for increasing the amount of aluminium in the future. The "solar aluminium" is sold under the CelestiAL brand name. BMW and Mercedes-Benz component manufacturers have secured an exclusive contract with EGA and were the only consumers of CelestiAL as of November 2021 (Kareta, 2021).

Natur-AL produces aluminium made from 100% renewable energy (hydropower and geothermal energy) at its aluminium plant in Iceland. The plant was inaugurated in 2020. Natur-AL aluminium has one of the lowest carbon footprints in the world with direct emissions below 2t$CO_2$e per tonne of aluminium. Its total $CO_2$ emissions are less than one-quarter of the industry average. Natur-AL$^{TM}$ Zero is the full offset pure carbon-neutral aluminium product line. Natur-Al has a 150 000 metric ton deal to supply Glencore with the "green aluminium" (World Economic Forum, 2020).

## 3.2 Reducing direct emissions of primary production

While significant progress has been made over the past 20 years, globally, direct/production emissions still contributed to 25%-30% of total production emissions in 2018 (World Aluminium, 2021). In South Africa, direct emissions accounted for 12% of total emissions of the Hillside smelter in 2021 (South32, 2021). Direct emissions from primary production can be reduced through engineering improvements to production processes and/or introducing new technologies which aim to improve energy efficiency or reduce GHG emissions. There are limited technologies which provide a solution to direct emissions. Available technologies face the challenges of scalability and affordability.

### 3.2.1 Engineering improvement technologies

Engineering improvements can improve energy efficiency and carbon intensity. Typically, engineering improvements can be made to existing production processes and are implementable in the short term.

Over the past two decades, several improvements have been made to primary aluminium production. In the 2000s, BHP Billiton implemented a National Aeronautics and Space Administration

(NASA) adopted insulating paint[19] at its smelters which improved thermal efficiency (TIPS and GGGI, 2014).

According to South32, the Hillside smelter is an efficient smelter operating at technical capacity. Hillside's Scope 1 carbon intensity is 1.9 $tCO_2e$/t aluminium, which is far below the global average of 8.5 $tCO_2e$/t aluminium (South32, 2021). The smelter has introduced a number of projects to improve energy efficiency, namely energy monitoring and management systems, process controls, variable speed drivers, energy saving light bulbs, and state-of-the-art point feed prebake technology (Kilian, 2013).

In 2021, South32 announced it would introduce the AP3XLE energy efficiency technology at Hillside. AP3XLE was successfully implemented at Mozal and has improved energy efficiency from 13.6MW/t to 13.1MW/t. Similar gains are expected at Hillside.[20] The AP3XLE energy efficiency technology is a pot lining technology that reduces approximately 4% of direct GHG emissions without increases in power consumption while increasing production volumes. South32 is expecting to spend about US$18 million over five years to install it at Hillside (South32, 2021). The technology is scheduled to be implemented at Hillside from the 2023 financial year.

South32 is also investigating implementing the EnPot energy modulation technology. Aluminium smelters currently require an always on electricity supply to keep the electrolysis process running. The energy input of a smelter cannot be varied by more than a few percentage points, meaning smelters operate at full capacity 24/7 for their entire lifespan. EnPot gives smelters the ability to turn their energy consumption up or down by as much as 30%. This means that smelters can better match energy supply enabling them to use renewable energy sources more efficiently (AlCircle, 2022; Dorreen et al., 2017).

EnPot covers the sidewalls of a pot with patented "heat exchangers", connected to an external ducting and suction system. When power is reduced, the airflow to the exchangers are also reduced, effectively insulating the pot to maintain the required heat balance. Alternatively, when the power is increased, the airflow is also increased to boost heat transfer and maintain the balance. This allows power usage to be changed at any time while maintaining pot temperatures and preventing process disturbances. Enpot enables a 20% stable modulation at any time for any duration and a 30% long-term modulation. In the case of a power outage, the Enpot system can be used at maximum insulation mode for up to four hours. This prevents a recharging phase when the power is restored (EnPot, 2019).

The EnPot technology has been proven with plant trials and reached full commercial installation in 2017. The system was successfully installed at Trimet's Essen Smelter in Germany in 2017. EnPot has enabled the smelter to dynamically increase or decrease the energy use. The Trimet smelter has now become a buffering bridge of energy supply and demand in Germany, acting as a virtual battery storage of 12GWh for the grid. This is equivalent to about 25% of Germany's current pumped storage hydropower capacity. The installed EnPot system has proven to be robust, stable and reliable with no major equipment failures or problems since start up (Deign, 2017; EnPot, 2019).

Enpot supports the rapid uptake of renewable energy as it provides a solution to balancing electricity demand and the variability of renewable generation. It allows energy-intensive smelters to modulate energy use on demand at a much lower cost. The smelter can offer demand-side

[19] A thin paint cover of 5 to 12 millimetres containing little beads filled with air. The technology is a=a spin-off of research conducted by NASA. The paint reduces thermal losses.
[20] Interview with South32.

response services to the grid during peak and off peak renewable generation capacity (Djukanovic, 2017; EnPot, 2019).

Installing Enpot does not fundamentally change the smelting process. It is a non-invasive process as it can be installed while potlines are fully operational. The only moving parts are the suction fans, which have built-in redundancy (EnPot, 2019). An Australian investment evaluation in 2017 revealed a capital cost of US$100 million for a medium size smelter retrofit (IEEFA, 2020).

### 3.2.2 Disruptive technologies

The Hillside smelter uses the Hall-Héroult process, the only commercial industrial process to produce aluminium from alumina. The Hall-Héroult process produces $CO_2$ and other GHGs.[21] Over the last six decades, there has been research and development to explore alternative technologies. Several disruptive technologies are being tested, each with their challenges in terms of scale, technology readiness level and affordability. The new technologies are still in trial and research and development stages, and none have proven commercial viability. Significant research and development needs to be done to enable widespread deployment by 2030 (World Aluminium, 2021).

#### 3.2.2.1 Inert anodes

Currently, the Hall-Héroult process relies on carbon anodes, which produce $CO_2$ as they degrade. Carbon anodes account for about 10% (about 1500 $kgCO_2$/tonne of aluminium) of primary production emissions.

In contrast, inert anodes are made from materials which are non-consumable or do not degrade. The use of inert anodes could significantly improve direct carbon intensity of aluminium production. Inert anodes produce pure oxygen rather than GHGs (Haraldsson, 2020).

Inert anodes can also improve production processes. The lifetime of inert anodes are much longer than carbon anodes, which would lead to fewer anode changes (Kvande and Drabløs, 2014). Inert anodes can also improve plant operating efficiency by eliminating anode effects. The oxygen gas produced as a by-product could be sold for use in other production processes (Haraldsson and Johansson, 2018).

When implemented on their own, however, they have negative end-use energy efficiency. Direct retrofitting would increase the energy demand for the electrolysis process. While GHG emissions would be reduced, the increased energy demand would have an impact on total GHG emissions depending on the energy source. Inert anodes would be ideal for locations where primary energy is sourced from low-carbon energy sources (Haraldsson and Johansson, 2018).

In addition, the technology is not yet commercially available. The technology is being trialled in pilot projects by several aluminium companies. Most of the research is focused on developing the correct anode material. Materials, such as ceramics, metal alloys and cermet, are being explored as potential candidates, however, an adequately effective anode material has not been identified. These materials present engineering challenges, such as metal purity[22] and anode longevity[23] (Haraldsson and Johansson, 2018). Another key issue is technology adaptation. Current Hall-Héroult cells cannot be retrofitted to use inert anodes.

[21] The Hall-Héroult process periodically produces small amounts of PFCs.

[22] The main material groups for inert anodes are cements, ceramics and metals. The corrosive nature of these materials could compromise metal purity during the electrolysis process.

[23] A material with long-term stability in conventional electrolytic cells had not yet been found as of 2018.

Inert anodes are not consumed during the electrolysis process. As such, not much is understood about the end-of-life requirements. Infrastructure may be required to dispose of or recycle the waste (UN CTCN, 2020).

Inert anodes could require a new cell designs which could mean new smelting plants. Retrofitting existing smelters may only make sense if existing process elements already need replacement, or if the regulatory environment makes the cost of retrofit preferable to creating a high-carbon product. Young smelters, or ones which have had recent cell replacements, would need incentives to make retrofitting financially viable (Benedyk, 2020).

Several companies, including Rio Tinto, Alcoa, RUSAL and Arctus Aluminium, are actively pursuing research and development of inert anodes. Due to the proprietary nature of the technology and the competitive environment, it is difficult to assess the benefits of inert anodes beyond carbon reduction. Infinium, part of the AluK group, is working on inert anodes sheathed with zirconium oxide[24] tubes (Springer and Hasanbeigi, 2016). The technology has been demonstrated for the processing of titanium, manganese and rare earth metals and is being tested for aluminium. In 2018, Alcoa and Rio Tinto announced the development of an inert anode technology and have formed a joint venture to further develop the technology. Construction of the first commercial-scale prototype cells at a smelter in Quebec, Canada, began in June 2021. They are aiming to complete demonstration by 2024, with commercialisation to follow. RUSAL's Krasnoyarsk plant in Russia has produced primary aluminium using inert anode technology at industrial scale (one tonne of aluminium per day per cell). Test deliveries of a pilot batch of aluminium commenced in the spring of 2021, and the company aims for mass-scale production by 2023 (IEA, 2020a).

Wetted cathodes present a solution to the energy efficiency issues of inert anodes. The combination of wetted cathodes and inert anodes can reduce energy requirements in the electrolysis and anode manufacturing processes by 3.05MWh/t (15%-20%) and GHG emissions by approximately 25% per tonne of aluminium compared to the modern Hall-Héroult technology (Haraldsson, 2020).

A well-fleshed economic analysis has not been conducted on inert anodes. Some ball-park figures have been given at between US$1-US$2 billion for greenfield projects incorporating inert anode technology (UN CTCN, 2020). An economic evaluation taking into account the investment cost, the longer lifetime of inert anodes compared to carbon anodes, and the increased energy costs is needed. Researchers estimate that if testing and research continues, inert anodes could reach commercialisation post-2030 (Haraldsson, 2020).

#### 3.2.2.2 Wetted cathodes

The use of conventional cathodes requires a metal pad on the surface to provide protection against the corrosive electrolyte. This creates movements and standing waves in the aluminium as well as aluminium/electrolyte interference due to electromagnetic forces. The result is a large Anode-to-Cathode Distance (ACD) to avoid shortening between the anodes and the metal (Haraldsson, 2020). Wettable cathodes allow the molten metal to wet the cathode, and a high aluminium pad is not needed. Wetted refers to improved electrical contact between molten aluminium and the carbon cathode material. Wetted cathodes allow for a low-temperature electrolysis (LTE) systems approach to aluminium smelting. The LTE system differs from conventional Hall-Héroult approach in that the anodes material do not react with the oxygen gas released from alumina to produce carbon dioxide. Unlike carbon anodes, the metal anodes are not consumed and oxygen is released from the process (Benedyk, 2020; Haraldsson, 2020).

[24] A white crystalline oxide of zirconium.

A stable, wetted cathode would allow the anode to be brought closer without high magnetohydrodynamic[25] stability and elevated risk of an anode effect. Wettable cathodes enable the molten metal to wet the cathode whereby a thin aluminium layer can be formed. ACD is reduced and, without adverse effects on current efficiency, the enormous magnetic field disturbance is reduced. Energy savings are achieved through the reduced cathodic voltage[26] and by the reduced ACD. Wettable cathodes can provide energy savings of between 0.4-3.1kWh/kg of aluminium (Haraldsson and Johansson, 2018).

Theoretically, the technology reduces energy consumption by about 20% of the smelting energy consumption by lowering the ACD. When combined with inert anodes (as discussed above), additional energy savings of between 15%-20% can be achieved according to best estimates. By creating a cathode surface that is inert and wettable to the molten aluminium pad, the ACD can be reduced by half or more, thereby reducing the voltage drop with substantial energy savings. Currently, the technology is still in the developmental stage. Testing is underway to assess industrial scale deployment  (Haraldsson and Johansson, 2018; World Economic Forum, 2020).

The key challenge with wettable cathodes has been the identification of a suitable cathode material. The material needs to have some of the properties of conventional carbon cathodes, such as high electrical conductivity; good thermal shock resistance; low solubility and reaction with molten aluminium; acceptable resistance to penetration; and corrosion by molten cryolite (Benedyk, 2020).

For the past 60 years, finding one material with all of these properties has been an issue. Titanium diboride ($TiB_2$) is the material most trialled and was proposed as a reliable candidate, however, it is expensive and fragile. The manufacturing process of $TiB_2$-based cathodes is also facing challenges (Haraldsson, 2020; Keniry, 2001).

Theoretically, the combination of wettable cathode with inert anodes can reduce the energy consumption compared to the carbon anode process. However, the combination's heat requirements have not yet been tested. The use of wettable cathode with inert anodes could expose the sidewalls directly to the cryolite bath. This could reduce the lifespan of cell sidewalls. New cell sidewall materials, which are highly corrosive resistant, would need to be identified. The materials would also need to have high thermal insulation to keep the heat inside the cell and maintain the heat balance of the cell (Haraldsson, 2020).

Identifying an appropriate cathode material is crucial to the implementation of wettable cathodes. Current research efforts have not identified a material that fits the requirements. Researchers are unclear on the timeframes for resolving this issue. Information on the investment cost, economic feasibility and ease of implementation for wettable cathodes is scarce. The technology is still in early stages, thus a cost evaluation which assesses the investment cost, operations and energy costs has not been conducted (Haraldsson, 2020).

#### 3.2.2.3 Carbothermic reduction

Carbothermic reduction uses a chemical reaction instead of an electrochemical reduction to reduce alumina to aluminium. Although no electrolysis is involved, electrical energy is required. In the carbothermic process, an alternating current is used to heat up the raw materials, alumina and carbon. In this process, alumina reacts with carbon at high temperatures to form aluminium and carbon monoxide (Springer and Hasanbeigi, 2016).

[25] A phenomena arising from the motion of electrically conducting fluids (such as plasmas) in the presence of electric and magnetic fields.

[26] The voltage between the anode and cathode terminals.

Carbothermic reduction requires a lot of heat, however, it is a more thermodynamically efficient chemical reaction per unit of energy input than electrolysis in a Hall-Héroult cell. The direct carbothermic reduction converts alumina into aluminium carbide, which is then reduced to produce metallic aluminium (Haraldsson, 2020) .

Compared to the Hall-Héroult process, carbothermic reduction provides the potential for both lower energy use and increased productivity (Springer and Hasanbeigi, 2016). The process promises to reduce energy consumption from 13kWh/kg to 11kWh/kg of aluminium. The carbothermic process can also increase aluminium yields by 67% (Haraldsson, 2020).

Theoretically, carbothermic technology has the potential to produce energy savings of 34% compared to the Hall-Héroult carbon technology, however, the production of CO in the carbothermic process could increase $CO_2$ emissions by 60% if the CO gas is released in the atmosphere. The CO produced from the carbothermic reduction is 90% pure and can potentially be collected and used as raw material for several different chemical products (World Economic Forum, 2020). PFC emissions produced in the carbothermic process are also lower than in the Hall-Héroult process (Haraldsson, 2020).

Persistent issues, such as the formation of aluminium carbide,[27] high temperature requirements, energy delivery for reaching high temperatures, aluminium volatiles, and the formation of undesired by-products, have yet to be addressed (Haraldsson and Johansson, 2018). More knowledge about reaction mechanisms and alumina reduction is needed to address these issues.

The carbothermic process requires less physical space and has a lower dependency on economies of scale. Capital costs could be 50% lower than for the current process and production costs could be reduced by 25%. There would be a greater freedom to relocate the reduction plants closer to the casting facility, which would allow for additional energy, economic and environmental benefits (World Economic Forum, 2020).

Research on the carbothermic process of alumina reduction started about 70 years ago, however, a commercially viable industrial method has not been found. Even though the overall GHG emissions reduction are significant, without carbon capture and storage (CCS) capturing all the CO gas, the carbothermic process is not a solution to minimise the carbon footprint of aluminium production. It is estimated that the technology will be commercially viable by 2050 (World Aluminium, 2021; World Economic Forum, 2020).

## 3.3 Reducing direct emissions of secondary production

As with primary aluminium production, direct emissions from secondary production and semi-fabricators could be reduced through engineering improvements in the production processes or through the introduction of new technologies. The key areas for reducing GHG emissions in direct secondary production are the increase in metal yields and improving energy efficiency.

### 3.3.1 Engineering improvements

#### 3.3.1.1 Increasing metal yields

Reducing process scrap loss can decrease the total energy needed to produce a unit of final product as it increases metal yields. Process scrap loss implies that more material is needed to produce a unit of final product. Additional energy is required to remelt the process scrap to bring it back into

[27] Aluminum carbide (Al4C3), in the form of pale yellow crystals, can be made by heating a mixture of the elements at temperatures above 1 000°C. Aluminum Carbide is hazardous and can affect lungs and cause skin and eye irritation. It is a flammable and reactive chemical.

production. Improving metal yields can provide energy savings of between 20%-30% depending on the furnace used (Tongthavornsuwan and Tangwarodomnukun, 2015).

Metal yields are a crucial factor in the aluminium scrap recycling process. Improving metal yields is influenced by many parameters, such as the surface area to volume ratio, scrap shape, type of alloy, scrap history, contaminants and the amount of required flux additives in the melting process.

Managing scrap samples and purchases can assist to avoid contamination from the varying types of aluminium scrap, differences in surface area to volume of scrap, and accumulation of impurities which can reduce metal yields. Monitoring systems which provide real-time data on the type of scrap purchased, the quantities, and the source can assist to reduce metal loses due to purchasing errors and scrap mismanagement (Haraldsson and Johansson, 2018).

Melting cleaned scrap free from contaminants is important to increasing metal yields. Melting clean scrap can also reduce energy use, GHG emissions, and dross or skimming generation. Contaminants can also alter the chemical composition of aluminium and reduce the metal quality and recovery. Contaminants and metal impurities can be eliminated by physical separation, frequent sow cleaning operations[28] and refining techniques to purify the metal (Tongthavornsuwan and Tangwarodomnukun, 2015).

#### 3.3.1.2 Improving energy efficiency

One of the key sources of energy/heat waste is extensions in melting time. Reductions in melting time can be achieved through process improvements such as changing the order in which different scrap metals enter the furnace. Differences in scrap shape and size can affect the melting time and in turn increase the energy use. By arranging that relatively thick metal pieces are charged first into the furnace, followed by smaller ones, overall melting time can be reduced. This is due to the rapid oxidation of aluminium that usually takes place at the early state of melting operations. When smaller pieces are applied first in the furnace, they can be vigorously oxidised and in turn vaporised quickly, thus lessening the production yield. Thick and bulk aluminium pieces should be supplied at first to encourage a substantial amount of liquid metal, whose internal energy can expedite the melting of smaller scraps consecutively charged into the furnace (Capuzzi and Timelli, 2018).

The surface area also influences melting time. If the scrap has a large surface area, the melting time will be shortened and vice versa. Additionally, cracks or porous areas in scrap can increase the melting rate when they are infiltrated by the molten metal. Therefore, the surface area to volume ratio should be increased to reduce the overall melting time (Capuzzi and Timelli, 2018; Tongthavornsuwan and Tangwarodomnukun, 2015).

Scrap aluminium comes in a great variety of shapes and dimensions. Comminution is the cutting, shearing, tearing, and bending of aluminium into desired shapes and sizes for melting. The objectives of comminution are to reduce energy use by ensuring proper distribution of scrap size. Comminution also aims to remove undesired materials, liberate assembled parts and increase bulk density. Machines and equipment required for comminution include rotary shears, rotary cutters and translator shears (Tongthavornsuwan and Tangwarodomnukun, 2015). Smelters need to select the appropriate machine depending on the type of furnace and scrap.

South African secondary producers use reverberatory furnaces which are brick lined and use natural gas as a primary energy input. Reverberatory furnaces give a high volume processing rate, with low

[28] Cleaning sow operations involve removing dross from liquid aluminium before it is placed in sow castings where the metal is transferred from ladles into large steel moulds where the metal cools and solidifies.

operating and maintenance cost. However, they have high metal oxidation rate, low energy efficiency, and large space requirements (Capuzzi and Timelli, 2018).

Modifications to reverberatory furnace could improve energy efficiency and increase metal yields. The use of hot exhaust gasses to preheat the incoming air can improve energy efficiency by 40%-50%. Heat recovery mechanisms through the use of heat exchanger, regenerative burners and recuperative burners can also be included in reverberatory furnaces. Recuperators are counter flow heat exchanges which use the excess heat from exhaust gases to preheat the combustion air, scrap, and metal charge in a furnace. Heat exchangers on the exhaust gas from large furnaces can save about 24% of fuel on average. Better insulation materials can further reduce energy use by 2%-5% (Capuzzi and Timelli, 2018; Haraldsson and Johansson, 2018).

Zimalco has introduced several energy efficiency improvement projects over the last decade. These include making improvements to melting furnace design. Other energy efficiency improvements consisted of changing burner directions and sealing furnace doors more efficiently to ensure reductions in heat waste. Zimalco also has one major furnace improvement project scheduled for mid-2022 to further improve the energy efficiency of the plants.[29]

Wispeco is investing in the modernisation of their plant. The remelter also uses regenerative burners and heat recovery mechanisms to save in energy to their melting furnaces.

Hulamin is planning to introduce several process improvement to reduce their use of gas and electricity. The forced switch-off of various machines during 2020, due to Covid-19 lockdowns, provided an opportunity to better understand the baseload electricity consumption of the company. It gave insights into options to improve shutdown procedures and other baseload saving options. These insights will be the basis for introducing new processes to further improve energy efficiency (Hulamin, 2020).

In 2020, Hulamin started the verification of their onsite supplier fuel gas flowmeters, with an expected completion date of 2021/22. The new flowmeters would provide data on the gas supply that will be used to monitor and verify internal consumption against supply. The modifications will provide real time data on gas consumption at the coil coating line which will improve consumption efficiencies per coil of aluminium produced. The insulation sensors on the coating line are expected to reduce gas consumption by up to 5% (Hulamin, 2020).

In 2020, Hulamin also started a replacement programme to replace aging compressors with modern, high-efficiency compressors to reduce electrical energy consumption. The replacements were reinitiated in 2021 due to delays caused by COVID-19 restrictions. Hulamin is also planning projects to further improve production efficiencies. These include rolling out VSDs to prevent fans running at a fixed rate. The company is investigating the use of waste heat recovery mechanisms to use the heat that comes off compressors. The plan is to harvest the heat and use it into other operations (Hulamin, 2020).

### 3.3.2 New technologies

Despite considerable improvements in the energy efficiency of melting furnaces, the overall energy consumption of secondary aluminium production still can range from 7.7MJ/kg to 20MJ/kg depending on the type of aluminium scrap and the furnace technology (Paraskevas et al., 2015). The focus of research and development in secondary aluminium production has been to address the issue of metal quality, metal yields and energy intensity. Emerging technologies aim to improve

[29] Interview with Zimalco.

energy efficiency and reduce GHG emissions through improved sorting and cleaning, alternative furnace models and heat recovery.

#### 3.3.2.1 Energy efficiency

Industrial scrap, such as turnings, chips and cuttings, represent approximately 18% of total industrial aluminium scrap mass. Aluminium recyclers find recycling this scrap problematic due to high metal losses during remelting. Avoiding remelting can save both energy and metal. Spark Plasma Sintering (SPS[30]) is an emerging technology used in aluminium recycling for producing fully dense billets or final-shape products directly from aluminium turnings or chips. SPS is a pressure assisted, pulsed electric current Joule heated sintering[31] method. The scrap is first pre-compacted at room temperature and then it is sintered below the solidus temperature at 490°C under 200MPa pressure (Paraskevas et al., 2015).

SPS can increase both energy efficiency and material savings. The material savings arise from the reduced losses due to oxidation, which is a problem for smaller scrap, such as chips and turnings. SPS technology has been shown to have 90%-95% lower energy demand than conventional hot pressing sintering technology (Paraskevas et al., 2013). This is due to the lower temperature and processing time required. While SPS is better than conventional sinter technology, the size of sample materials is an issue for industrial applications. Fabricating larger samples with SPS could result in heterogeneous properties within the samples due to uneven heat distribution. In larger industrial applications, the recently developed hybrid spark plasma sintering offers a solution to the heat distribution issue. Hybrid sintering is the combination of SPS with an additional resistance or inductive heating (Paraskevas et al., 2015). The technical feasibility of SPS has been proven. Chinese Haoyue Lab launched the Smini SPS machine in 2018. The Smini SPS machine cost US$50 000-US$100 000 in 2018 (Haoyue Lab, 2019).

#### 3.3.2.2 Separation and sorting

Colour separating has been one of the most used automated industrial separating technologies. Colour separating is based on the colour differences in the types of aluminium scrap. High silicon and manganese contents turn scrap grey while zinc and copper turn aluminium dark grey. Prior advancements in colour separating included computer software, which enhanced the ability to separate metals with slight colour variations (Steinert, 2016). The key problem with colour separators was that it could not separate alloys within an individual alloy group.

Research has been underway to improve colour sorting. New techniques use a combination of weight and 3D imaging to separate aluminium scrap into wrought and casting alloys according to differences in densities and 3D shape parameters. 3D imaging equipped with a linear laser and optical charge-coupled device determine the content of aluminium scrap through triangulation. This technique uses a multivariate analysis. Each fragment is identified as cast or wrought by an algorithm using threshold values determined from a database of weight and 3D shapes of sampled fragments. This technology is still at the research stage; however, preliminary data shows it costs

[30] The process can also be found in literature as field activated assisted sintering (FAST), electric discharge compaction/consolidation (EDC), pulsed electric current sintering (PECS), plasma pressure compaction (P2C), pulse electric discharge process (PEDP), plasma activated sintering (PAS), electric field sintering, plasma pressure consolidation, pulse current pressure sintering (PCPS) and pulsed current hot pressing (PCHP)

[31] Sintering is a thermal process of converting loose fine particles into a solid coherent mass by heat and/or pressure without fully melting the particles to the point of melting.

less than current X-ray sorting systems. It is probable this method could replace dense media[32] or manual sorting. However, the efficiency of the method depends on the implemented algorithm for identification and the database of samples accumulated (Steinert, 2019).

TOMRA's X-Ray Transmission (XRT) sensor is the latest X-ray based sorting technology developed by TOMRA. Compared to the existing X-Ray Fluorescence, the XRT technology employs additional sensors that sort based on atomic density (shape and size), allowing a high level of sorting purity irrespective of size, moisture or surface pollution. The technology delivers a unique density detection with unsurpassed sorting accuracy and throughput. The XRT technology has been proven in South Africa in chrome and coal sorting as well as in diamond sorting in Lesotho. The technology cost chrome miners in the Samancor Eastern Chrome Mines US$18 million. In Lesotho, the technology improved the sorting so much it recovered about 15 times the investment value over a four-year period (2017-2020) (Gleeson, 2020; Moodley, 2021).

## 3.4 Increasing recycling rates and improving availability of quality scrap

### 3.4.1 Improving availability of quality scrap

South Africa is a net exporter of scrap metal. About 70% of aluminium scrap is exported. One of the key issues identified by the secondary aluminium industry is the availability of quality scrap aluminium on the domestic market. For secondary aluminium producers, quality scrap material is a key input for manufacturing and increased access to quality scrap would improve the efficiency of their production processes.

The lack of availability of quality scrap metal for the domestic industry has resulted in recommendations that the current PPS (discussed in section 2.2) be replaced with export duties. Despite the PPS, secondary aluminium producers still experience issues with accessing affordable quality scrap aluminium.[33]

In July 2021, a new export duty was introduced. For aluminium, the suggested rate was R1 000/t. While secondary producers welcomed the tax, they remained concerned that the tax alone would not be enough to curtail scrap exports. Additional support and enforcement of regulations would be important in securing quality scrap metal for local consumers.

### 3.4.2 Increasing recycling rates

Aluminium recycling accounts for less than 10% of global GHG emissions but accounts for 30% of the demand. Increasing recycling rates for old scrap would reduce overall long-term value chain GHG emissions. The reductions in GHG emissions would be achieved by replacing carbon-intensive primary aluminium production with scrap aluminium (IEA, 2020b; International Aluminium Institute, 2021).

The IAI modelling estimates that most metal losses occur in the collection portion of the recycling cycle. Metal losses from scrap processing, remelting and refining are only 1.7MT while collection losses are 4.1MT (International Aluminium Institute, 2021). Global recycling rates for end-of-life products are currently above 70%, having seen a 10% increase in the past 10 years. Currently, end-of-life collection rates are highest in the construction, electric power and transport sectors, where recycling rates are between 80%-95%. Recycling rates for large and small consumer items are comparatively lower, at about 70% (World Aluminium, 2021). The high collection rates in the

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[32] Dense media separators use water-based slurries with known specific gravity to separate non-ferrous materials with different densities.

[33] Interviews with Hulamin, Zimco and Wispeco.

transport, construction and electric power sectors are due, in large, to the close relationship between dismantlers and recyclers as well as the recognition of the high intrinsic value of end-of-life aluminium products (World Aluminium, 2021). Apart from UBC's collection rates, the collection rates for other sectors in South Africa are unknown.

Increasing recycling rates production scrap recycling is discussed in section 3.3.1. This section focuses on increasing end-of-life scrap. End-of-life scrap can be improved through improving collection rates and through closed-loop production designs.

#### 3.4.2.1 Improving collection

The objective of improving old scrap aluminium collection rates is mainly to divert aluminium away from landfills and into recycling systems. Globally, in 2018, seven million tonnes of aluminium were not recycled due to collection losses. This is projected to increase to 17 million by 2050 if recycling rates do not change. Across market segments, collection rates for (small and large) consumer scrap are the lowest. Initiatives to improve collection rates in these sectors are paramount (International Aluminium Institute, 2021).

Scrap collection and recovery rates could be increased by improving recycling channels, investing in recycling facilities, and by better connecting participants along supply chains. Focusing on end uses that currently have low collection rates would be important. Improving collection channels would require increased consumer awareness, convenient return systems and infrastructure that support business and customer participation.

In the automotive sector, the key challenge with scrap lies in proper dismantling and sorting of different aluminium alloys to retain the quality and value of the original components. Scrap collection rates in the automotive industry are already high, however, using QR[34] codes on components which have information on the scrap contents could improve the dismantling and collecting process (Recycling World, 2018).

In the construction sector, the dominance of low alloyed aluminium and large components make identification and separation easy. Promoting best practices to avoid building product scrap being mixed together could assist in improving scrap aluminium collection rates. This would require that dismantlers know which construction components contain aluminium at demolition sites (World Aluminium, 2021). Materials identification techniques and technologies, combined with targeted dismantling operations, could generate higher scrap collection. In both the transport and construction sectors, collection rates could be improved through coordination and strengthening the relationship between dismantlers, collectors and recycling plants (AFSA and CSIR, 2017).

A lack of consumer awareness and convenient stations to dispose of aluminium for recycling are key bottlenecks to consumer and packaging aluminium collection rates. Educating consumers on aluminium recyclability and the environmental benefits through educational programmes, awareness activities, workshops and campaigns would be important (Velaphi, 2013). Curbside collection and incentive programmes, such as Deposit-Return Systems (DRS), could increase collection rates. DRS allow consumers to get a portion of their purchase cost returned when they take their products to be recycled. The system has been successful in Slovakia for aluminium beverage cans where consumers receive a reward of EUR15 cents per can (Linnenkoper, 2022).

In South Africa, waste pickers collect significant amounts of waste materials. Recycling plants could also work with waste pickers to incentivise the collection of more aluminium scrap. Landfill mining could also increase collection rates if it could be done in a safe manner. Municipalities and local

[34] Quick response.

waste collection companies need to work with waste pickers, local collection and sorting companies to develop recycling facilities and invest in capacity.

Hulamin, South Africa's largest aluminium recycler, has committed to achieving a beverage can recovery rate of 85% in South Africa by 2025. It aims to do this by supporting the beverage can recycling industry through collaboration with key suppliers and stakeholders in the packaging and metal packaging industry. Hulamin runs a sustainable scrap supplier enterprise initiative which involves the provision of guaranteed buy-back agreements, equipment training and mentorship (Hulamin, n.d. and 2020).

Hulamin has a state-of-the-art recycling centre, which is designed to efficiently recycle challenging post-consumer scrap, such as UBCs. The recycling centre has increased the amount and variety of end-of-life scrap that can be recycled. Through its scrap supplier enterprise initiatives, the recycling centre has grown scrap purchases at a compound annual rate of 14.7% since 2015. Hulamin purchases a wide variety of aluminium scrap types and formats, including class scrap from can makers, UBCs, auto body sheet scrap, high-purity end-of-life wire, lithographic plates from the printing industry, and various customer buyback scrap (Hulamin, 2020).

#### 3.4.2.2 Closed-loop product design

Consumer goods are produced with varying aluminium alloys which cannot be completely used in secondary aluminium production for other sectors such as automotive or building sectors. This results in metal losses as these alloys cannot be brought back into the system. Ensuring that products are designed in a way they can be collected, sorted and recycled is essential to increasing recycling rates (World Aluminium, 2021).

Manufacturers could design closed-loop products which encourage easy disassembly, reuse and recycling. Closed-loop product design can enable the return of the metal back into the market to serve the same or similar purpose as the original product. Manufactures across the value chain need to work together to ensure their products are designed for circularity (Aluminium Federation of South Africa and CSIR, 2017). This could be enforced through regulations requiring manufacturers to design circular products.

In South Africa, Extended Producer Responsibility (EPR) schemes place the responsibility on manufacturers, importers and distributors to manage the end-of-life of the products they put out. For aluminium packaging, the EPR for packaging waste came into effect in May 2021. The Department of Forestry, Fisheries and Environment has tasked the industry's Producer Responsibility Organisation, MetPac-SA, to develop EPR plans as allowed by the regulations. The PRO was required to submit an EPR strategy by November 2021. The PRO is responsible for collecting levies to meet the recycling strategy targets. Under the EPR regulation, PRO and producers were required to register by November 2021. They must implement environmental labels for identified products by November 2024 and conduct life cycle assessments for identified products by November 2026. MetPac-SA has set product design with recycled content targets of 40% for aluminium UBCs by 2026. (MetPac-SA, 2021).

## 3.5 Using substitutes

Aluminium has multiple applications across numerous industries and, due to its properties, it is often the preferred metal. Aluminium can be substituted for materials that have similar characteristics; however, the extent of the substitutability depends on the end use, cost and design of aluminium products. From a climate change perspective, the substituting materials would need to be more sustainable than aluminium. While several materials have been proposed, materials exhibiting similar characteristics while contributing less to GHG emissions are scarce.

In the transport sector, aluminium is the preferred metal. It is preferred due to its lightweight, non-corrosive, thermal adaptability and durability characteristics. These characteristics have resulted in increased fuel efficiency, improved performance and safety in the sector. Materials such as magnesium, zinc and polymer composites could be explored as substitutes for aluminium in the automotive sector. Zinc alloys have greater strength resistance and allow for greater variation in section thicknesses while maintaining its tolerance. Zinc has a lower melting temperature and requires less pressures for casting than aluminium (Institution of Mechanical Engineering, 2020). Magnesium is another viable substitute for aluminium. Magnesium alloys are lighter than aluminium and provide better stiffness and energy absorption. Magnesium alloys are highly ductile and their super plasticity reduces overall manufacturing time, effort and costs. The trade-off with magnesium is that it can be difficult to work with and requires high temperatures for formability and has lower strength. Composites are an alternative material for aluminium bonnets, roofs and tailgates. They are highly corrosion resistant, have shape flexibility, and are dent and stone-chipping resistant (A*STAR, 2017).

The main barriers to these materials substitution are that their production is not significantly less harmful to the environment than aluminium. There would also be high costs associated with new manufacturing equipment required to widely introduce them. They are also not infinitely recyclable and would require new skills and equipment for repairs and servicing (A*STAR, 2017; Institution of Mechanical Engineering, 2020).

Substitutes for aluminium in aerospace and aviation would need to meet specific specifications and characteristics. Aluminium makes up 75%-80% of modern aircrafts. Carbon fibres are becoming a viable alternative candidate to aluminium in certain components. Carbon fibres are 30% lighter than aluminium, use less water and energy, allow for large sections of aircrafts to be made at once instead of having to join together lots of smaller aluminium panels, and are stronger than aluminium. The issues with carbon fibres is that they are expensive and are not as recyclable as aluminium (Dexcraft, 2015). Research is underway to develop a corrosive resistant titanium which could be a substitute for aluminium in the aerospace sector. This titanium would not be susceptible to stress, fatigue, inter-granular or galvanic corrosion. Yet, titanium's weigh poses a problem as it is heavier than aluminium. Its use and substitution would be for specific components only (Cottingham, 2019).

In the construction sector, stiff polymer composites and magnesium alloys could be viable substitutes for aluminium. Research and development is underway to design materials which could provide the same or similar characteristics to aluminium for applications in the construction sector (European Aluminium, n.d.).

In packaging, a variety of materials could have the potential to substitute aluminium in various uses. Most of the attention has been on beverage can replacements. Aluminium free pouches are beginning to replace traditional cans for drinks. These pouches can hold the same volume but take less space in storage and on the shelf. They also provide manufacturers with variety in design as they can be flat or stand-up pouches. Pouches are attractive to consumers due to their reusability as they are made with resalable caps and spouts. The issue is that these pouches are not infinitely recyclable and an assessment on consumer reuse rates has not been conducted (Elamin, 2017.) .

PET bottles could be another alternative to aluminium cans. PET bottles uses less energy and produce less GHG emissions than primary aluminium cans. Although PET bottles are fully recyclable, they are not infinitely recyclable and the long-term GHG emissions not materially better than that of aluminium cans, particularly closed-loop beverage cans (Reuters, 2019).

Aluminium foil is also widely used in households for cooking and baking. Alternatives to aluminium foil for household use include silicone baking sheets, parchment paper, cedar wax and beeswax.

Given the low reuse and recycling rates of aluminium foil, these materials could be viable substitutes (Reuters, 2019).

## 3.6 Climate change compatibility avenues – summary

This section, as summarised in Figure 15 (see page 25), outlined five avenues for a climate compatible aluminium value chain in South Africa. Only four could promote the climate change compatibility of the value chain: decarbonising the energy input; engineering improvements; disruptive technologies; and recycling. While substitutes would be useful in certain products, the extent to which they can contribute to the climate change compatibility of the South African aluminium value chain is marginal.

The first avenue would be to decarbonise the energy input by increasing utility scale renewable energy capacity or distributed renewable energy generation through the use of IPPs. Given the high contribution of indirect GHG emissions from coal-powered electricity, addressing indirect emissions is key to ensuring the climate compatibility of the value chain. The decarbonisation of the national power system would require an acceleration of renewable energy capacity, increasing battery storage while reducing the coal-powered generation capacity.

Across the value chain, electricity is sourced from Eskom. Hillside, the primary aluminium smelter, is entirely dependent on Eskom, sourcing 100% of its electricity requirements from the national utility. Hillside requires utility scale renewable energy and battery storage to reduce its GHG emissions. South32 has announced that it is looking at options for "greening" Hillside in partnership with Eskom, the government and other relevant stakeholders.

In the other parts of the value chain, electricity is used in conjunction with natural gas and liquid fuels in the production process. Electricity from Eskom accounts for 34%, 33% and 20% of the power mix for Hulamin, Wispeco and Zimco respectively. The secondary aluminium sector has indicated investigating distributed generation renewable energy, biomass, and gas-based electric generation as a means to decarbonise and to mitigate from their loadshedding risk.

Improving energy efficiencies for both primary and secondary aluminium production could contribute to the climate compatibility of the value chain. Reducing direct emissions from both primary and secondary production would require making engineering improvements or/and implementing disruptive technologies. The reduction in GHG emissions would depend on the technology or processes employed. In both primary and secondary aluminium production, combinations of various technologies and processes would yield the best results. In the short to medium term, engineering improvements and technologies would be the best options for reducing direct emissions. Most novel or disruptive technologies are not commercially available or cannot be retrofitted in a financially feasible way at present.

While recycling rates are already high for aluminium, more could be done to increase recycling, sorting and collection as well as creating closed-loop production. Increasing recycling would reduce GHG emissions by reducing the need to produce primary aluminium. Increasing collection would require increased convenient collection infrastructure and increased consumer awareness, as well as a close relationship between manufactures and recyclers.

Last, substituting aluminium with other materials or products would require that they satisfy the requirements as well as fit the characteristics of aluminium. Aluminium is a highly versatile metal. It is the most used non-ferrous metal worldwide. Its multiple properties (lightweight, non-corrosive, high thermal and electrical conductivity, low density, non-toxic, non-magnetic) mean that finding suitable materials to substitute aluminium is difficult. Not only do the materials need to fit the characteristics of aluminium but they also need to have lower carbon footprint than aluminium. In a variety of applications, that has not been possible as of yet.

# 4. THE FUTURE OF THE SOUTH AFRICAN ALUMINIUM VALUE CHAIN

Climate action is increasing and carbon-intensive industries now face pressure to change their business models to align with a low-carbon future. As discussed in Section 2 and Section 3, South Africa's aluminium value chain is highly energy intensive. The major source of carbon emissions across the value chain are from coal-powered electricity used in production. As it stands, the future of the South African aluminium value chain is uncertain. The value chain needs to address its high carbon intensity or risk losing competitiveness.

This section presents a possible future for the South African aluminium value chain. First, it considers two scenarios and possible outcomes. Second, potential pathways are outlined. Third, a way forward and the implications are presented and the policy recommendations are discussed.

## 4.1 Scenarios for the future of the aluminium value chain

**Table 2: Scenarios for the future of aluminium value chain**

| | BUSINESS AS USUAL | DECARBONISE THE VALUE CHAIN |
|---|---|---|
| **Description** | • The electricity input remains primarily sourced from coal-powered electricity and liquid fuels for the foreseeable future.<br>• The national energy mix continues to decarbonise at the gradual pace experienced to date<br>• Energy and carbon efficiency technologies/processes are implemented at the same pace as previously. | • Material acceleration of the decarbonisation of the electricity input across the value chain.<br>• Material acceleration of the implementation of energy efficiency engineering improvements.<br>• Introducing novel disruptive technologies in the medium to long term. |
| **Outcome** | Short to medium term:<br>• Climate change policies reduce margins.<br>• Increased competition from low-carbon aluminium. | Short to medium term:<br>• Maintaining current market access<br>• Reducing value chain GHG emissions<br>• Lower exposure to carbon taxes and border taxes |
| | Medium to long-term:<br>• Further decline in margin due to carbon taxes and border taxes.<br>• Loss of international competitiveness.<br>• Loss of customers to "green" supply chains.<br>• Eventual mothballing of parts or entire value chain. | Long run:<br>• Increased market access.<br>• Gaining market share for low-carbon aluminium.<br>• A low-carbon value chain. |

*Source:* Authors.

### 4.1.1 Business as usual

As illustrated in Table 2 in this scenario, the current energy mix would shift, and production processes and technologies implemented at the existing pace. In the long run, this scenario would be catastrophic for South Africa and the aluminium value chain. As the global economy accelerates its shift towards a low-carbon trajectory, the highly carbon intensive value chains will face significant risks. Countries and companies are implementing stricter climate change policies and regulations. The European Union (EU), South Africa's largest aluminium export destination, accounting for 34% of aluminium exports in 2021, will implement a Carbon Border Adjustment Mechanism (CBAM). The

CBAM will impose a tax on direct and indirect embedded emissions in aluminium products imported into the EU. The CBAM will impact the value chain's competitiveness and erode profit margins (European Commission, 2021; Trade Map, 2022). Other jurisdictions, such as the United Kingdom, the United States and Canada, also plan to implement their own carbon border taxes (Brauch et al., 2021).

Demand for low-carbon aluminium is increasing, driven largely by shifting consumer preferences and shareholders who want greener supply chains. Automotive OEMs like Audi and BMW are sourcing low-carbon aluminium in attempts to green their supply chains. Electronic and tech companies, such as Apple, Tesla and LG, are also increasing the low-carbon aluminium content in their product ranges (Frangoul, 2021; Home, 2020).

Major aluminium producers are planning to increase production of low-carbon aluminium and several have set net-zero 2050 targets. Alcoa, Natur-AL, Hydro, Emirates Global Aluminium, Rio Tinto and RUSAL have led the charge in reducing their GHG emissions. These companies are producing aluminium from renewable energy and are taking steps to reduce direct emissions. Their customers are already paying premium prices for green aluminium[35] (Healy, 2021). A market for green aluminium' is forming. Many producers of green aluminium have begun rebranding and differentiating their low-carbon products from carbon intensive products (Reuters, 2020).

This scenario outlines a possible future if the decarbonisation of the grid and distributed renewable energy are not implemented fast enough. The planned energy efficiency improvements are stalled or are not implemented. In this scenario, South African aluminium would lose market access and international competitiveness overtime. Primary aluminium producer Hillside would be significantly at risk in the long run as it is 100% reliant on grid-based electricity. Downstream players, such as Hulamin, are reliant on primary aluminium from Hillside. This scenario would eventually lead to the primary aluminium smelter shutting down and/or the decline of the entire value chain. Downstream players would only survive on scrap inputs and imported low-carbon primary aluminium.

The implications for South Africa's economy and industrial development would be significant. Aluminium contributes 0.6% to GDP. It accounts for 2% of total exports and employs 11 600 people directly and 28 900 indirectly. Primary and secondary aluminium producers have strong linkages with the automotive, construction and packaging sectors. Aluminium also makes up a significant proportion of the waste management sector as it is one of the most recycled metals in the country. As global efforts to achieve carbon neutrality by 2050 intensify, it is increasingly evident that, in its current state, the South African aluminium value chain would not survive beyond 2050 (if not earlier).

### 4.1.2 Decarbonising the value chain

This scenario presents the future of the value chain if decarbonisation efforts are accelerated. As illustrated in Table 2, decarbonising the value chain would primarily rely on: decarbonising the electricity input and introducing technological improvements.[36] Section 3 provided the broad range of avenues available to ensure the climate compatibility the South African value chain.

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[35] Aluminium that is considered "green" primarily due to its production power source.

[36] While increasing recycling rates is important to the climate change compatibility of the value chain, aluminium recycling rates are already high and closed-loop production is being pursued by industry players. Improvements to recycling rates should be made, however, they will not materially change the climate compatibility of the value chain. Opportunities to increase recycling and to reduce direct emissions should still be taken across the value chain. Furthermore, while aluminium could, in theory, be substituted for materials that have similar characteristics, the extent of substitution would depend on the requirements of the various products. To be suitable

From these avenues, two pathways emerge for the value chain. Table 3 outlines the two pathways to decarbonising the value chain. The pathways shown present varying levels of GHG emissions reduction capacity and have different implementation timelines. An ideal approach would be one where both pathways are pursued simultaneously to ensure the highest emissions reductions.

**Table 3: Pathways for the climate compatibility of the South African aluminium value chain**

| PATHWAY | DESCRIPTION AND EXAMPLES | EXAMPLES | EMISSIONS REDUCTION CAPACITY | TIMELINES |
|---|---|---|---|---|
| **Technology** | Engineering improvements implementable in the short to medium term reduce direct emissions of existing production methods. | • APX3 energy efficiency and Enpot energy modulation technology in primary production.<br>• Heat recovery and furnace redesign in secondary production. | Medium | Short to medium term |
| | Novel/disruptive technologies implementable in the long term, which change existing production methods to reduce direct emissions. | • Inert anodes and wetted cathodes in primary production.<br>• Spark Plasma Sintering technology and XRT sensor in secondary production. | Medium to high | Long term |
| **Electricity** | Decarbonisation of energy inputs by increasing access to clean, reliable affordable electrical energy | • Accelerating utility scale renewable energy generation capacity at Eskom.<br>• Accelerating large-scale renewable energy-based distributed generation (through IPPs).<br>• A combination of both<br>• Implementing utility-scale energy storage. | High | Medium to long term |

### 4.1.3 Technology

South African aluminium producers are not involved in technological development and rely on the technology available in the market. The existing technologies in the market are either engineering improvements or disruptive technologies, which are expensive and have not reached commercial viability.

According to South32, Hillside is a technically efficient plant. Hillside's carbon intensity for direct emissions is 1.9 $tCO_2e$/t aluminium which is significantly lower than the global average of 8.5$tCO_2$-e/t aluminium. Direct emissions only account for 12% of total emissions. South32 is planning to further increase the efficiency of Hillside, by implementing the APEX3 energy efficiency technology and Enpot energy modulation technology, scheduled for 2026 (South32, 2021, p. 32). While these

alternatives from a climate change perspective, they would be required to be low carbon. In practice, alternatives are very limited.

improvements will reduce direct emissions, in relation to total carbon footprint, the gains from these improvements will be marginal.

Given Hillside's energy source and energy requirements, the proposed technologies will assist in modulating and reducing energy use. The Enpot energy technology could also be beneficial with the use of renewable energy as it allows the smelter to modulate its energy use up to 30% downwards or upwards. The technology can turn the smelter into a virtual battery which would further assist in stabilising the national grid (BUSA, 2012).

Disruptive technologies, such as inert anodes, wetted cathodes and carbothermic reduction, have not yet reached commercial viability. Rio Tinto, Alcoa, RUSAL and Arctus Aluminium are making progress in the development of inert anode technology. However, the technology demonstration is only planned for 2024, after which industrial applicability would need to be proven. Wetted cathodes and carbothermic reductions are still in research and development stages. Engineering issues around identifying appropriate materials and industrial methods have not yet been resolved (UN CTCN, 2020). In addition, the technologies require retrofitting and redesigning smelters. They are also protected by proprietary rights. Hillside would require licensing to access the technologies.

In secondary production, engineering improvements and disruptive technologies range from rearranging the order of scrap samples in furnaces to installing heat recovery mechanisms and XRT sorting technologies. Engineering improvements are short-term changes to production processes which can increase metal yields and improve energy efficiency. However, they do not address the majority of GHG emissions[37] in secondary production. The projects planned by Hulamin, Zimco and Wispeco will contribute to GHG emissions reductions; however, compared to indirect emissions, the gains will be marginal.[38] Disruptive technologies, such as SPS and XRT sorting, are costly and are not being pursued by industry players at present.

The technology pathway presents an opportunity to further reduce the carbon footprint of the value chain. However, if followed on its own, it would not secure the survival of the value chain. It should be pursued along with the electricity pathway.

### 4.1.4 Electricity

From the literature and the stakeholder interviews, one pathway emerges which can ensure the climate compatibility of the South African value chain in a carbon constrained future. Section 2 and Section 3 show that the majority of GHG emissions across the value chain are from coal-powered electricity. Indeed, the technology pathway would improve efficiencies and reduce GHG emissions, however, given the technical efficiency of aluminium producers, these improvements would be marginal. This section outlines the electricity-related decarbonisation options for primary and secondary aluminium producers and presents the implications of decarbonising the electricity input across the value chain.

### 4.1.5 Primary aluminium

As illustrated in Box 1, the premise under which the primary aluminium production was introduced in South Africa, i.e. access to cheap surplus electricity, no longer holds. Over the last decade, electricity has become significantly more expensive, the national grid is experiencing a +6 000MW generation capacity shortage and loadshedding has increased since 2007.

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[37] The majority of GHG emissions in secondary aluminium are from electricity use and primary aluminium metal supply.

[38] Interviews with Hulamin, Wispeco and Zimco.

Hillside urgently needs to decarbonise. The smelter is facing internal pressure to reduce emissions as it contributes 55% of South32 group's GHG emissions, mostly due to coal-powered electricity from Eskom. South32 has set a GHG emissions target of a 50% reduction in operational GHG emissions (Scope 1 and Scope 2) by 2035 compared to the 2021 baseline. South32 has announced that it is looking to secure low-carbon electricity for Hillside. The initial outcome of the scoping exercise suggest that renewable energy would be technically feasible. The group is engaging with the South African government, Eskom and other potential partners to identify options for renewable energy infrastructure. According to South32, Hillside could be an offtake partner to support third-party investment in renewable energy infrastructure.

Besides internal South32 group dynamics, Hillside is, in any event, under external pressure to reduce emissions. Changes in climate policies, shifting consumer preferences, and changes in carbon pricing and regulation will erode the profitability of the smelter and could lead to it being unsustainable.

If South32 is unable to secure affordable low-carbon electricity, Hillside would become uncompetitive. Accordingly, South32 has started (just) transition planning in case of closure.

Decarbonising Hillside's electricity input could be achieved through the three approaches discussed below.

## Decarbonisation Eskom's grid

This approach would require accelerating new renewable energy generation and storage capacity builds. In the IRP 2019, government commits to increasing renewable energy generation from 6% in 2019/20 to 41% in 2030. Eskom aspires to build large-scale renewable energy aligned with the IRP. In addition to building renewable energy and battery storage capacity, Eskom would also need to upgrade its transmission and distribution network.

As such, renewable energy and battery storage build needs to be undertaken at a (much) faster pace than is currently being built. South Africa requires about 4GW of renewable energy per year over the next 30 years to reach net-zero by 2050. The National Planning Commission (NPC) recommended that an energy emergency be declared to override the red tape preventing the construction of new electricity capacity. The NPC is proposing that 10 000MW of new generation and 5 000 MW of storage could be built in two years.

To accelerate the pace, a myriad of issues would need to be overcome. Eskom would need to address its current generation capacity supply shortage while decommissioning old coal-fired power plants. The utility's R400 billion debt would need to be serviced and reduced accordingly. Investments in the transmission and distribution network would be required to enable utility-scale renewable energy, all the while the ongoing unbundling of the transmission, generation, and distribution divisions unfolds.

Hillside is under internal and external pressure to decarbonise by 2035. While South Africa is already on a decarbonisation path, the concern is that the renewable energy cannot be earmarked for Hillside and that the Eskom's glide path may not be fast enough to ensure Hillside is decarbonised by 2035.

Table 4 shows the socio-economic implications of a pathway based on decarbonising the national electricity grid.

**Table 4: Socio-economic implications for decarbonising the national electricity input**

| STAKEHOLDER | IMPLEMENTATION REQUIREMENTS | ESTIMATED COSTS | ESTIMATED BENEFITS |
|---|---|---|---|
| Hillside | Support the acceleration of renewable electricity-based generation in the national grid. | If the decarbonisation of the grid is not fast enough, progressive loss of competitiveness, leading to closure of the smelter. | If the decarbonisation of the grid is rapid enough:<br>- Renewable energy-based electricity for production processes.<br>- Reduction in indirect GHG emissions and lower carbon intensity of aluminium products.<br>- Increased business resilience and improved competiveness.<br>- Reduction in vulnerability to climate change and potential losses due to climate policies. |
| Eskom | Accelerate new renewable energy-based electricity generation capacity and battery storage builds.<br>Invest in the upgrade of the distribution and transmission infrastructure to support renewable energy.<br>Adhere to the coal-powered plants decommissioning plan to reduce coal's contribution to national power mix<br>Conclude discussions on BESS to secure long duration battery storage. | Investment and associated costs of increasing renewable energy-based generation capacity and battery storage.<br>Costs associated with decommissioning aging coal fleet.<br>The investment and associated costs of transmission and distribution infrastructure upgrades.<br>The investment and associated costs of increased storage capacity. | Maintain Hillside as a customer if decarbonisation is fast enough.<br>Reductions in electricity generation, GHG emissions and lower power sector carbon intensity.<br>Long-term sustainability of national grid. |
| Government | Formulate and implement legislation that incentivises an accelerated decarbonisation of national grid<br>Introduce support measures to accelerate the national grid's decarbonisation. | The costs associated with implementing support measures for decarbonising Eskom.<br>The costs and implication of changing the regulatory and legislative framework to facilitate fast adaptation of grid-tied renewable energy. | Reduced national GHG emissions and a lower national carbon intensity.<br>Reduced national vulnerability to climate change and climate change policies.<br>Increased long-term domestic industry competiveness due to low carbon intensity, including Hillside. |

| | | | |
|---|---|---|---|
| Workers and communities | n/a | Aluminium value chain: loss of jobs and livelihood (unless decarbonisation is fast enough)<br>Rest of society: heightened and fastened requirements for just transition in coal value chain. | Aluminium value chain: long-term sustainability if industry can survive decarbonise period<br>Rest of society: increased competitiveness and sustainability of economy, including reduced vulnerability. |

## Hillside procuring renewable energy independently

Hillside has a power demand of 1205MW at a base load factor of 99%, meaning it requires a large amount of power all the time. Due to the variable nature of renewable energy, to run Hillside on renewable energy alone the smelter would need 5 000MW of solar and/or wind and storage capacity. Hillside would have to procure the required renewable energy and storage through several long-term PPAs. This would require significant investment in generation and storage capacity. The business case for such a large investment would need to be financially feasible and attractive for South32.

According to energy expert Clyde Mallison, Hillside could secure solar and wind energy at a factory gate price of R0.03/kWh by 2030. This would enable a zero Scope 2 emissions smelter by 2030. Hillside could purchase the renewable energy and storage from IPPs. Since Hillside would not be in a position to build the required renewable energy generation capacity on or near the plant, the electricity would have to be wheeled to the plant. For this, it would need to use the distribution and transmission network of Eskom as well as relevant municipalities.

The capital required could be raised by issuing a dollar denominated PPA through an IPP, thereby attracting dollar-based financing and more attractive interest rates.

Hillside could take the following approach to securing renewable energy by 2030:[39]

- Block stages: Hillside could procure all the renewable energy and storage they require in four block stages, procuring up to 1 000MW per stage. The smelter could also access up to 2GW of pumped storage over an eight-year period. This approach would be challenging as raising investment funding and the procurement process would need to be done fairly rapidly for the first stages.
- Exponential stages: Hillside could procure renewable energy in an exponential manner, procuring low amount of generation capacity at the beginning (2MW-10MW) and ramping up to purchase more towards the end. This approach would help the group capitalise on the falling prices of renewable energy and battery storage while easing its way off the national grid.

South32 announced in July 2022 that it had partnered with Solana Energy to build solar power infrastructure in the Richards Bay and King Cetshwayo District economic regions. The project is expected to add 2MW and 2.5MW of renewable energy capacity to the local grid within 12 months. The project will help the businesses that supply Hillside access solar-based electricity. Hillside could leverage this partnership to generate renewable energy for its own operations.

Table 5 shows the socio-economic implications of Hillside procuring electricity independently.

[39] Interview with Clyde Mallison.

**Table 5: Socio-economic implications of Hillside procuring electricity independently**

| STAKEHOLDER | IMPLEMENTATION REQUIREMENTS | ESTIMATED COSTS | ESTIMATED BENEFITS |
|---|---|---|---|
| **Hillside** | Conclude the feasibility study on renewable energy and energy storage capacity requirements.<br>Invite IPPs to participate in quotation process.<br>Procure renewable energy generation capacity and battery storage from IPPs.<br>Engaging with Eskom and relevant municipalities for a suitable wheeling agreement and tariff rate. | The operational costs of procuring distributed renewable energy and energy storage capacity through IPPs. | Renewable energy for production processes<br>Reduction in indirect GHG emissions and lower carbon intensity of aluminium products.<br>Reduction in vulnerability to climate change and potential losses due to climate policies<br>Increased business resilience and improved competiveness. |
| **Eskom** | Formulate and implement changes to wheeling legislation to facilitate wheeling of large-scale distributed renewable energy generation.<br>Upgrading distribution and transmission network to facilitate use of network by large renewable energy providers. | The (progressive) loss of a key industrial customers and the revenues generated.<br>The (progressive) loss of the flexibility to interrupt supply to Hillside to manage capacity during loadshedding.<br>The investment and associated costs of upgrading the distribution and transmission network. | No real benefits, besides the (short-term) reduced pressure on the grid and some additional space on the transmission grid. |
| **Government** | Ease the regulatory and legislative process to allow for large-scale renewable energy wheeling through Eskom's network (and if needed municipal grids). | The costs and implication of changing regulatory and legislative framework to facilitate large-scale wheeling through Eskom network to large industrial consumers. | Reduced national GHG emissions and a lower national carbon intensity.<br>Reduced national vulnerability to climate change and policies.<br>Survival of a key domestic industrial player. |
| Workers and communities | n/a | Aluminium value chain: none, unless decarbonisation is not fast enough.<br>Rest of society: none, unless it leads to further instability of supply and higher electricity pricing for other customers. | Aluminium value chain: long-term sustainability of employment and livelihood.<br>Rest of society: none. |

## Hillside and Eskom public-private partnership

Hillside and Eskom could use their long-standing commercial relationship to establish (PP to secure renewable energy and storage options for Hillside. This relationship would be mutually beneficial since Eskom would retain its largest industrial customer and Hillside would secure much-needed low-carbon energy. South32 has stated that it wants to engage with Eskom to secure low-carbon electricity supply for Hillside. This approach could be the most suitable approach for South32 secure low-carbon options for Hillside.[40] This approach would require amendments to and/or a new NPA contract between Hillside and Eskom.

The partnership could entail repurposing old Eskom power stations to generate renewable energy for Hillside. Large short-duration energy storage facilities would need to be used to supplement the renewable energy. When extra capacity is available, it could charge the battery storage for use during low capacity periods.

The De Hoop dam Tubatse hydro-battery project, in Limpopo (some 650 km away from Hillside), could enable Hillside's use of renewable energy sources from 2030 to beyond 2050. The project has been stalled for several years due to financial constraints. Tubatse's capacity and capital requirements would make it ideal for Eskom and Hillside. The hydro-battery project has been suggested by energy experts as a PPP which could provide 12 000MWh of battery storage for Eskom and Hillside. The project would be accompanied by 1 000MW of solar PV and wind-based electricity generation, which would be wheeled over Eskom's grid to power Hillside, and an additional 1 000MW of solar PV and wind to recharge the battery. This project would need Eskom and South32 to leverage their long-term commercial relationship and mutual interest in the survival of the smelter (Creamer, 2022b). The hydro-battery project could also assist in stabilising the growing fleet of wind and solar energy. The Tubatse hydro-battery project should be accompanied with other options such as battery storage and other large short duration storage facilities.

In addition, South32 is investigating implementing the EnPot energy modulation technology. EnPot gives smelters the ability to turn their energy consumption up or down by as much as 30%. Smelters can then better match energy supply with demand, enabling them to more efficiently use renewable energy sources. It allows energy-intensive smelters to modulate energy use on demand at a much lower cost (Djukanovic, 2017; EnPot, 2019). Enpot could enable the PPP as Hillside's energy demand could be managed with greater margins.

To secure renewable energy for Hillside by 2035, the partnership would require the following:

- The timely formulation and implementation of a PPP agreement between Eskom and Hillside, with the appropriate risk sharing between both parties;
- Since the PPP would occur under duration of the current NPA, a new NPA would have to be negotiated and approved which incorporates the PPP;
- The relevant financial and support measures from both Hillside and Eskom; and
- The appropriate regulatory and legislate framework to enable such a PPP.

Table 6 shows the socio-economic implications of a Hillside-Eskom PPP.

[40] Interview with South32.

Table 6: Socio-economic implications of a Hillside-Eskom PPP

| STAKEHOLDER | IMPLEMENTATION REQUIREMENTS | ESTIMATED COSTS | ESTIMATED BENEFITS |
|---|---|---|---|
| **Hillside** | Engage with Eskom and government to establish a PPP to secure low-carbon solutions.<br>Leverage the industrial relationship with Eskom to facilitate a PPP.<br>Renegotiate a new contract with Eskom to accommodate PPP<br>Invest in renewable energy generation capacity and battery storage through a PPP with Eskom. | Investment and associated costs in renewable energy and energy storage through a PPP with Eskom. | Low-carbon electricity for production processes<br>Reduction in indirect GHG emissions and lower carbon intensity of aluminium products.<br>Reduction in vulnerability to climate change and potential losses due to climate change policies<br>Increased business resilience and improved competiveness. |
| **Eskom** | Engage with Hillside and government to establish a PPP to secure low-carbon solutions.<br>Renegotiate a new contract with Eskom to accommodate PPP.<br>Secure funding and invest in large renewable energy generation capacity and battery storage for PPP. | Investment and associated cost of renewable energy generation and storage for PPP.<br>Investment and associated costs of upgrading distribution and transmission network to facilitate PPP. | Reduction in Eskom's GHG emissions and lower power sector carbon intensity .<br>Retaining Hillside as largest industrial customer. |
| **Government** | Ease the regulatory and legislative process to facilitate PPP with Eskom and Hillside. | Costs associated to implement support measures for decarbonising Eskom.<br>Associated costs and implication of easing regulatory and legislative framework to facilitate PPP between Eskom and Hillside. | Reduction in national GHG emissions<br>Reduced national vulnerability to climate change and climate change policies.<br>Retaining primary aluminium smelting as an economic activity. |
| **Workers and communities** | n/a | Aluminium value chain: none, unless project is unsuccessful and/or decarbonisation is not fast enough.<br>Rest of society: none, unless it leads to further instability of supply and higher pricing of electricity for other customers. | Aluminium value chain: long-term sustainability of employment and livelihood.<br>Rest of society: none. |

While the financial implications of such a partnership are unknown, it would require significant investment financing. Given Eskom's financial health and debt crisis, it would be challenging for the utility to generate the funds to participate in the PPP. The financial implications of the PPP would also need to be financially feasible for South32. The time constraints required to secure low-carbon energy for Hillside mean that any delays in establishing the PPP and implementing the low-carbon energy options could delay the South32 group achieving its emissions reduction targets.

## 4.2 Secondary aluminium and downstream sectors

Secondary aluminium producers and semi-fabricators are not as reliant on Eskom's grid for production as Hillside. Natural gas and liquid fuels are the primary sources of energy for their production processes. The increase (to 100MW) and (upcoming removal) of the licence-exemption cap should enable secondary aluminium industry players to procure their required electricity supply through IPPs. Already, the key players in the secondary aluminium sector are investigating options to decarbonise their electricity supply through IPPs or special purchasing agreements with their local municipalities.

- Hulamin has set plans in motion to procure solar- and wind-powered electricity. It is working with the Msunduzi Municipality to get a municipal agreement to get a PPA for renewable energy. Hulamin is also engaging with the municipality, forestry companies and saw mills to use their biomass for electricity generation.
- Wispeco is engaging with an IPP to provide its plant with renewable energy.
- Zimalco indicated they will pursue renewable energy generation when the company's financial outlook improves.

**Table 7: Socio-economic implications for secondary aluminium and downstream producers procuring distributed generation**

| STAKEHOLDERS | IMPLEMENTATION REQUIREMENTS | ESTIMATED COSTS | ESTIMATED BENEFITS |
|---|---|---|---|
| **Industry players** | Conclude feasibility studies on renewable energy demand for facilities.<br>Conclude engagements with local municipalities to get municipal agreements for PPAs in procuring renewable energy and battery storage through IPPs.<br>Include climate change risk into business planning and operations to develop a financial model which supports the renewable energy tariff rates. | Costs associated with renewable energy and battery storage procurement process.<br>Costs associated with plant upgrades to facilitate use of renewable energy and battery storage. | Renewable energy for production processes<br>Reduction in indirect GHG emissions and lower carbon intensity of aluminium products.<br>Reduction in vulnerability to climate change and potential losses due to climate change policies<br>Increased business resilience and improved competiveness. |
| **Municipalities** | Formulate and implement regulatory and legislative framework which enables distributed | Costs and implications of changes to regulatory and legislative framework to facilitate uptake of | Reduced GHG emissions and lower municipal carbon intensity.<br>Municipality attracting/ retaining industries which |

| | | | |
|---|---|---|---|
| | generation capacity for industrial players. Engage with and conclude agreements between industry and IPPs. | renewable energy by industrial consumers. | require low-carbon electricity. |
| **Government** | Ease the regulatory and legislative process to enable distributed generation for large industrial use. Introduce support measures enabling distributed generation for large industrial use. | Associated costs and implication of easing regulatory and legislative framework to facilitate distributed generation for large industrial use. The costs associated to implement support measures for distributed generation for large industrial use. | Reduced national GHG emissions and a lower national carbon intensity. Reduced national vulnerability to climate change and climate change policies. |
| **Workers and communities** | n/a | Aluminium value chain: none, unless project is unsuccessful and/or decarbonisation is not fast enough. Rest of society: none, unless it leads to further instability of supply and higher pricing of electricity for other customers. | Aluminium value chain: long-term sustainability of employment and livelihood. Rest of society: none. |

## 4.3 The future of the South African aluminium value chain – summary

The future of the South African aluminium value chain is uncertain. Based on the literature and stakeholder engagement, this section presents future scenarios and pathways for the South African aluminium value chain.

### Scenario one: business as usual

In this scenario, the shift in energy generation and production/technologies methods continues to be implemented at the current gradual pace. This scenario paints a picture of the future of the value chain if decarbonisation of the energy input and efficiency technologies are not implemented fast enough. This scenario is not viable for the aluminium value chain. In the long run, it would lead to either parts of, or the whole value chain, shutting down. As the global economy shifts towards a low-carbon trajectory, highly carbon intensive value chains will face significant risks and loose competitiveness.

## Scenario two: decarbonise the value chain

Decarbonising the value chain entails decarbonising the electricity input and reducing direct emissions. From the avenues highlighted in Section 3, two pathways emerge for the aluminium value chain. Decarbonising electricity and implementing technologies to reduce direct GHG emissions.

Decarbonising electricity would require accelerating utility-scale and distributed renewable energy generation, transforming the distribution and transmission networks, and deploying large-scale energy storage facilities. Direct GHG emissions could be reduced through engineering improvements and disruptive technologies. Increasing recycling would require creating closed loop production and improving collection rates.

The electricity input pathway would have different implications for different stages of the value chain. Primary aluminium producer Hillside is dependent on electricity from Eskom. "Greening" Hillside would require utility-scale renewable energy and battery storage. Hillside could take three approaches to decarbonising electricity.

- The first option is to decarbonise the Eskom grid. This would mean accelerating Eskom's decarbonisation plan. The key concern is that the glide path would not be fast enough for South32's decarbonisation targets. South32 aims to reduce 50% of its group emissions by 2035. Hillside currently accounts for 58% of the group's total GHG emissions. Another concern is that Eskom cannot earmark renewable energy for Hillside. Lastly, the renewable energy tariff rates might not be financially feasible for Hillside. While the current tariff under the new pricing contract is publicly unknown, the special pricing contract has historically led to the smelter paying lower than Megaflex rates.
- Second, Hillside could procure electricity independently through IPPs. This would require up to 5 000MW of renewable energy and large-scale battery storage. The smelter could procure the renewable energy in two ways. Block stages, where it procures renewable energy in blocks, or exponentially, where it procures a little at the beginning and more towards the end. The exponential approach would be more suitable as the smelter could take advantage of the declining prices of solar PV, wind energy and battery storage. However, the scale of the generation capacity to be procured makes it difficult. In addition, this would lead to Eskom losing Hillside as an anchor customer.
- Third, South32 could enter into a PPP with Eskom to procure renewable energy and battery capacity for Hillside. A new PPA could be introduced which would require leveraging the long commercial relationship between Eskom and Hillside. This approach could be the most suitable approach for South32 and Eskom to secure low-carbon power for Hillside. This approach would require amendments to and/or a new NPA contract between Hillside and Eskom and could, for instance, be implemented through the Tubaste hydropower-battery project.

Secondary producers, Hulamin, Wispeco and Zimco Metals, could decarbonise their electricity inputs through distributed energy from IPPs. These companies are already investigating solar PV and wind energy as well as biomass as low-carbon alternatives to the grid.

In terms of R&D, the local value chain players are not involved in technology development. They have to use the technology that exists in the market. The current disruptive or novel technologies, such as inert anodes, are not commercially available. While engineering improvements do improve direct production efficiencies, the gains are marginal compared to decarbonising electricity.

Along the value chain, every opportunity to reduce both direct and indirect emissions should nevertheless be taken. The primary source of carbon intensity in the South African aluminium value chain is electricity. Moving forward, decarbonising electricity inputs should be a primary focus for all stakeholders in the value chain. The future of aluminium is riddled with risks from carbon border taxes, increased climate regulation, and customers who want to "green" their supply chains.

# 5. CONCLUSION

The recent extreme weather events across the world have once more shown the impact of climate change. The numerous flooding events across the United States and South Africa, the heatwaves across Europe and California, and the severe droughts in Ethiopia are early warning signs of what could be expected if climate change is not addressed.

As climate change action intensifies, carbon-intensive industries, like aluminium, will need to rethink their business models and align them with a low-carbon future. Many countries and companies are already on a path towards a low-carbon future. Climate change policies, such as carbon prices, carbon border taxes, supply chain greening strategies, and circularity approaches, are being implemented. These policies will place lagging carbon intensive industries at risk if they do not decarbonise.

The research in this report shows that South Africa's aluminium value chain is highly carbon intensive. This is primarily due to the coal-powered electricity input. Across the value chain, the major source of carbon intensity is indirect emissions from electricity. Addressing the electricity input is key to ensuring the climate compatibility of the value chain.

In Section 3, the broad range of avenues for the value chain were presented. Section 4 presented the possible future of the value chain and its implications. From this section, two pathways emerge to decarbonise the value chain. [41] The first is the technology pathway in which engineering improvements and disruptive technologies would contribute towards reducing direct emissions. While this pathway would benefit the value chain, it would not address the primary issue from a climate compatibility perspective.

The energy pathway would be the most promising avenue for a climate-compatible aluminium value chain. It would entail decarbonising the electricity input across the value chain. In primary aluminium production, this pathway would require utility-scale renewable energy capacity and battery storage. Hillside is highly dependent on electricity from Eskom. Electricity accounts for 88% of its total GHG emissions. Decarbonising the electricity input for primary aluminium production is important as Hillside is facing both internal and external pressure to decarbonise. Without intervention into sourcing low-carbon electricity, the Hillside smelter would become uncompetitive and eventually shut down.

Decarbonising electricity for Hillside could be done through three approaches: 1) decarbonising the national grid; 2) Hillside procuring renewable energy independently through IPPs; and 3) a low-carbon electricity generation partnership with Eskom. The partnership approach would be the most suitable as it would be mutually beneficial to both Hillside and Eskom. Eskom and Hillside could work together to secure renewable energy for Hillside.

The climate compatibility of the aluminium value chain would require significant climate mitigation measures (and, although not the focus of this report, important adaptation measures as well, particularly due to the coastal location of large parts of the value chain). These would include improving energy efficiency, the use of renewable energy, and improving direct carbon intensity. To achieve this, all stakeholders in the value chain should prioritise GHG reduction measures.

[41] The substitution and recycling avenues were not presented as pathways. Substituting aluminium for other materials would require that the materials satisfy the requirements for the various products and be low carbon. Besides niche applications, no serious alternative exists at present. Recycling rates for aluminium are already high. While the impact of these avenues would be marginal in the South African context, where applicable, these avenues should still be pursued.

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