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Green hydrogen for sustainable (re)industrialisation in South Africa: Industrial policy for hard-to-abate industries and linkages development

Antonio Andreoni, Jason F. Bell and Simon Roberts

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About the authors

Antonio Andreoni is a Professor in the Department of Economics, SOAS University of London and South African Research Chair in Industrial Development, University of Johannesburg.

Jason F. Bell is a Researcher for the Centre for Competition, Regulation and Economic Development (CCRED) at the University of Johannesburg.

Simon Roberts is a Lead Researcher for the Centre for Competition, Regulation and Economic Development (CCRED) and a Professor in Economics at the University of Johannesburg.

CCRED: Centre for Competition, Regulation and Economic Development
69 Kingsway Ave,
Auckland Park,
Johannesburg, 2092
E-mail: infoccred@uj.ac.za | www.competition.org.za
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Department: Trade, Industry and Competition
REPUBLIC OF SOUTH AFRICA

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Abstract

Climate change is now acknowledged to require far-reaching changes within and across countries to reduce emissions and their socio-economic-ecological impact. South Africa has to rapidly pivot to a lower carbon trajectory to retain access to export markets where environmental regulations such as the ones imposed by the EU are rapidly closing market access. At the same time, the transition is an opportunity for sustainable re-industrialisation given South Africa's advantages in renewable energy. The question is how will the transition happen? Will the change be part of building local linkages to ensure capabilities in inputs for renewable energy and linkages to a diversified green industrial base, or will it be in export-oriented enclaves aimed at greening European industry? This paper focuses on the possibilities for Green Hydrogen (GH2) in hard-to-abate heavy industries and the potential for the changes to catalyse the re-industrialisation of the South African economy. Specifically, we examine the key industrial policy questions South Africa needs to confront in decarbonising and restructuring its worst industrial emitters – i.e., steel, cement, and chemicals – at the heart of the South African economy. The paper analyses specific opportunities in different sectoral value chains and finds a strong case for rapid transformations in steel and fertilizer. Realising these opportunities requires an integrated industrial and energy strategy and cross-government commitment to its realisation. The persistence of gaps between energy and industry means that enclave initiatives will result and linkages to the broader economy will not be realised.

Keywords: Climate Change; Green Hydrogen; Sustainable Re-industrialisation; Chemicals; Steel; Cement; South Africa

JEL codes: O14, Q56, L52, L61, L65,

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1. Introduction

Climate change is now acknowledged to require extensive and far-reaching changes within and across countries to reduce emissions and their socio-economic-ecological impact. The long-term impacts of climate change will exacerbate already large and pervasive inequalities between and within countries in the Global North and Global South (Generation Climate Europe, 2022). Among other structural dimensions, these inequalities reflect the structure of economic activity, including industrial production and trade, that has continued to favour carbon-emitting industries and sectors.

How countries address these issues will have implications over the coming decades, including the industry and energy policies central to our concerns in this paper. Contrary to other sub-Saharan African countries, many of South Africa's key industries (from a linkages standpoint) act as suppliers of direct and indirect inputs into more advanced production processes in countries primarily located in the Global North. Many of these countries, especially within the European Union, are producing policy frameworks, interventions, and taxonomies to address their respective greenhouse gas emissions. Given the emission-intensity of its industry, South Africa faces significant and far-reaching implications from changes in demand for its industrial exports as more countries adopt similar climate mitigation approaches along the lines detailed in the European Green Deal (EGD) (Bell, et al., 2022).

Considering these risks, Green Hydrogen (GH2) is a viable route for large-scale decarbonisation of many of the world's most energy-intensive sectors (Kovač, et al., 2021). Hydrogen can be generated from both fossil fuels and renewable energy sources. It is known as "grey" hydrogen (when from natural gas) hydrogen.[1] "Green hydrogen" (GH2) is produced sustainably via water electrolysis using renewable or zero-carbon emission electricity sources, such as solar and wind. Once created through liquefaction, hydrogen can be transported and stored for a long time; however, these processes, from isolation up to transportation, are still relatively expensive and prone to leaks which are both dangerous (given hydrogen's high flammability) and negative for climate change.

This paper explores the possibilities for GH2 as a crucial catalyst for the re-industrialisation of the South African economy, focusing on three key hard-to-abate sectors – i.e. cement, steel and chemicals. South Africa is one of the most well-positioned countries to transform these industries (Muslemani, et al., 2021). However, the historical record highlights the failure of South Africa to structurally transform the economy from the heavy energy and mining-based industries (Andreoni et al. 2021). To correct its course, South Africa has to rapidly pivot to a lower carbon trajectory and use this shift as an opportunity for sustainable re-industrialisation.

Against this record, we examine the critical industrial policy questions that South Africa needs to confront in decarbonising steel, cement, and chemicals – which are at the heart of the South African economy. The question is how South Africa pivots to a lower carbon trajectory. Will the change be part of building local linkages to ensure capabilities in inputs for renewable energy and linkages to a diversified green industrial base, or will it be in export-oriented enclaves aimed at the greening of European industry? This requires

[1] It is known as "black" hydrogen when made from coal. "Blue" hydrogen is made when combined with carbon capture and utilisation or storage technologies.

analysing specific opportunities that GH2 offer in different sectoral value chains and factors including their relative factor endowments, geographical advantages, technological capabilities and linkages development potential.

The many transitions already underway in other countries[2] make understanding the implications for South African industries from this pulling-along effect of paramount importance, for local development and the wider Southern African region. Adopting a regional lens is necessary given that many countries still employ policy frameworks and market interventions that actively discriminate against renewable energy resources (Imasiku, et al., 2021). Transitioning to a hydrogen-based economy is expensive and will require active government intervention, which pivots specific industries, while at the same time coordinating linkages development and infrastructure in space and time. This paper's three industry case studies provide a baseline to direct investments and coordinate transformative efforts.

The rest of the paper is structured in three main sections. In section 2, building on emerging evidence, we contextualise the risks and opportunities for GH2 in South Africa. We focus on the hard-to-abate sectors and the conditions under which these sectors can be restructured sustainably by deploying GH2 technologies. In section 3 we look at three industry cases for South Africa in Chemicals, Steel and Cement. These sectors are the highest industrial emitters. For each of these sectors, we provide an overview of the sector and specific challenges, focusing on the emerging strategies of their main large companies and the opportunities for industrial policy interventions. The scope and speed of GH2 transition in these three sectors is shaped by the specific set of firm capabilities, business and policy incentives, and compulsion mechanisms – domestic and international – characterising each. These can be shaped and directed by strategic and aligned industrial and energy policies and market regulations. Section 4 briefly discusses South Africa's draft Commercialisation Strategy for GH2 from an industrial policy perspective. Lastly, section 5 concludes by sketching an integrated set of action points for an 'entrepreneurial-regulatory state' (Andreoni and Roberts, 2022a and 2022b) willing to seize GH2 as an opportunity for sustainable re-industrialisation.

2. Contextualising the risks and opportunities for South Africa's green hydrogen transition

2.1 The carbon intensity of modern industrial production

Industrial production has historically been one of the worst emitters (Betts, 2021). Moreover, almost all industrial sectors were built on the back of energy derived from fossil fuels such as coal, oil, and gas. The relative abundance of these fuels led many countries to adopt them as the primary means of powering their energy systems resulting in enormous amounts of CO_2 emissions commensurate with massive gains in technological, social, economic and developmental progress (Ritchie, et al., 2022). As much as 65% of historic

[2] By 2022, around forty-five countries had published hydrogen roadmaps and have started deploying industrial policy packages to move towards a green hydrogen economy, including developing a GH2 infrastructure home, and sourcing renewable energy to fuel GH2 production abroad (IRENA & RMI, 2023). China already leads hydrogen production globally; the EU developed the comprehensive Hydrogen Strategy for a Climate-Neutral Europe in 2020 and Germany invested in Namibia to develop a GH sector supplying German domestic industrial base; and, Chile launched a national strategy to make solar-based hydrogen for use in the mining industry in 2021 (IRENA, 2022; Altenburg et al., 2022).

human-made emissions are accounted for by CO_2 produced from burning fossil fuels, industrial processes, land use changes, and, notably deforestation (Sievernich, et al., 2022).

Most historical CO_2 emissions originate from countries in the global North (United Kingdom, United States, and Europe). However, since 1950, China's emissions have grown substantially to the point where it accounts for 28% in 2021, while the historically high emitters declined. Much of these historical emissions were driven by heavy industries such as iron and steel, chemicals, and cement (IEA, 2022).

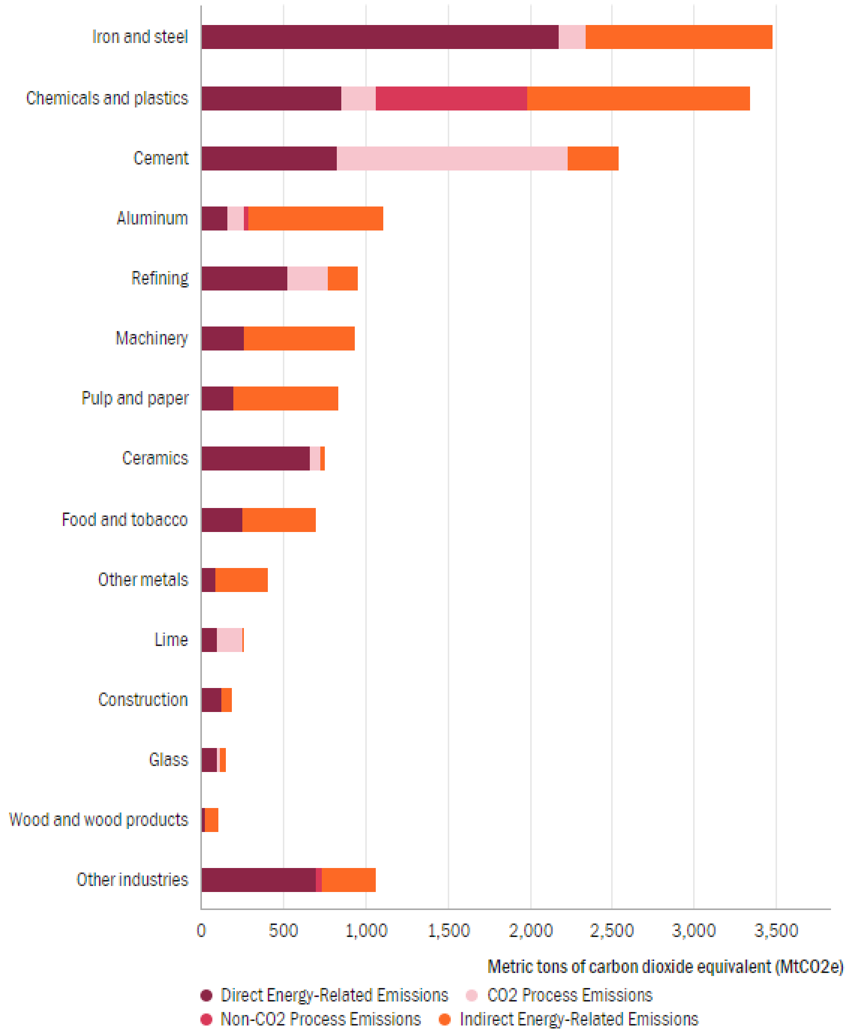
Globally, these same sectors have remained the most significant emitters of CO_2 and other greenhouse gases (GHGs).[3] Specifically, three types of emissions must be considered (Griffiths et al., 2021). First, direct energy-related emissions are associated with the industrial use of fuels for power and heat. Second, indirect emissions are those related to sourced energy and heat such as in generating electricity used in production. The last category is direct process emissions from chemical transformations occurring in industrial processes (e.g., metal oxide reduction processes in cement and steel manufacturing) (Sievernich, et al., 2022).

While the energy sector accounts for around 13 GtCO2 emissions, or 23% of total global emissions, decarbonisation needs to extend beyond the energy sector. All industrial sectors – from agro-food and garments, chemicals and steel, aerospace, and automotive industries – contribute to climate change differently in direct, but also indirect and mediated ways along upstream and downstream value chain segments. For example, the steel sector, a key upstream industry, accounts for around 3 GtCO2e emissions, or 5% of total emissions (including indirect emissions) and around 30% of all industrial carbon emissions (OECD, 2023). The sector's emissions have risen by around 15% since 2010.

Understanding the different needs, capabilities, and opportunities for sustainable industrial restructuring is the first critical step towards targeting and coordinating policies. From an industrial base perspective, three sectors – i.e. iron and steel, chemicals and plastics, and cement – rank well above other sectors regarding GHG emissions (proxied by CO_2 equivalent, Figure 1). Iron and steel emissions are mainly due to direct energy-related emissions, while indirect energy-related emissions are relatively more significant in the case of chemicals and plastics. These direct energy emissions stem from the sector's heavy coal use (IEA, 2020). In the case of cement, CO_2 process emission accounts for the bulk of total sector emissions. Except for refining and ceramics, where direct energy-related emissions are larger, the emissions are mainly due to indirect energy-related emissions in all other major industrial sectors, such as aluminium and machinery.

[3] Steel, chemicals and cement accounted 7.2%, 5.8%, and 3% of total GHG emissions in 2021 based on data from Our World in Data.

Figure 1: Global GHG emissions by industry, 2014



Source: Rissman, et al. (2020)

Notes: Emissions associated with transporting input materials and output products are considered part of the transportation sector, and are not included in this figure. "Chemicals and plastics" includes all fluorinated gas emissions, even though most of those gases (e.g. refrigerants, propellants, electrical insulators) are emitted due to the use or scrappage of products. Chemicals production by refineries is included in the "refining" category, not the "chemicals and plastics" category. "Ceramics" includes brick, tile, stoneware, and porcelain. "Food and tobacco" includes the processing, cooking, and packaging of food, beverage, and tobacco products, not agricultural operations. "Other metals" include copper, chromium, manganese, nickel, zinc, tin, lead, and silver. "Lime" only includes lime production not accounted for in another listed industry (e.g. cement).

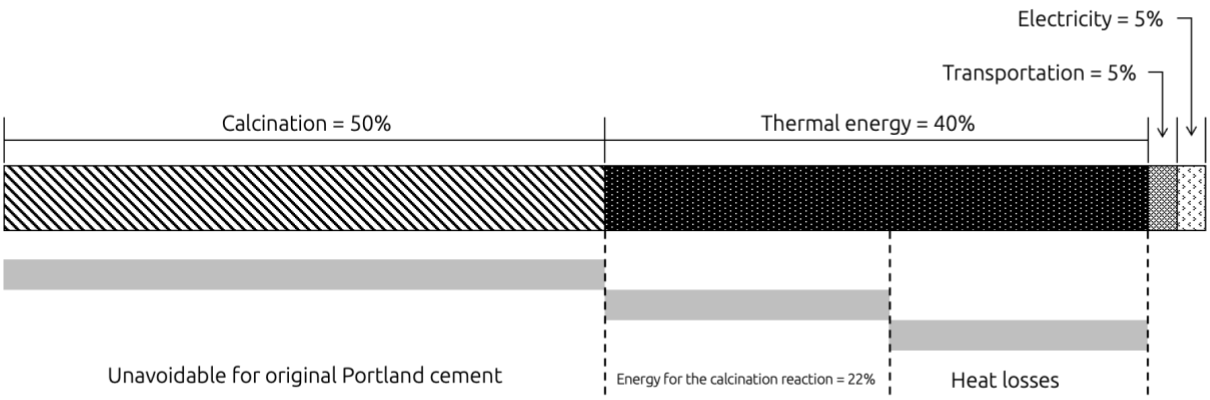
The global steel industry accounts for close to 8% of global emissions from the energy sector and ranks as one of the highest emitting industry sectors (around 30% of industrial carbon emissions (OECD, 203). Since steel demand is expected to increase by 6% by 2030, greening the steel sector and reducing its emissions is crucial to achieving green sectoral targets in a sector where 1 tonne of output releases 1.85 tonnes of CO_2 (Ali, 2022). These emissions reductions can come through various processes such as efficiency programs, carbon capture and storage, using green electricity in electric arc furnaces, and substituting coking coal with GH2. The substitution involves introducing green hydrogen as a reductant substitute for coking coal to produce directly reduced iron (Ali, 2022).

Globally, the chemicals sector accounts for around 4% of GHG emissions (Chung et al., 2023). Fertilizer production is a major source of these emissions and also represents an opportunity to decarbonise using green ammonia (for nitrogenous fertilizer). We examine issues in this product grouping. In addition, given its diverse linkages and the increasing demand for plastics from crucial end-use sectors such as packaging, automotives and construction reduced emissions from plastic production is also important for decarbonisation of these end-use sectors. Around half of the chemicals sector's CO_2 emissions originate from feedstock consumption as energy input and are classified as industrial process emissions[4] (IEA, 2022). However, data on the chemicals sector's emissions show that the sector is not on track with the proposed 2030 net-zero scenarios (IEA, 2022).

Several routes can be taken to bring the sector closer to net-zero targets. These include abating Scope 1 and 2 emissions (mostly from ammonia production), supplying new end-markets, building sustainable product portfolios, and creating circularity in the sector's ecosystems (Deloitte, 2022). The biggest potential gains will come from substituting green hydrogen as a feedstock and fuel for production, displacing fossil fuels (Centre for Global Commons, 2022). Scaling up this substitution will lead to decarbonising several essential products such as fertilisers and ammonia, and can bolster decarbonisation linkages across a wide variety of sectors (Rambhujun, 2020).

For the cement sector, a breakdown of the CO_2 emissions shows where the most emissions are generated in the production of cement (Figure 2). Unlike other sectors where most GHG emissions emanate from fuel burning, at least 50% of the cement industry's direct emissions are released during the calcination process (process emissions)[5] and are considered unavoidable for original Portland cement (Lowitt, 2020). Energy emissions from the combustion of fuels account for around 25-40% of GHG emissions from clinker production.

Figure 2: CO_2 emissions during the production of cement



Source: Adapted from Lowitt (2020) using IEA data

Most studies evaluating the potential for reducing GHG emissions from clinker production focus on reducing energy emissions from using low-carbon fuels, gas, or hydrogen. While important, reducing process emissions is also critical to achieving many net-zero targets (Nhuchhen, et al., 2022). Aiming to reduce the two primary emissions (process and energy)

[4] These are emissions generated as a result of chemical reactions inherent to the materials being produced (IEA, 2022).
[5] Calcination is a process when limestone is heated and break down into calcium oxide and CO_2 (Shah, 2021).

offers the most effective method of reducing emissions from clinker production. For example, two alternatives are being explored to reduce process emissions from the calcination of limestone. These are substituting or mixing limestone with coal fly ash and blast furnace slag and, secondly, employing carbon capture and storage (Shah, 2021) or CO_2 Looping and Recovery (Jiang, et al., 2019). However, these alternatives come with complexities, limits, and high costs.

2.2 Risks and opportunities for South Africa: a structural transformation perspective

South Africa is one country of the many that have exploited the burning of fossil fuels since the late-1800s. This was due to the country's abundance of coal to cheaply power heavy sectors such as mining, steel and chemicals as part of the then-apartheid government's structuring of the economy around the minerals-energy complex (MEC) and state-owned national champions (see Fine & Rustomjee, 2018). However, evidence on CO_2 emissions by sectors and subsectors in South Africa is not readily available. Information is patchy, and not always updated, and sectoral classification and aggregation tend to conflate the picture. In Appendix 1 we attempt to report the leading figures available to contrast them with the overarching industry emissions benchmark reported in Figure 1.

Given its dependence on coal, South Africa's energy generation is the most critical contributor. However, the chemicals sector also looms large given its fossil-fuel dependence, and metals and cement are major emitters, in line with the international benchmark. Emissions are often not contained within sectors, given that upstream industries provide inputs to downstream industries through industrial raw materials. Emissions upstream reverberate downstream in terms of the product emission footprint. The chemicals industry, in particular, indirectly contributes to the carbon emission of other downstream industrial and non-industrial sectors – agriculture and food production – where ammonia is widely used.

For a country like South Africa, the main impetus for pivoting to green hydrogen to reduce the carbon intensity of its highest emitting sectors originates from the risks of reduced market access to major trade partners such as the EU, the US, and China (Bell, et al., 2022). These countries are introducing a wide range of climate-centric industrial and trade policies and restrictions. While motivated by climate change concerns, these initiatives are also driven by ongoing geopolitical tensions, global restructuring of the global industrial landscape, and more muscular industrial policy. The increasing impact of climate change and widespread awareness of its socio-ecological irreversible repercussions has also driven such legislation in these advanced industrial economies.

An important development driving the need for South African industry to rethink its production processes is the EU's Carbon Border Adjustment Measures (CBAM) framework, which forms part of its more extensive net-zero pledges called the European Green Deal (EGD). From an industry perspective, the CBAM will initially target carbon leakages in historically notorious sectors such as cement, iron and steel, aluminium, fertilisers, electricity generation, and hydrogen before potentially extending to products from the chemicals and polymer sectors (Table 1). In this initial round, the CBAM will target direct emissions directly from the production processes of the products in these sectors while some indirect transmissions arising from the emissions produced for the electricity utilised in these processes will be included.[6]

Table 1: Scope of products for CBAM

	Sector	List of material products
Initial industry scope	Cement	Clinker Portland cement
	Iron & Steel	Iron & steel primary forms Hot rolled & further steps Coated hot rolled & further steps Forged, extruded and wire
	Aluminium	Aluminium unwrought Aluminium unwrought alloyed Aluminium products Alloyed aluminium products
	Fertilisers	Ammonia Urea Nitric acid Ammonium Nitrate
	Electricity generation	Electricity
	Hydrogen	Grey hydrogen
Future industry scope	Chemicals	Soda ash Carbon black Vinyl chloride monomer Methanol Formaldehyde Ethanol Acetone Aromatics Styrene Phenol Ethylene oxide/ethylene glycols
	Polymers	Polyethylene Polyvinylchloride Polypropylene

Source: European Commission (2022)

In the South African-specific context, these sectors form much of the backbone of the manufacturing sector, with each having strong linkages to other value-adding sectors (Andreoni et al., 2021). Data on trade, employment, carbon intensity, and reviews of EU climate-centric policy documents highlight the vulnerabilities facing these sectors through the development of a Carbon Intensity Scorecard (CIS, see Bell, et al., 2022). The CIS emphasised that South African policymakers must confront the risks facing the Basic metals and fabricated metal products sectors (including iron & steel); the products of Chemicals and allied sectors (including fertilisers), and Cement. Not transitioning to GH2 leaves specific

[6] https://www.europarl.europa.eu/news/en/press-room/20221212IPR64509/deal-reached-on-new-carbon-leakage-instrument-to-raise-global-climate-ambition

export-oriented sectors (steel in particular)[7] at serious risk from massive changes in EU demand and importing behaviours due to the EU's suite of climate change-related mitigation policies.

Against this backdrop, and in light of the different characteristics, challenges, and opportunities of different industrial sectors, the paper takes a deep-dive into the three major industries – chemicals, steel and cement. Given that these industries will transition to green production in South Africa and worldwide over the next decade and have been identified in South Africa's Green Hydrogen Commercialisation Strategy released for comment in December 2022, as priority industries for industrial development in South Africa, we discuss a framework for GH2 transition in these hard-to-abate sectors. To lay the basis for the assessment in each industry, we briefly map out the structure, main companies and the structural transformation challenges.

3. Chemicals

3.1. **Overview**

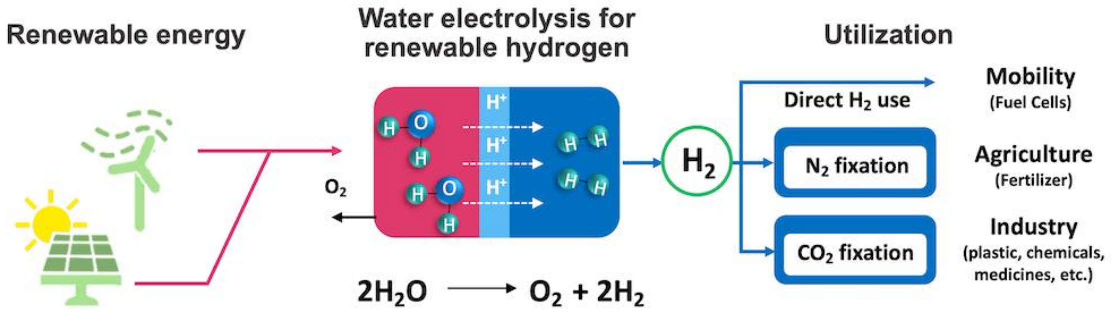
Today, chemicals is often used as a catch-all term covering interrelated and diversified industries such as petroleum and liquid fuels, fertilisers, ammonia, plastics and rubber products (Rustomjee, 2008). Regarding its environmental impacts, the chemicals sector ranks as one of the highest emitters of GHGs. It is one of the more complex sectors to achieve net zero given the various production processes involved at the different levels of the value chain. Only a portion of emissions can be reduced through energy efficiency, bio-based feedstocks, and closing material loops (Deloitte, 2021; Chung et al. 2023).

Achieving large-scale decarbonisation of the chemicals sector requires technological advancements to convert much of the existing production infrastructure to favour GH2 production and utilisation. Figure 3 provides a schematic of the main applications of GH2 in the chemicals sector. Specifically, GH2 allows for the production of green ammonia and fertilisers via nitrogen fixation, and CO_2 fixation in other chemical processes leading to polymers, plastic products manufacturing, and other chemical components for the medical and drug industry. Finally, green ammonia can also act as a transport medium for hydrogen, and GH2 can be utilised as a fuel for electricity generation and powering large vehicles such as ships (Jones, 2022; see also IEA, 2021). Production of ammonia from fossil fuels is nearly twice as emissions-intensive as crude steel production and four times as intensive as cement production in direct emissions (Chung et al, 2023 citing IEA, 2021).

While it is very diverse, there are several core fossil-fuel-based chemical products for which green hydrogen is the most promising to decarbonise. We focus on ammonia-based fertiliser with critical linkages into agriculture. 70% of ammonia is used for fertilisers consumed by the agriculture industry, which is essential for agriculture's decarbonisation. Ammonia is also used in explosives manufacture and green ammonia is thus critical for decarbonising mining of minerals required for renewable energy such copper and platinum group metals.

[7] Cement is a relatively non-traded product and so does not facing significant trade risks.

Figure 3: GH2 transition opportunities and utilisation in the chemicals sector



Source: Phillips (2022)

Green ammonia for fertiliser is the second most crucial positive tipping point identified for a breakthrough in a recent study, after electric vehicles (Meldrum, et al., 2023). Three green ammonia projects are already operational around the world and the first commercial-scale facility is due to come on stream in 2023. These projects will be instrumental in driving down the costs of fertilisers in the medium- to long-term.

Internationally ammonia costs over 2011 to 2020 (before the energy price spikes) have averaged $300/t (Meldrum, et al., 2023). It is generally produced from natural gas. Ammonia prices have been around $1000 over 2022 due to the Russia-Ukraine war. Green ammonia is being produced in early 2023 at around $700/t with the first utility project at scale in construction at NEOM (in Saudi Arabia). Costs are projected to fall to $500/t in 2025 in planned exporting locations such as Namibia and Brazil, with a GH2 price of $2.2/kg. Green ammonia costs are projected to fall further to $400/t over the coming decade. This compares with the historic average price of $300/t for 'grey' ammonia from fossil fuels. A carbon tax of $100 would increase the cost of grey ammonia from $300/t to $500/t (given the amount of emissions to produce ammonia[8]), which would be at parity with green ammonia in 2025 and more expensive than the expected future green ammonia price.

Prices of ammonia are higher than world prices for those countries which import, such as South Africa, which means producing green ammonia is relatively more attractive if it replaces imports and can lead to lower prices for ammonia and fertilizer.

3.2. Industry structure and CO_2 emissions in South Africa

South Africa's chemicals sector can be traced back to 19th-century diamond, coal, and gold mining (Booth, 2011; Majozi & Veldhuizen, 2015). With the creation of Sasol and its petrochemicals complex, the South African chemicals sector was able to diversify into a wide range of products and categories throughout the second half of the 20th century. Government support continued into the democratic era including through a favourable regulatory regime for liquid fuels and with the ANC government deciding to release Sasol from obligations to repay its apartheid-era subsidies and not to impose a windfall gains tax (Mondliwa & Roberts, 2019).

[8] See ACWA Power presentation at GH2 summit, Cape Town, December 2022 for energy use in ammonia production.

Fertilisers and explosives have been essential products in the development of South Africa's chemicals industry and are essential for agriculture and mining across Africa and are integral to the sector's geographic development. The Anglo-American corporation developed these products to supply mining as part of its industries. Because of this, close to half of South Africa's chemicals manufacturing is located in Gauteng, with Kwa-Zulu Natal and the Western Cape accounting for 18% and 16%, respectively (Majozi and Veldhuizen, 2015). This geographic concentration was primarily due to the vast gold mining operations around Johannesburg, which demanded explosives and other chemicals, and the proximity to the coal deposits which were the feedstock for Sasol.

Due to its involvement in the early chemicals sector, Sasol now dominates the South African chemicals industry and is the only ammonia producer, supplying ammonia to Omnia and AEL. Sasol is the largest producer of liquid fuels and basic organic chemicals co-produced in integrated plants. However, much of Sasol's production is extremely carbon and energy intensive, from coal and natural gas. Chemicals contribute around 13% of South Africa's total emissions, 90% of which originate from Sasol (Creamer, 2021a). From 2004 Sasol moved to natural gas for a substantial proportion of its feedstock. The gas is sourced from Mozambique by pipeline under agreements with the Mozambican and South African governments on very favourable terms (Mondliwa and Roberts, 2019).

As the dominant producer of chemicals in South Africa, Sasol is central to the decarbonisation of chemicals in the country. Considering its emissions (Table 3), Sasol has a strong compulsion to decarbonise, and it has several options to achieve this. The option with the most potential, given that 50% of the emissions stem from feedstock utilisation, is through scaling up the substitution of green hydrogen for fossil fuels. This is central to Sasol and other chemicals firms adopting low-carbon innovations, locating close to end markets, and driving adaptation within and across value chains (Yankovitz, et al., 2022).

Table 2: Sasol emissions by main plants

Sasol Scope 1 and 2 emissions	2021
Secunda	57.4
Sasolburg	4.9
Other	4.8
Total - million Mt CO2e	67.1

Source: National Treasury (2021)

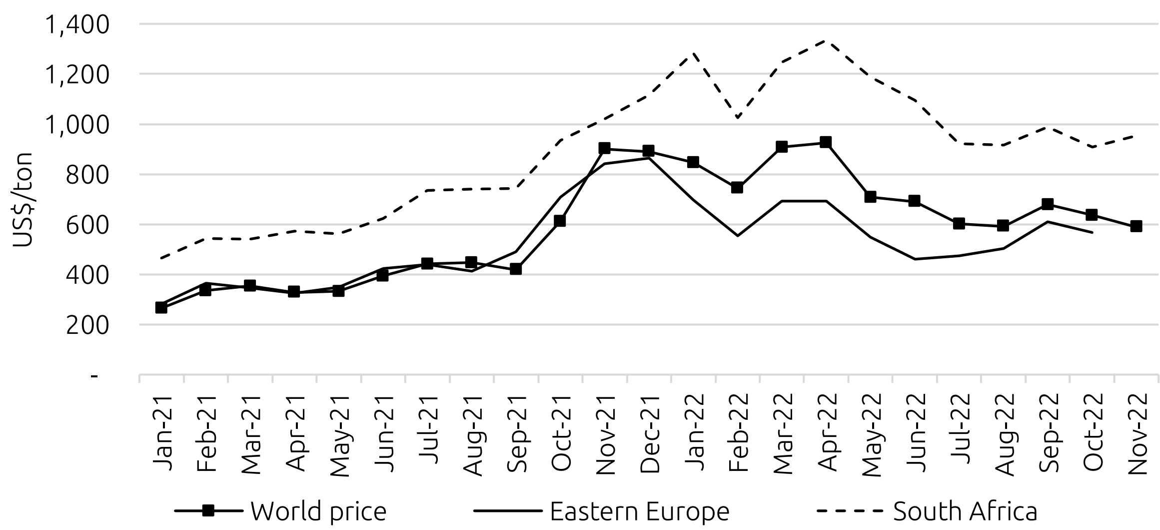
Moreover, the decarbonisation of Sasol can take one of two paths. There will either be large-scale closure of Sasol's synfuels or a switch to GH2. Sasol is well placed to achieve the switch as it already has the relevant industrial capabilities and a strong compulsion to explore and pursue such GH2 transition pathways. It has substantial proprietary capabilities in hydrogen production and is a large producer and user of grey hydrogen. We focus on ammonia production to fertiliser, which links to agriculture demand.

From a structural transformation perspective, it matters whether the GH2 transition happens within an enclave or as part of a concerted strategy for the green transition to open the way to technological upgrading and sustainable investments in related upstream and downstream industries. The latter path can reverse the trajectory of the under-development of downstream chemicals and plastics products relative to upstream refinery and basic chemicals (Mondliwa and Roberts, 2019). This is a challenge for industrial policy and the regulatory regime that has facilitated Sasol's growth while enabling the company to retain its entrenched and vertically-integrated position.

With reference specifically to ammonia and linked products, scale economies and linkages mean there are only a very few firms primarily manufacturing fertiliser and explosives products in South Africa. Sasol is the sole ammonia manufacturer in South Africa, with around half being a by-product from its synfuels production and half from natural gas feedstock. Omnia also imports ammonia by ship and rail to its inland plant. Sasol and Omnia manufacture ammonium-nitrate fertilisers and Sasol, Omnia and AEL manufacture ammonium-nitrate explosives.

Manufacturing green ammonia through green hydrogen in South Africa is more than just critical from a structural transformation and climate change perspective. There is also a business case for reducing and stabilising the price of fertilisers in the southern African markets where prices are substantially above international levels (Figure 4). Prices of urea fertiliser (a standard and widely used nitrogenous fertiliser made from ammonia which is not produced in South Africa), have been $200-300/t above world prices due to the import costs. Ammonia prices in South Africa are also above world prices, at import parity levels which is the world price plus all the transport costs to import to inland South Africa. In other words, the ammonia prices are likely to be already at or above the costs of green ammonia if this is produced with a reasonable projected renewable energy cost. If we factor in a carbon tax on grey ammonia then green ammonia is even more competitive.

Figure 4: Urea fertiliser prices, 2021-2022



Source: World price is from the World Bank. Eastern Europe & South Africa prices are from Grain SA.

High prices of fertilisers act as a bottleneck to agriculture productivity and a risk to food security. Moreover, in the case of South Africa, increasing sustainable production of green ammonia would also reduce dependence on imports of additional liquified ammonia (by Omnia), urea and other fertilisers. These considerations have already seen Omnia agreeing on 31 January 2023 to partner with German renewable energy group PNE to explore the feasibility of green ammonia production.[9]

3.3. Sasol's strategy for a green chemicals sector

Sasol is at the heart of South Africa's industrial base with one of the most emissions-intensive methods of producing liquid fuels and other hydro-carbons from coal and natural gas. Given that Sasol produces most of South Africa's basic chemicals output, the sector's transition to greener and less carbon-intensive outcomes and production processes primarily depends on the company's strategic vision. At the same time, Sasol must rapidly transform to stay in business, as carbon taxes and other measures are introduced worldwide.

In 2021, Sasol committed to reducing its GHG emissions with its 2050 Net Zero targets and "Future Sasol" strategy. This details the roadmap through which Sasol has committed to reduce the 65,9 million tonnes of emissions from its energy and chemicals divisions across the globe (Sasol, 2022a and b). The imperative for it to change its production has seen Sasol leading green hydrogen initiatives in South Africa. A key question is whether these initiatives are linked to broader-based growth in green chemicals.

At the same time, Sasol has begun several projects to lock it in as a top hydrogen producer in South Africa and globally (Zail, 2021). The changes would see Sasol migrate from its current grey hydrogen production using coal and gas, to renewable electricity to power its production of green hydrogen. Sasol plans to utilise natural gas as a transition feedstock before employing only green hydrogen and other potential sustainable energy sources by 2050 (Creamer, 2022a). The impetus for the transition to green hydrogen is further driven by the European energy crisis and the ongoing Russian invasion of Ukraine, which has led to a massive increase in demand for alternative fuel sources (Burkhardt, 2022). The key to the viability of Sasol's green hydrogen plans rests on its ability to produce green hydrogen at competitive prices to become a top exporter to the EU, among other trading destinations.

To help it achieve its production, cost, and export targets, Sasol has begun plans to transition its flagship Sasolburg plant as early as 2023 to act as the company's green hydrogen production base (Creamer, 2021b). Sasol's transition is aided by plans to develop a green hydrogen special economic zone supported by local and international funders such as the German government. These ventures include ammonia (much easier to transport than green hydrogen) in the proposed Boegoebaai special economic zone in the Northern Cape province (Sasol, 2022c).

The main initiatives are:

- Boegoebaai in the Northern Cape, with the South African government, to produce GH2 and ammonia at scale for export, and ammonia being used to replace heavy fuel oil as shipping fuel (as identified in the commercialisation strategy for shipping fuel). This large-scale development aims to support 40GW of electrolyser capacity by 2050.

[9] https://www.engineeringnews.co.za/article/omnia-signs-mou-with-german-energy-group-to-explore-green-ammonia-production-2023-01-31. The preliminary plans are for 150MW wind and solar (internal and external to Omnia) linked to an electrolysis plant with and an air separation unit which could scale-up to produce 100 000 t/y of green ammonia. Omnia currently uses 280 000 t/y of ammonia; therefore, the plant would manufacture about 30% of its requirement.

- Saldanha Bay green steel with AMSA, which has an electric arc furnace using DRI (direct reduced iron)
- Vaal Triangle which includes:
    - AMSA's Vanderbijlpark plant with a blast oxygen furnace is located: GH2 can replace coking coal as a reductant, and carbon capture used to reduce emissions (as thermal coal is the energy source, unless and until the blast oxygen furnace is converted into an electric arc furnace)
    - Sasolburg plant, with plans including transition of production of 500th tonnes of ammonia and methanol from grey to green H2
- Secunda where Sasol's other major plant is located, including a sustainable aviation fuel initiative – initially aiming to displace just 1% of grey hydrogen used at Secunda with green hydrogen produced with a 200MW electrolyser and 450MW of renewable electricity produced in Mpumalanga
- Sasol has also announced it aims to procure 1200MW of renewable energy capacity from IPPs by 2030, for its own use.

Sasol's commercialisation of its green hydrogen capabilities is also being assisted through joint ventures, partnerships, and development financing with international companies such as Itochu, Toyota, Imperial, and institutions such as the Central Energy Fund and Industrial Development Corporation (Creamer, 2021b; Banya, 2022). Additionally, Sasol's ecoFT subsidiary has signed a deal with German aircraft manufacturer Deutsche Aircraft to advance technology for green hydrogen-based synthetic fuel (termed power-to-liquid) in aviation as part of efforts to minimise the CO2 footprint of aviation (Sasol, 2022d).

Sasol also entered into a joint venture with Mexican multinational, CEMEX and German-based green hydrogen firm, Enertrag, to transform CEMEX's Rüdersdorf production facility into the world's first zero-carbon cement plant (Miguens, 2022). These agreements all coincide with Sasol's desire to displace the production of grey hydrogen at its Secunda plant through its HyShiFT project (in partnership with Linde[10], Enertrag and Hydregen Energy), acting as catalysts for Sasol's decision to increase its green hydrogen production through sustainable aviation fuels (Creamer, 2022).

Sasol has also announced deals with local mining companies to supply hydrogen as a fuel to initially power forklifts with the view to wider applications in the future (Mukherjee, 2022). Other GH2 industrial applications include hydrogen and fuel cells in the mining sector. Specifically, Anglo-American's 220-tonne truck has been employed at one of its platinum mines in the northern region of South Africa.[11]

In September 2022 at the TICAD conference in Tunisia, Sasol signed a Memorandum of Understanding with the Japanese company ITOCHU to jointly study and develop the market and supply chain for green ammonia with a focus on its use as bunkering fuel and for power generation. The MoU includes ITOCHU's potential involvement and participation in Sasol's green ammonia export-oriented projects.

[10] The German government recently announced a €15-million grant for Linde for the HyShiFT Mpumalanga project.
[11] https://www.aljazeera.com/news/2022/5/6/s-africa-launches-the-worlds-biggest-hydrogen-fueled-truck

3.4. Industrial strategy and political economy feasibility

Considering the extensive linkages the chemicals sector has with the rest of the economy, including the steel and cement sectors, the greening of the chemicals sector, including key sub-sectors such as fertilisers, ammonia, and explosives, must be viewed as a critical goal in aiding these and other sectors' transitions toward greener outcomes and lower CO_2 emissions.

However, the competitiveness of green hydrogen production is intimately linked to the currently high capital costs associated with electrolysers, and the future sectors demanding hydrogen, such as fuel-cell electric vehicles, creating a demand-push for competitive GH2. For hydrogen to be able to compete with natural gas in industrial applications viably necessitates an economically viable CO_2 mitigation option and CO_2 prices between 100 and 200 €/tn (Ball & Weeda, 2015). Moreover, the cost of GH2 is also influenced by the subsequent advancements of its production technology, the availability of existing infrastructure, and the feedstock price (Kayfeci, et al., 2019).

Sasol holds a strong position to become the cost-effective large-scale producer of green hydrogen in South Africa. However, achieving competitive GH2 production requires aligning interlocking investments – both industrial and infrastructural – and commitment to long-term and patient developmental finance. A crucial starting point is the alignment of these fragmented sectoral initiatives with and within the GH2 masterplan. The GH2 master plan is critical in balancing potential trade-offs regarding renewable energy mix for GH2 production, transmission via grid or pipelines and storage.

Such coordinated investments have a vital locational aspect too. At the moment, the geographic locations of much of Sasol's green hydrogen capabilities represent a major challenge for an industrial strategy that ultimately needs to align to the capabilities and interests of a single firm. The internal demand for Sasol's green hydrogen comes from inland regions, making developing an industrial strategy for green hydrogen production as much a geographical question as an infrastructural one. Moreover, Sasol has agreements to export green hydrogen and other sustainably-produced fuels to power decarbonisation projects abroad.

The materialisation of Sasol's GH2 ambitions has to do most critically with lowering the costs of green hydrogen production. In this respect, South Africa has a strong competitive advantage as a renewable energy producer with onshore wind turbines – the so-called 'wind-to-hydrogen approach' as well as solar. Potentially, this approach offers infinite energy to power electrolysers to produce GH2 before transporting large quantities via pipelines; hence it offers significant cost advantages over other methods such as High Voltage Direct Current transmission systems (Creamer, 2022b). If ammonia is produced, it can be more readily transported, by pipeline or rail tanker. Green ammonia for fertiliser and explosives will compete with ammonia and fertiliser products that are priced substantially above international price levels. Moreover, the demand for these products is from the agriculture and mining sectors.

4. Steel

4.1. Overview

Steel and non-ferrous metals are among the hard-to-abate sectors where green hydrogen, along with electricity from renewable energy, is important for decarbonisation. Steel products can be divided into flat steel sheets and long steel products (mainly used in construction). Flat steel mills are large-scale and manufacture mainly from iron ore. Producers of long steel products are smaller scale and predominantly use scrap metal as the input in South Africa. South Africa has several smaller long steel producers who will be able to produce green steel using electricity, as electricity generation moves to renewables.

The main challenges for decarbonisation are in the flat steel mills manufacturing from iron ore, using thermal coal for energy and coking coal as a reductant in the production process. Green steel can be made using the DRI (Direct Reduction of Iron ore) technology pathway (OECD, 2023). This typically uses coking coal as a reductant, to reduce high-quality iron ore to sponge iron by extracting the oxygen. Hydrogen can replace coking coal. The iron is then processed into steel typically through the use of electricity in electric arc furnaces.

Steel is identified as one of the early opportunity domestic applications, for 2025-2030, in South Africa's Green Hydrogen Commercialisation Strategy (SAGHCS) released for comment in December 2022. The AMSA Saldanha project is a flagship project, along with green ammonia, methanol, jet fuel, and fuel cells for road transport. A budget of R0.2bn has been pencilled in for pre-feasibility and feasibility, and R13.2bn for investment in production.

The nature of steel production means it has also been identified in other countries as a lead industry for GH2. For example, India's National Hydrogen Mission plans to bring down the cost of green hydrogen to $1.50/kg and reach 5Mt/y green hydrogen capacity by 2030, placing it among the cheapest GH_2 producers worldwide. This is important for the world steel industry as India is the largest steel manufacturer produced through the DRI technology pathway. Another steel producer, Australia is targeting a GH2 price of $2/kg by 2030, while Chile's roadmap targets it being the cheapest GH2 producer on the planet, at less than $1.5/kg by 2030.

Regulations on the steel industry in Europe which see imports increase would not reduce the carbon emissions from steel used in Europe and instead result in carbon leakage which has motivated the CBAM by the EU. In order assess the subsidy required for the local industry to decarbonise with GH2, it has been calculated that GH2 costs in Europe in 2022 that are approximately three times that of alternatives mean an approximately 30% higher steel cost for European producers.

Green steel imports from countries where GH2 is cheaper to produce have been referred to as 'green leakage' (of jobs and value-added). Protecting the industry in Europe means subsidies, imports of GH2 or imports just of the earliest stage of sponge iron for processing in Europe. Instead of trade accelerating greening of steel internationally through leveraging off low-cost potential in countries like South Africa, these developments would represents an effective deindustrialisation (to further reduce the sophistication of imports of steel products). It is also consistent with the US and EU announcement in 2021 to negotiate a "carbon-based sectoral arrangement on steel and aluminium trade" to counter the "flood of cheap steel" and provide an advantage to their domestic steel industries. China is the main target; however, it will impact other exporters, including South Africa and Egypt as steel exporters, and Mozambique, Egypt and Nigeria as exporters of aluminium.

The global steel industry restructuring under decarbonisation is thus going to depend on several interdependent factors including (see also OECD, 2023):

- Renewable energy costs
- Green Hydrogen costs
- Coordinated policies (or lack thereof) for the competitiveness of local industries
- International carbon duties and trading arrangements
- Strategies of multinational companies to optimise across regions

While the lower GH2 costs in South Africa should mean a low cost-base for green steel, the application of duties by important export markets such as the EU and lack of coordination in South Africa can undermine the realisation of the potential from renewable energy. The downstream linkages from steel to a diversified range of products means green steel is central to South Africa's green re-industrialisation.

4.2. Industry structure and CO_2 emissions in South Africa

South Africa's steel industry was built on low-cost mineral and (coal-based) energy inputs. This, together with scale economies, means it has been export-oriented. The same applies to stainless steel and aluminium (although aluminium does not have local mining linkages). We focus on steel as the most important metal for broad-based industrial applications. The steel industry, especially flat steel, has had a high proportion of exports and investments in plants for export, however investments in specialised steel have been lagging behind. Steel is also the main material input to metals fabrication – including in the automotive sector – and machinery manufacturing – especially mining equipment – which has substantial value creation and employment along several downstream value chains – including underground and overground equipment (Andreoni et al., 2021). South Africa has run a trade deficit.

The main steel producer was historically state-owned (Iscor) and vertically integrated into coal and iron ore mining. Following privatisation, this lead producer was subsequently acquired by the then Mittal group and became ArcelorMittal South Africa (AMSA), part of the largest steel producer in the world. AMSA has three main production facilities in South Africa: the integrated blast oxygen steel mill at Vanderbijlpark; the Saldanha Steel mill with an electric arc furnace and using DRI at Saldanha Steel; and the long steel plant at Newcastle. As such, AMSA's emissions rank the highest in the South African steel industry (Table 4). Other producers include Highveld Steel which produce heavy steel plates and long steel products and Scaw which makes mainly long steel products and grinding media from scrap metal in electric arc furnaces (now Barnes). Acerinox (Columbus Stainless) has a substantial and export-oriented stainless steel plant.

Table 3: AMSA emissions by main plants

	Unit	2021
Direct CO2 - Scope 1	t/t liquid steel	2.09
Indirect CO2 - Scope 2	t/t liquid steel	0.63
Total GHG - Scope 1 and 2	t/t liquid steel	2.72
Total GHG - Scope 1 and 2	**million Mt CO2e**	**8.41**

Source: National Treasury (2021)

There are essential and diversified linkages from steel production to downstream sectors (Figure 5). Long steel products are predominantly used in the construction industry while flat steel products have linkages to diversified fabricated metal products and to manufacture machinery and equipment. The linkages in South Africa have been relatively weak, exemplifying the lack of structural transformation in the South African economy. With the appropriate industrial policy and infrastructure mix, the global movement to GH2 in steel provides an opportunity for a reset in South Africa.

Figure 5: Top 10 sectors in South African steel output demand, 2021

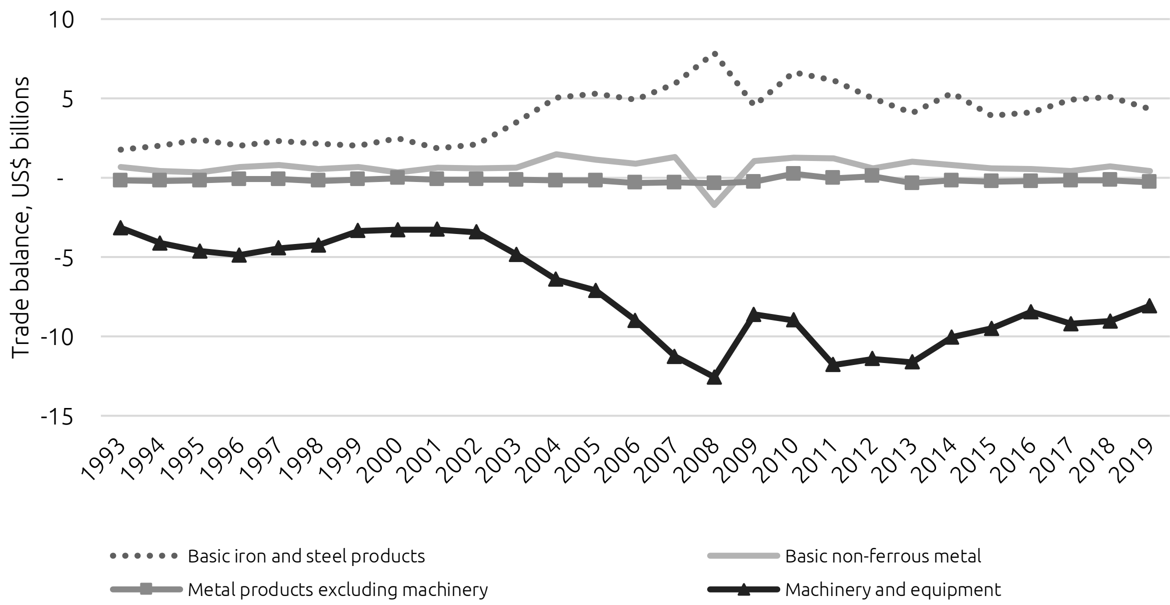
Source: Quantec

Notes: % of total sales of basic iron and steel products, QSIC 351, from I-O tables

The failure of economic diversification to build industrial capabilities in downstream sectors is evident in the growing trade surplus over the 2000s of basic iron & steel products. At the same time, machinery & equipment recorded a growing trade deficit over the same period (Figure 6). Fabricated metal products recorded roughly balanced trade throughout. The low steel production costs, founded on iron ore, coal and electricity, did not translate into competitive labour-absorbing downstream sectors using steel as an input. This was due to many factors including monopolistic pricing by the main steel producer, an overvalued exchange rate based on the commodities boom, and an industrial policy which focused on the upstream industry rather than diversified manufacturing capabilities (Andreoni, et al., 2021).

In the 2000s, South Africa had the lowest quartile costs in steel production despite coking coal being imported. AMSA's Saldanha and Vanderbijlpark plants were among the lowest-cost plants in the world in the early 2000s. Indeed, Saldanha Steel was built as primarily an export plant based on low-cost inputs and its location for export to European markets. Its low-cost position was partly due to having supplies of iron ore at cost, delivered via rail from Sishen. This favourable position changed under the conversion from the old order to new order mining rights and the iron ore was charged to Saldanha at export prices, rather than cost-based, and AMSA mothballed the plant.

Figure 6: South Africa's net exports



Source: Andreoni, et al. (2021)

The global move to renewable energy and green hydrogen for steel-making promises the opportunity to be low cost once again across the key inputs, as green hydrogen replaces coking coal as a reductant. To realise this in South Africa requires coordinated investments in renewable energy generation, establishing a low-cost base for electricity once again, and links to the production, storage and transport of GH2. Re-establishing cost-based iron ore pricing will be an important support for a low-cost green steel strategy. The returns from this strategy will be much greater if the steel is supplied at fair prices to local industry buyers to support diversified green industrialisation.

In sum, structurally transforming the South African steel industry could unlock significant value addition and employment opportunities downstream. In 2022, the metals and machinery industries accounted for the largest source of formal employment in manufacturing, contributing 263,780 formal jobs, of which 123,246 were in the downstream machinery and equipment, and fabricated metal products industries.[12] The strong linkages with support industries such as engineering services, transport, and logistics generate further employment.

4.3. **AMSA's strategy for green steel**

The decisions of ArcelorMittal regarding AMSA will largely determine the steel industry changes. The international scale of ArcelorMittal, including plants in the EU, and its shareholding means that its changes are heavily influenced by international developments and the expectations of the rules which will be introduced. In this regard, the steel industry is at the centre of global deals on the green industry, concentrated in a few countries and a few large companies. The top five countries produce 75% of world steel with China accounting for 50%. The industry is organised with the International Iron & Steel Institute for industry, and the OECD Steel Committee bringing governments and industry together. Global steel production is relatively concentrated in a small number of large companies with

[12] Based on data from Quantec as of April 2023.

the top five being ArcelorMittal, three Chinese companies (Baowu Group, Ansteel Group, Shagang Group) and Nippon Steel of Japan.

The long lead times for major steel investments mean that changes are required in the short term to meet net-zero commitments in 2050. Technological developments and reductions in renewable energy costs mean that it is expected that near-zero emission steel should approach the cost of high-emission steel, in the most favourable locations, by 2030. The question is whether the investments will be made in South Africa to ensure it is one of those favourable locations. The SA Hydrogen Strategy Roadmap has green steel at both Saldanha and Vanderbijlpark as pilot projects. While Saldanha's plant is relatively modern, using electric arc furnace Corex/Midrex technology for DRI which is continuous production, Vanderbijlpark is based on blast oxygen furnaces (BOF) that produce in batches using thermal coal for energy. BOF have much higher emissions (OECD, 2023). This would likely need to be changed to an electric arc furnace as it is much more efficient to use renewable electricity to replace coal as the primary energy source. Similarly, hydrogen replaces coking coal as the reductant. Key drivers for DRI is high grade iron ore (OECD, 2023), where South Africa has large reserves in the Northern Cape.[13] Together with GH2 it can be the base for some of the lowest cost green steel production.

ArcelorMittal's strategy for AMSA is part of its global planning and it has four green steel projects in the pipeline (in Canada, Belgium and France, OECD, 2023 table 3). The European Union is moving rapidly to set expectations and the levers they will meet (including the imposition of CBAMs). ArcelorMittal is reportedly interested in South Africa in agreeing on a 1mntpa green iron offtake from Saldanha[14] and has been promoting Saldanha green steel potential in South Africa's GH2 strategy. The discussions are around 'green iron' rather than steel as the EU is concerned about job losses in the steel industry with the importation of sponge iron, meaning that the processing into steel would occur in European plants.

The renewable energy potential in South Africa can thus anchor reinvestment in the steel industry subject to an agreement being reached. South Africa is one of the most attractive international locations to make green steel, including for European export, given the renewable energy potential, existing industry base, iron ore and infrastructure (Trollip, et al. 2022). The European steel plants have to decide how to meet the EU requirements. ArcelorMittal is in a good position given its ownership of AMSA. However, the record is poor on reaching an effective framework for the industry which creates value and employment along the value chain (Andreoni, et al., 2021). Instead, the contestation over short-term rents and industry support has undermined the mutually beneficial commitments required.

4.4. Industrial strategy and political economy feasibility

The steel industry poses a complex industrial strategy challenge. The largest steel company in the world is holding out for the protection of rents and maximum policy support. At the same time, it is imperative for the development of South Africa that the investments are part of a diversified industrialisation strategy. In past instances, the allocation of rents has not delivered expected investments in upgrading the production plants and technologies. It has largely failed downstream metal fabrication and machinery industries with significant domestic value added, R&D and employment potential. In some cases, the disconnect between upstream steel production and downstream industries has paradoxically led

[13] High grade ore makes up less than 5% of global iron ore supply.
[14] This would mean around 0.5mntpa could be available for local demand.

companies to prefer importing steel products from abroad or absorbing the costs of lack of price and quality competitiveness (Andreoni et al., 2021).

An outcome which sees large subsidies and massive support for the export of green iron will have little net benefit to South Africa (and could even be harmful depending on the size of support provided). It would also be challenging to implement from a political economy perspective as it would further exacerbate power asymmetries in the metals to machinery value chains. On the contrary, an orchestrated set of interlocking investments in renewable energy and technological advancements ion steel plants directed via a set of policy conditionalities could achieve the twin goal of decarbonising the industry and re-launching the critical metals to the machinery value chain in South Africa. In the negotiation process that would lead to the design and sandboxing of public-private conditionalities, South Africa must be able to coordinate across the critical policy areas (overcoming the current fragmentation) and develops alternative options. Indeed, conditionalities work best when incentives and compulsion mechanisms are exercised with a plurality of policy and regulatory instruments.

5. Cement

5.1. Overview

The global cement industry is one of the largest emitters of GHGs in the world (Figure 1). Emissions are related to various stages of its lifecycle, ranging from quarrying, preparation and pyro-processing of raw materials or raw "meal" to grinding and transportation (Muigai, et al., 2013). Cement production is largely not traded internationally by South Africa (aside from overland exports to neighbouring countries such as Lesotho and Botswana). Production is concentrated in a few multinational companies and is subject to commitments being made by the industry at the global level (Roberts, et al., 2022). Indeed, much of the industry output is non-traded. Against the backdrop of climate change and new national and international regulations, multinational firms will have to decide where they can extract the most extensive CO_2 reduction returns in proportion to how much they would have to spend to achieve them.

The South African cement industry (as an input into other materials such as concrete, the most consumed synthetic substance, IEA, 2018) comprises several manufacturers such as aggregate producers, admixture suppliers, cement extenders (fly ash and slag) suppliers, and precast producers, cement product manufacturers (including producers of cement building blocks, fibre cement roof sheets, pipes and roofing tiles), designers of structural concrete (civil and structural engineers), building and civil engineering contractors, and small-scale cement and concrete product consumers (e.g. home builders, Muigai, et al., 2013).

In terms of its environmental impact (measured by the CO_2 intensity of a tonne of production), South Africa's cement industry ranks above the global average (756 CO_2/t compared to 686 CO_2/t in 2021).[15] The poor performance of the domestic cement industry's emissions has continued despite South Africa's GHG mitigation reporting system introduced

[15] PPC Ltd Audited Annual Financial Statements 2021.

in 2017[16]. Shifting toward a greener means of production powered by a cleaner source of power (derived from green hydrogen) can assist the South African cement industry gain a much-needed competitive edge (regionally and internationally) and contribute to a marked reduction in the CO_2 intensity of the industry's linkages.

From the standpoint of output and other crucial economic metrics, the South African cement industry (under the larger grouping of non-metallic mineral products) does not rank as one of the largest compared to other manufacturing sub-sectors such as automotives and machinery and equipment. For example, the cement industry's output only contributes between 2 and 3 per cent of the production from the manufacturing sector in 2021.[17] Cement is critical to domestic sectors, such as construction and infrastructure development.

From an institutional perspective, the South African cement industry is governed by several Associations such as the Concrete Institute (previously the Cement and Concrete Institute funded by Afrisam, Lafarge, and Sephaku) providing technical services to the industry (Lozynskyy, et al., 2014) and Cement and Concrete SA (CCSA). The decarbonisation of the sector will require buy-in from these associations and require them to act as drivers of change and GH2 adoption.

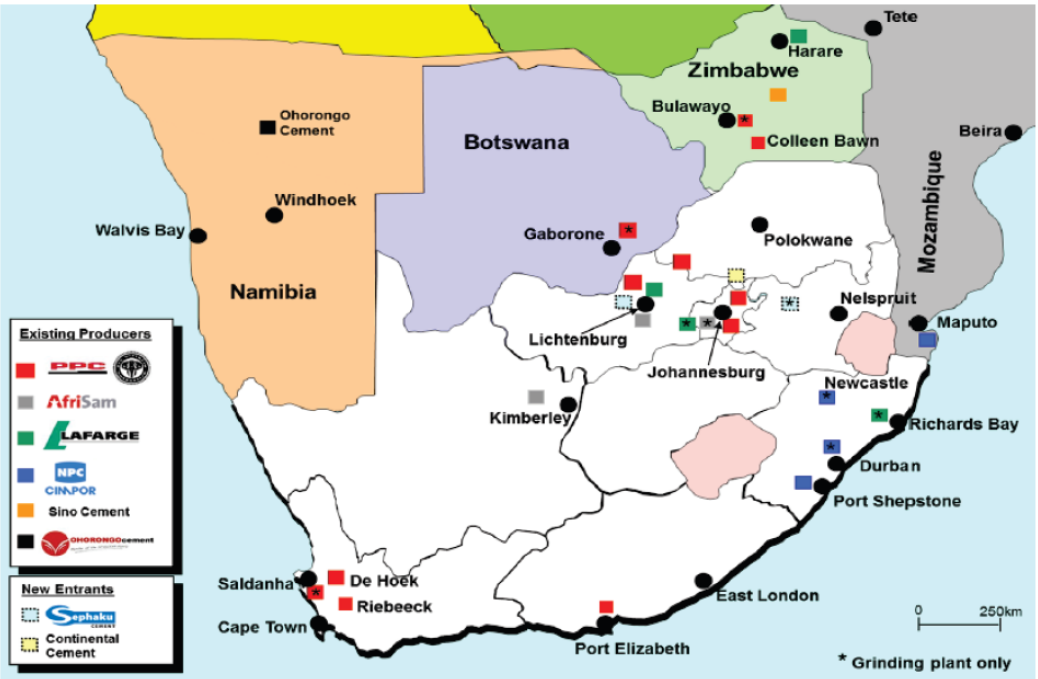
5.2. Industry structure and CO_2 emissions in South Africa

The structure of the local industry is such that large-scale production plants characterise it, and vertically-integrated firms produce a homogenous product described by high sunk costs (Paelo, et al., 2018). The main cement producers South African are PPC Ltd, Afrisam (South Africa) (Pty) Ltd, Lafarge Industries South Africa (Pty) Ltd, Sephaku Holdings, and NPC Intercement.[18] The prevailing structure of the South African cement industry has enabled it to remain relatively stable throughout its lifespan, albeit at the perils of fluctuating demand from other sectors. This stability was fostered by creating a state-governed monopoly between the big four producers (PPC, NPC, Lafarge and AfriSam) in 1940 (Lowitt, 2020). In recent times, after investigations and charges of collusion shook up the market, the South African cement industry has settled into a steady pattern of operations, with the top six producers being PPC (with a market share of 22%), NPC (15%), Sephaku (12%), Afrisam and Lafarge (9%), and Mamba (5%) as of 2016.

The South African cement industry is geographically concentrated on and around limestone deposits (Paelo, et al., 2018). This concentration of cement firms in proximity to its raw material inputs is given the low value and heavy weight of the products that make them expensive to transport (Phillips, 2022). Most cement manufacturers are located in Gauteng, with other firms operating primarily in provinces such as KwaZulu-Natal and the Western Cape (Figure 7). Due to the scale of their production, some firms have operations in multiple locations and are also engaged in operations on the downstream and upstream within the domestic value chain.

[16] South Africa's Greenhouse Gas Emissions Reporting System (SAGERS) is a Greenhouse Gas Reporting Module of the National Emissions Inventory System (NAEIS). It was developed as part of a larger suite of mitigation measures and builds off the South African National Climate Change Response Policy (NCCRP), published in 2011. The SAGERS makes it easier for companies to submit and report on their carbon budgets and mitigation plans.
[17] Based on data accessed through Quantec.
[18] Other include Mamba Cement Company (RF) (Pty) Ltd, Saint-Gobain Construction Products South Africa (Pty) Ltd, Idwala Industrial Holdings (Pty) Ltd, Bontebok Limeworks (Pty) Ltd, Kerneos Southern Africa (Pty) Ltd, Specialty Minerals South Africa (Pty) Ltd, S A Lime and Gypsum (Pty) Ltd, Afrimat Ltd, PBD Holdings (Pty) Ltd, and Cemza (Pty) Ltd.

Figure 7: Cement plants in Southern Africa, 2016



Source: AfriSam (2017)

The particular structure of the South African cement industry and its strong linkages to other sectors makes it highly vulnerable to policies and decisions are taken in other sectors and spheres of economic activity. For example, in recent years, several risks and policy choices have influenced the industry's decisions and threaten to markedly impact its competitive ability if it faces pressure from shifting global demands. One of these risks to the established producers has been the entrance of new producers, most recently with Mamba Cement and Cemza in 2014, that has intensified the industry's competitiveness (Phillips, 2022). However, to date, the most significant change within the South African cement industry came from the entrance of Sephaku, with its large-scale production plants (Roberts et al., 2022). Meanwhile, local cement producers have also benefitted through targeted policy interventions to reduce dumping and restrict the importation of cement by state-owned entities and government-funded projects under the country's localisation policies in 2021 (Erasmus, 2021).

5.3. Strategies of the leading companies for greening cement production

Several of the largest cement producers in South Africa have already begun discussing the problems of CO_2 emissions in their respective operations and are investigating the potential for implementing hydrogen as an alternative energy source. For example, PPC recognises the importance of reducing its CO_2 intensity and has committed to reducing its CO_2 intensity year-on-year to meet evolving targets set out by government institutions such as DEFF.[19] As part of its efforts, PPC has initiated several decarbonisation projects to reduce its carbon footprint in line with the requirements of the Task Force on Climate-related Financial Disclosures Creamer, 2021c). PPC's decarbonisation roadmap includes investments

[19] See Footnote 4 above.

amounting to R664m to reach its targets between 2025 and 2030 in line with global net-zero emissions by 2050 (Creamer, 2021d; Sguazzin, 2021).

Similarly, some of the main cement producers operating in South Africa have followed similar pathways and announced plans and initiatives to tackle carbon emissions from cement production. Afrisam has a long history of plans to reduce the carbon emissions of its products beginning in 1994 with the publishing of its Environmental Policy which preceded the introduction of its green cement product range in 2000. This was followed up by improvements in materials science to the point where Afrisam (in collaboration with Concrete Laser Flooring) replaced up to 70% of its cement mixture with fly ash, activated slag, and admixtures to combat the finite restrictions on cement in response to ever-growing demands for green building materials in South Africa and globally.

As one of the largest producers of cement globally, Lafarge's South African cement operations will be guided by decisions taken in other markets in response to changing sentiments around carbon emissions. Several of Lafarge's international subsidiaries have begun preparations to reduce the company's carbon footprint from manufacturing cement. This carbon reduction strategy includes a wide array (exceeding 20) of carbon capture and storage projects (CCS) across the United States, Canada, and Europe. One of Lafarge Holcim's landmark CCS projects in its Lägerdorf in Germany is planning to utilise GH2 in the production of synthetic fuel from captured CO_2.[20] This project is part of a larger consortium of companies who are turning to GH2 to decarbonise their respective sectors and break away from a traditional linear model of business and embrace a circular model that considers the whole system or value chain.[21]

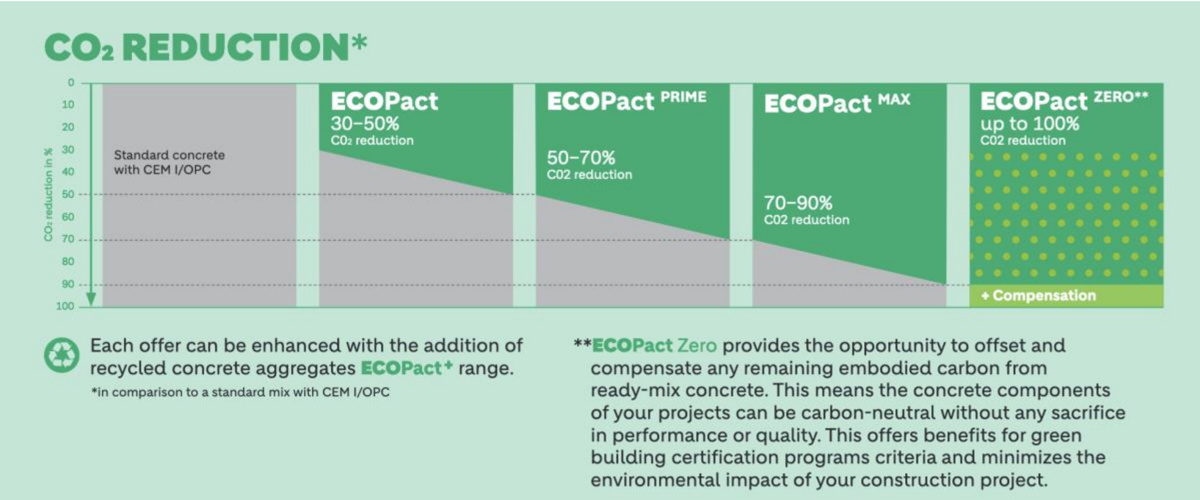
Other examples of initiatives for the greening of cement come by the way of a large investment in a solar park in Egypt.[22] In South Africa, Lafarge recently introduced its ECOPact Portland cement containing between 30% and 100% less carbon emissions made possible through recycled materials (Slater, 2022). This move was prompted by the Green Building Council South Africa's net-zero green building rating tools, launched in 2017 (Figure 8).

[20] https://www.holcim.com/media/media-releases/media-release-carbon-capture-projects-USA-germany

[21] https://fuelcellsworks.com/news/lafarge-omv-verbund-and-borealis-to-collaborate-on-major-decarbonization-project-focused-on-co2-capture-green-hydrogen/

[22] https://renewablesnow.com/news/lafarge-egypt-inks-usd-93m-solar-deal-to-green-cement-production-784650/

Figure 8: Lafarge's ECOPact



Source: Holcim

The recent initiatives launched by Lafarge and the traditional commitment of Afrisam to energy and material efficiency are promising. Still, they are mainly related to emissions reductions by blending recycled materials and reduction mechanisms to off-sets emissions. No signs of the similar ambitious plans launched internationally around GH2 for cement exist in South Africa yet.

5.4. Industrial strategy and political economy feasibility

An industrial strategy for greening South Africa's cement industry is paramount given that it possesses strong linkages into sectors such as construction, logistics, and capital equipment and is key to infrastructure development (Paelo, et al., 2018; dtic, 2020). Other sectors with strong linkages to the cement industry include agriculture, forestry and fishing, metals, metal products, machinery and equipment, petroleum products, chemicals, rubber and plastics.[23] These extensive linkages make the cement industry's products critical for achieving structural transformation and development in higher-value-adding sectors.

The overwhelming size of the largest producers in the South African cement industry means that they can influence the direction of the entire market. Moreover, given the homogeneity of the products manufactured in the South African cement industry, the industry can be considered 'competition neutral'. This means that if one firm were to facilitate a move that would guarantee a competitive edge, the other firms in the market would likely follow suit.

Transitioning to a net-zero and green energy system for the cement industry can create linkage opportunities across sectors and value chains (Nhuchhen, et al., 2022). From the standpoint of an industrial strategy for the South African cement industry, the largest producers (PPC, NPC, Sephaku, Afrisam, and Lafarge) should be considered as part of a CO_2-reduction coalition aimed at greening the cement production process in South Africa through all available means. This coalition of firms should work to rapidly reduce the CO_2 emissions from cement production to complement some other initiatives already in place, such as the increased use of recycled products (Phillips, 2022). Other initiatives this coalition can foster include CCS which can be used as a feedstock once reacted with hydrogen (IEA, 2018).

[23] Based on input-output data from Quantec using the latest data (2021).

Achieving these goals in the South African cement industry primarily concerns two key issues. Firstly, a strong case needs to be made for reinvestment by the most prominent producers to equip their plants with technologies that can enable the use and storage of hydrogen in cement production. The costs are currently high but are also expected to drop significantly over time. Examples can be found in Canada and Europe of the benefits for firms from investing in the requisite technologies to either produce hydrogen on-site or have the facility to store purchased hydrogen, or a mixture of both (El-Emam, et al., 2021). This leads to the second issue: a successful industrial strategy for greener cement production using hydrogen as a fuel for reducing energy emissions and powering carbon recycling and capture and storage technologies to reduce process emissions hinges on the geography of the industry and supporting ecosystem. Therefore, the location of hydrogen production facilities must be carefully planned in proximity to cement production hubs to reduce the losses from hydrogen transportation. This will ensure a stable hydrogen supply and allow firms to operate with higher levels of certainty, enabling them to more efficiently plan for the future and offering them a competitive edge from access to a cleaner and greener hydrogen supply for heating.

6. South Africa's proposed approach to the GH2 transition: An industrial policy perspective

6.1. The structural transformation role for green hydrogen in South Africa

Owing to the sectors' carbon intensity and the coming trade barriers in major export destinations for steel, exploring the opportunities from greener energy and production methods is paramount. Prospects have already begun materialising in the form of green energy and hydrogen technology for these hard-to-abate sectors (Andreoni & Roberts, 2022a).

GH2's unique properties have made it an ideal energy vector candidate for green transition and emissions reductions across several sectors, especially those industrial sectors relying on chemical transformations that are more difficult to abate (which include steel, cement and chemicals). There also exists strong scope for hydrogen-linkages across sectors. This is due to hydrogen-related technologies having progressed significantly, mainly thanks to the fact that there are capability similarities between existing industries such as chemicals and gas and hydrogen. Furthermore, hydrogen production, storage, transmission, handling and consumption have many overlaps with the current oil & gas industry, and the manufacture of equipment for hydrogen production and utilisation has linkages with existing industrial sectors.

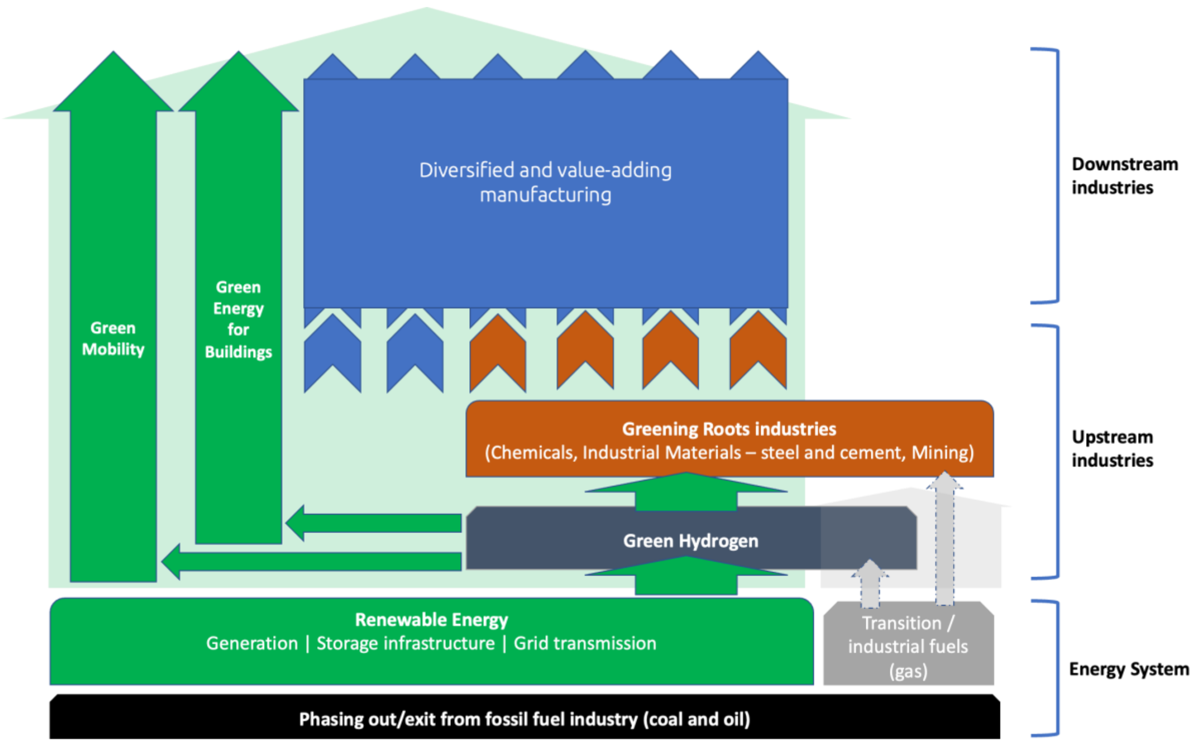
From the perspective of GH2's use in South African industries, several key stakeholders in hard-to-abate sectors (steel, chemicals, and cement) have announced plans and steps toward developing green hydrogen capabilities and solutions in South Africa (discussed more in Section 3). However, various industry-specific constraints and barriers remain, which, when combined with cross-sectoral coordination challenges, might end up restricting the hydrogen development opportunities (Andreoni & Roberts, 2022a). Disjointed initiatives that, ultimately, do not unlock systemic and interdependent investments also pose a substantial risk.

To ensure the efficacy of GH2 in South Africa's hard-to-abate sectors, coordination is first and foremost needed in upstream and downstream industries. Moreover, to supply these hard-to-abate sectors with GH2, South Africa must overcome barriers to investments in renewable energy generation upstream and infrastructural and systemic bottlenecks in transmission, storage and balancing the energy technology mix. Provided that some of these challenges are addressed speedily, the uptake of GH2 in hard-to-abate sectors needs significant and long-term financial commitment by the key industrial players.

Second, being extremely capital and scale-intensive, hard-to-abate sectors tend to have an oligopolistic industry structure. Large multinational corporations operate across countries with very different sets of strategies, capabilities and incentives. This means that despite the potential cost advantages in South Africa because of high wind and solar yields, even if these key players are globally moving towards GH2, they might not target South Africa as a key location. The reason is that the South African natural endowments of wind and solar, as well as iron ore, and technological capabilities, only become a competitive advantage if linked investments in the plants, pipelines and grid make the country a cost-competitive location.

Third, even assuming that these two barriers – renewable energy generation and GH2 investment coordination – are overcome, South Africa could still risk developing GH2 enclaves rather than an inclusive GH2 economy. It is essential to frame the GH2 risks and opportunities from a structural transformation perspective considering both sector-specific GH2 transitions – hence the required capabilities, incentives and constraints – and the structural interdependencies and potential for developing diversified linkages across sectors contributing to value addition (Figure 9).

Figure 9: A structural transformation perspective



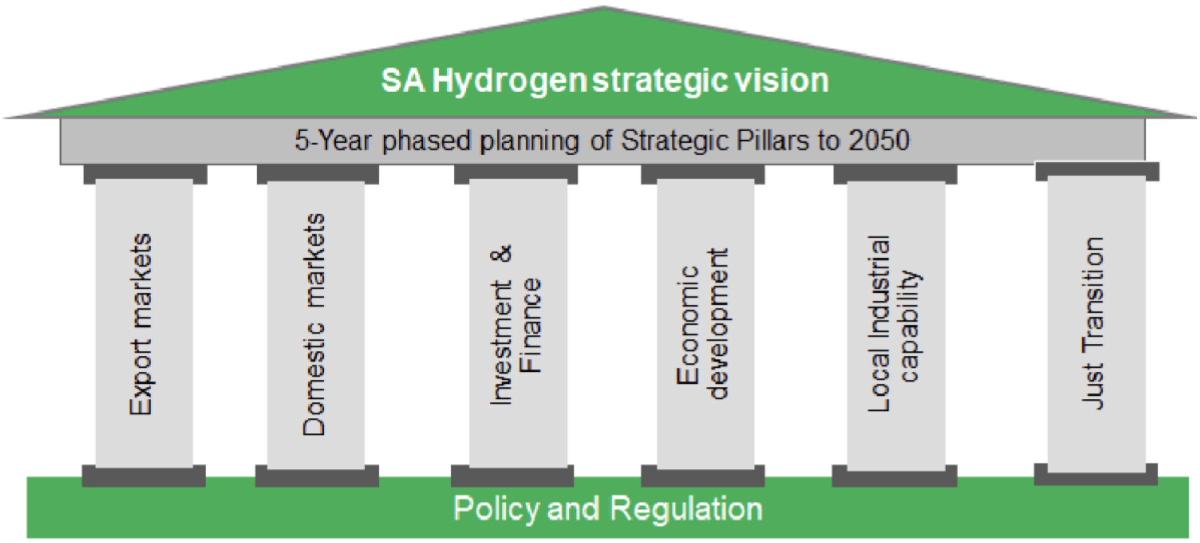
Source: Authors

There are also interlocked technological opportunities for linkages development across steel, machinery and chemicals industries. In downstream industries, as discussed above, we have seen developments in the application of fuel cells for mining and portable power generation, stationary power generation, and power for transportation (DMR, 2013). South Africa could leverage its large platinum-group metal resources to develop forward linkages in several emerging and innovative sectors, and become an exporter of value-added technologies based on its natural resources (platinum being the main catalyst in fuel cells).

6.2. South Africa's commercialisation of GH2

In line with South Africa's solar and wind potential, the Industrial Development Corporation led green hydrogen commercialisation strategy (GHCS) and the Department of Science and Innovation's hydrogen society roadmap identify the massive potential for green hydrogen production in South Africa. The evidence required for decision-making is also becoming more substantial. From the standpoint of reorientating the economy around GH2, the draft Commercialisation Strategy tries to achieve several ambitious objectives and action pillars (IDC, 2022, Figure 10).

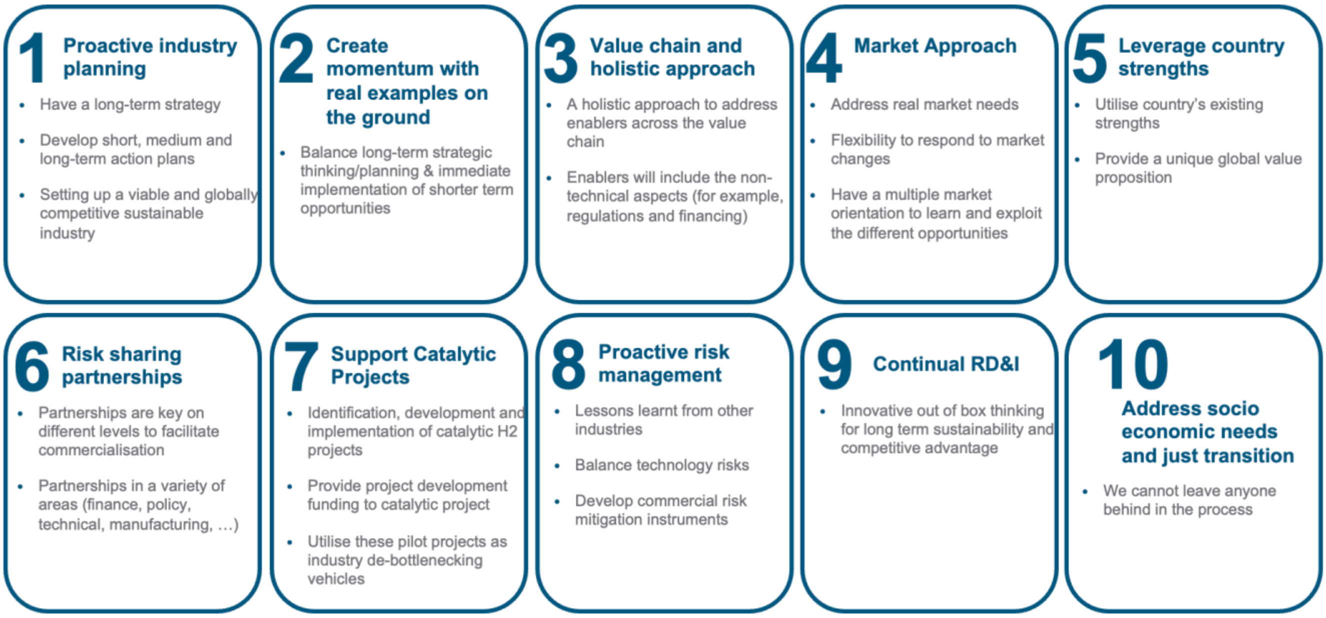
Figure 10: South Africa's hydrogen strategic vision



Source: IDC (2022)

The GHCS considers South Africa has an opportunity to aggressively position itself as an early leader of competitive GH2 exports while GH2 also plays a central role in decarbonising our discussed hard-to-abate sectors. Moreover, it aims to maximise economic and socioeconomic development benefits by supporting the development of local industrial capabilities and participation through a detailed action plan (Figure 11).

Figure 11: IDC's approach to developing the GH2 industry



Source: IDC (2023)

Regarding local economic linkages, the GHCS notes that the GH2 value chain offers significant scope for cross-pollination across a host of sectors such as government and finance, electricity, resource extraction and mining, and manufacturing (notably PGM beneficiation, steel and other metals industries, machinery and equipment for electrolysers and fuel cell stacks, and end-use applications; Table 5). These additional opportunities from a well-developed GH2 value chain also have robust feedback loops to commercialise GH2 further, generating stronger linkages with other economic sectors over time.

Table 4: GH2 linkages to other economic sectors

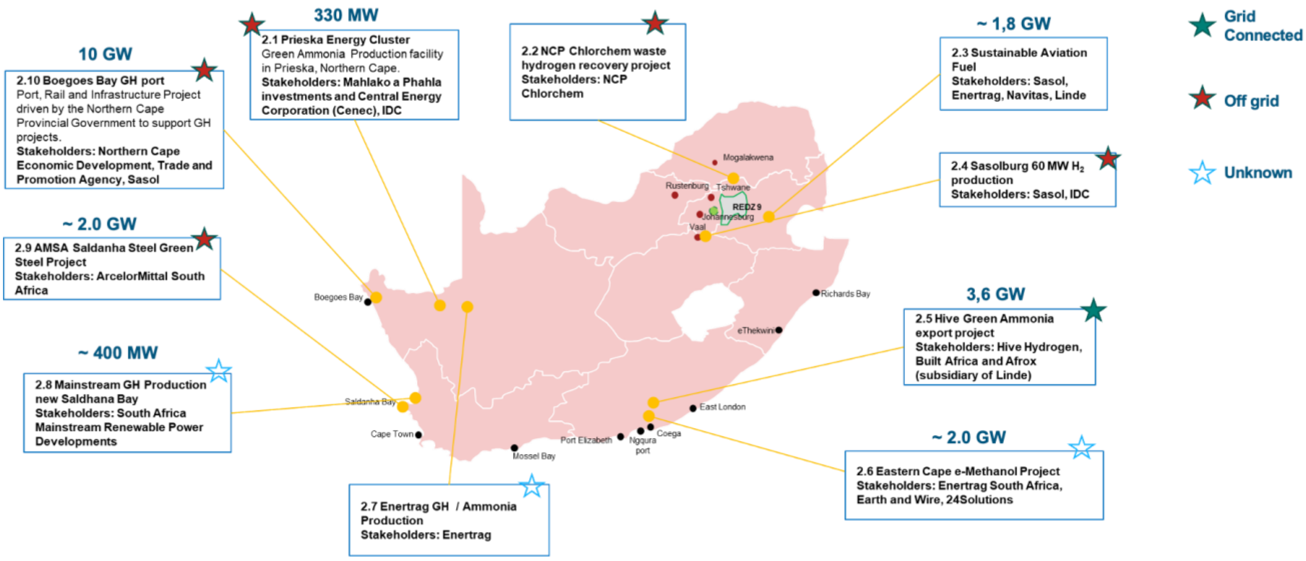
GH2 value chain / Economic sectors	Water resources	Renewable energy	Electricity grid and associated	Electrolyser and BoP	Compression, capture and storage	GH and beneficiated	Electricity from fuel cell and battery
Agriculture	X	X					
Electricity	X	X	X	X		X	X
Construction	X	X	X	X	X	X	X
Personal services							
Resource extraction and mining	X	X		X	X	X	X
Transportation and communication					X	X	
Manufacturing	X	X	X	X	X	X	X
Trade		X	X	X	X	X	X
Government	X	X	X	X	X	X	X
Finance	X	X	X	X	X	X	X

Source: IDC (2022)

From an industrial strategy perspective, the draft GHCS leverages several critical tools and levers to promote the development of GH2 capabilities in South Africa, and notably in steel and chemicals. The draft GHCS highlights similar points to our case studies as barriers to the GH2 transition that, if addressed, may foster an inclusive and sustainable GH2 transition. These barriers also impact how quickly the transition to a GH2 economy can be achieved. Some of these are sector-specific; in the cases of chemicals and steel, these are the sectors facing the most severe external risks. The decarbonisation of steel and chemicals is prominently discussed in the GHCS. In contrast, given its relatively untraded products, the cement sector is less discussed.

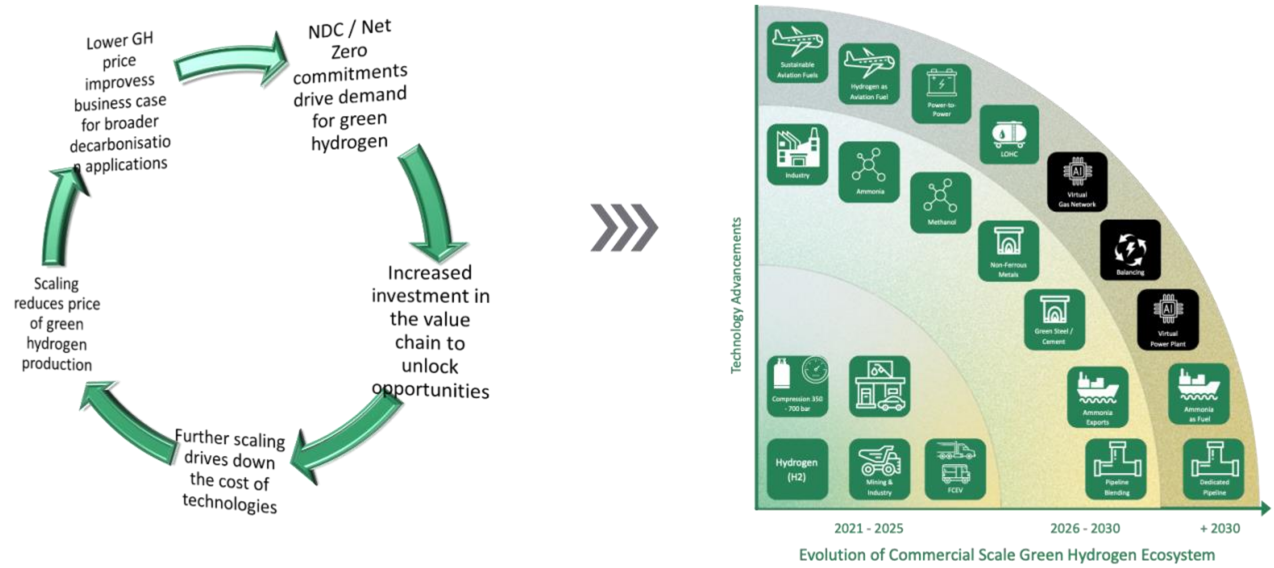
From the standpoint of promoting the development of sectoral linkages, the GHCS adopts a value chain lens that focuses on developing linkages across multiple inter-linked sectors with the potential for creating value addition and local content capabilities in solar and wind. It also speak to the need for an enabling regulatory and financial environment for GH2 and understands the deficiencies and challenges of the current financial landscape in South Africa. The GHCS places a vital importance on spatial aspects of the GH2 transition, suggesting that catalytic projects be located close to sectors with the highest potential for gains in competitiveness and exports (steel and chemicals), while nurturing the sequential development of local linkages (Figures 12 & 13).

Figure 12: Expected catalytic projects for green ammonia and steel, 2025/26



Source: IDC (2023)

Figure 13: The evolution of the IDC's value chain focus for green hydrogen



Source: IDC (2023)

The IDC's central and coordinating role in the commercialisation of GH2 marks a turning point for its mandate, which, in previous years, has been to act purely as a financier of industrial development projects earmarked by the state. By championing the GHCS, the IDC has begun to take on a greater role in South Africa's industrial policy space such that it is also directly influencing the policy decisions of the state based on its market insights and sectoral knowledge. Time will tell whether the IDC can effectively engage the interests of the prominent players in these sectors to buy into its strategic and funding directions. This can be achieved through well-governed incentives and conditionalities attached to its funding commitments.

Nevertheless, the immense scale of the GHCS and the smorgasbord of objectives in the GHCS requires coordination across various actors, stakeholders, and government departments. Because of the scale of this industrial strategy with different sectoral nuances, there are substantial risks that fragmentation and a crisscrossing of mandates may end up hindering the overall development of GH2 for industry. Similarly, buy-in, political accountability and strength will be essential for negotiating GH2 transitions and investment plans in these hard-to-abate sectors, and will require that all state stakeholders tasked with different aspects of implementing the GHCS work together to ensure South Africa's hydrogen strategic vision is realised. Furthermore, the IDC and other state stakeholders must be cognisant of the sector-specific nuances that may impede their efforts in these sectors and, therefore, overall. This also necessitates integrating and aligning the sector-specific industrial strategies with a broader set of tools and levers to ensure the successful transition of South Arica away from its persistent dependence on coal to GH2.

Achieving the GHCS will take much work. While several low-hanging fruits can be exploited for some quick wins in the GH2 industry, the wholesale success of the GHCS also rests on accomplishing other industrial and energy goals. We outline our proposals for an integrated and aligned industrial policy framework in section 7.

7. Conclusions: Towards an integrated and aligned industrial policy framework and actions for South Africa's GH2 transition

South Africa's transition to GH2 is underpinned by a set of risks and opportunities, external and internal. There is a risk that the GH2 for industry transition in heavy industries replicates the Minerals-Energy Complex industrial structure which locks in South Africa's GH2 industry around an enclave of large and leading firms, and limits the creation of downstream linkages. Realising the structural transformative potential GH2 across South Africa's hard-to-abate sectors (steel, chemicals, and cement), which form the backbone of the country's industrial structure will require targeted industrial strategies. These industrial strategies are required in order to coordinate the renewable energy investments with GH2 production for industry to decarbonise value chains. If GH2 is for the export of primary sponge steel and green ammonia then local industry linkages will be further undermined rather than deepened. The sector and value chain transitions will not be achieved solely through the efforts of the firms but necessitates combined efforts on the part of the government committing to a structured policy framework and the development finance landscape (led by the IDC).

Despite the impressive breadth of the IDC-championed GHCS, critical gaps are likely between the aspiration and implementation. Successfully navigating the GH2 for industry transition in South Africa depends on an integrated industrial and energy strategy and cross-government commitment to its realisation. The persistence of gaps between energy and industry, and between upstream and downstream firms means that enclave initiatives will result and linkages to the broader economy will not be realised. The main points which have to be addressed for an integrated framework for GH2 for the industry are as follows:

- The uncertainty about investments in the transmission grid is undermining renewable energy investments. Renewable energy is being held back as companies can only link renewable energy to GH2 if they do not require a grid connection.

- The failure to address grid infrastructure means higher costs - as projects cannot benefit from network infrastructure which should be shared. Instead of South Africa being a low-cost renewable energy producer (given solar and wind yields) it will be high cost, exemplified by the initial Hydrogen Valley plan which has high costs by international comparison due to assumptions of duplicating infrastructure and low learning effects.

- To realise the returns for green industrialisation beyond enclaves (which are either for export or only for very few ring-fenced operations such as the platinum mines), the government's strategy needs to keep up with the prominent private sector leaders in GH2 and locate the GH2 plans as part of structural transformation of the economy.

- The stop-start experience with renewable energy, including the linkages to input industries such as turbines, has undermined the credibility of the government's targets. This credibility needs to be rebuilt through actions. Plans for local turbine capabilities were not realised as demand expectations were not met when the government did not stick to initial plans.

- The renewable energy demands of green hydrogen, and the imperative for the steel, chemicals and cement industries to make the necessary changes, means massive demands for renewable energy need to be met which will attract input industries. The government needs to urgently reset expectations, committing to the grid investments under the separate independent transmission company and de-linking this from moving away from coal. Coal power will continue to be required, while the GH2 demand is additional.

- Given the measures coming into place worldwide, the hard-to-abate industries need the government to step up to the mark. We distinguish between two levels. The first level is the policy framework required for the firms to realise their narrow objectives. At the second level is the steps required for GH2 to be part of broader-based green growth so that the returns are shared, and broader support is ensured as part of structural transformation.

- In chemicals, Sasol is pushing ahead with its strategy for GH2 given its overwhelming dependence on fossil fuel feedstocks. At the same time, it has capabilities and industrial facilities to build on for GH2. The plans include anchoring the ambitious export-oriented investments for Boegoebaai and in partnership with AMSA for green steel exports from Saldanha. Our assessment points to the economic case for local industry linkages in green ammonia for fertilizer and explosives given the already much higher prices that green ammonia will compete with.

- South Africa's steel production has been based on high-quality iron ore and cheap energy. Iron ore remains an advantage, while transitioning to low-cost green hydrogen can replace import-priced coking coal as a reductant. For Saldanha Steel's electric arc furnace, renewable energy for electricity will produce green steel along with GH2 as a reductant. In AMSA's Vanderbijlpark plant, the blast oxygen furnace uses thermal coal requiring conversion to electricity for fully green production. The broad-based economy benefits will be derived from linked investments to ensure South Africa has competitive green steel for downstream sectors such as fabricated metal products.

- In cement, the multinationals in South Africa are at the forefront of moves worldwide to invest in decarbonisation. International investors are also pushing them to do this. The demand for GH2 and green energy on the part of the cement industry is a big demand-pull which can induce investments along the energy value chain.

- However, the record of the past three decades and more in South Africa is of energy-intensive exports being supported by very favourable policies, *without* shared benefits including employment creation and diversification. The backlash to this concentration in capital-intensive industries without employment generation has undermined coordination and seen the fragmentation of the state and widespread rent-seeking. It has undermined the core infrastructure in a vicious circle, bringing the economy to a standstill, sometimes quite literally.

- A concrete policy commitment to broad-based economic returns beyond the large upstream firms is essential if a broad support base is to be ensured. If the benefits of green energy for industry that South Africa's solar and wind potential offer are limited to heavy upstream industries then it will be unsustainable in political and societal terms. A small group of multinationals led by Sasol, AMSA and Anglo-Platinum may achieve decarbonisation in enclaves. Still, there will be the ongoing exclusion of the majority and a failure to lay the foundation for sustainable change in the economy's structure.

- The government strategy necessarily must be driven from the Presidency, as it is being, given the cross-economy nature of the issues. The cross-cutting nature of the investments and regulations required has concrete implications for the *institutions* required to build credibility. In particular,
    - The industry linkages and long-term investments mean that the IDC is well-placed.
    - Given the fractured nature of the energy and liquid fuels regulations, regulatory reform is essential to referee market power as part of an ‘entrepreneurial regulatory state’ that balances incentivising investment against ensuring fair terms and access to market participants. The competition authorities can undertake this with reforms to ensure more rapid decision-making and enforcement.

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Appendix

Appendix 1: CO_2 emissions by sectors and sub-sectors in South Africa, 2017

	CO2 Gg CO2	Total Gg CO2e	% national total	% sector total	% subsector total
National Total	433,406.20	512,660.60			
I - Energy	403,971.03	410,685.30	80.11%		
1.A - Fuel combustion activities	377,563.19	380,542.10	74.23%	92.66%	
1.A.1 - Energy industries	248,093.63	249,333.70			
1.A.1.a.i - Electricity generation	215,396.16	216,481.54	42.23%	52.71%	
1.A.1.b - Petroleum refining	3,328.03	3,332.99			
1.A.1.c - Manufacture of Solid Fuels and Other Energy Industries	29,369.45	29,519.13			11.84%
1.A.2 - Manufacturing industries and construction	28,645.29	28,765.51	5.61%	7.00%	
1.A.3 - Transport	53,597.63	54,694.55	10.67%	13.32%	
1.A.3.b - Road transportation	51,277.12	52,318.43			
1.A.4 - Other sectors	37,547.25	38,022.31			
1.A.5 - Non-specified	9,679.39	9,726.10			
I.B Fugitive emissions from fuels	26,407.84	30,143.10	5.88%	7.34%	
1.B.1 - Solid fuels	19.55	1,571.00			
1.B.2 - Oil and Natural Gas	641.83	641.83			
1.B.3 - Other emissions from energy production	25,746.47	27,930.40			
2 - IPPU	27,496.00	32,084.60	6.26%		
2.A - Mineral	6,257.30	6,257.30	1.22%	1.52%	
2.A.1 - Cement	5,246.40	5,246.40		16.35%	83.84%
2.A.2 - Lime	890.00	890.00			
2.A.3 - Glass	120.90	120.90			
2.B - Chemical	433.60	893.40	0.17%	2.78%	
2.C - Metal	20,274.50	20,388.70	3.98%	63.55%	
2.C.1 - Iron and steel	7,725.00	7,725.00			37.89%
2.C.2 - Ferroalloys	11,328.40	11,329.50			55.57%
2.C.3 - Aluminium	1,143.10	1,256.20			6.16%
2.D - Non-energy products from fuels and solvents	530.60	530.60			
2.F - Product Uses as Substitutes for Ozone Depleting Substances	NE	4,014.50			

Source: National Treasury (2017)