INDUSTRY STUDY

TECHNOLOGICAL CHANGE IN THE STEEL INDUSTRY

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TIPS industry studies aim to provide a comprehensive overview of key trends in leading industries in South Africa. For each industry covered, working papers will be published on basic economic trends, including value added, employment, investment and market structure; trade by major product and country; impact on the environment as well as threats and opportunities arising from the climate crisis; and the implications of emerging technologies. The studies aim to provide background for policymakers and researchers, and to strengthen our understanding of current challenges and opportunities in each industry as a basis for a more strategic response.

This industry study outlines the technological change in the steel industry, looking at emerging technologies and their impact. Other studies focussing on the steel industry map out the value chain, highlighting economic trends and the impact on national outcomes; and analyse the industry's international trends, looking at global trade and South African trade by country and product.

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CONTENTS

INTRODUCTION

A technological shift in machinery, production processes and systems is underway globally, driven by multiple factors such as geopolitical tensions, the growing need for sustainable development, demand for improved quality and precision, the need for efficiency resulting from labour costs or shortages in developed countries, and the possibilities opened by technological advancement, among others. The production of cleaner, efficient and more sustainable products is also an important contributing factor. The steel industry is no exception to technological change, as it faces significant challenges due to technological advancements and structural transformations taking place worldwide. While the South African steel industry lags in technological adoption, it is confronted with several issues, including inadequate infrastructure (such as energy and logistics), heightened exposure to geopolitical tensions, and the increasing pressure to transition towards cleaner, efficient and more sustainable steel production. These factors are placing a growing burden on local producers to embrace innovative technologies.

This report, part of a series focused on South Africa's steel industry, outlines the technological changes shaping the sector, with a specific focus on emerging technologies. It offers an overview of these technologies, analysing both their potential impacts and the key drivers of change. It covers both proven and experimental innovations across the steel value chain, providing insights into how they are influencing the future of steel production. In addition, it evaluates current technological trends in South Africa's steel sector and explores the potential disruptions these innovations may cause in the coming years.

1. EMERGING TECHNOLOGIES IN THE STEEL INDUSTRY

Globally, numerous emerging technologies are shaping the steel industry. These innovations have the potential to promote improved and sustainable production by advancing circularity and clean manufacturing practices, reducing downtime, improve human safety, reducing the time to conceptualise, develop and implement new products, and assist with market analysis, linkages to suppliers and customers, forecasting, and operational decision-making. When integrated, these technologies could work together to drive significant improvements across the industry. Table 1 discusses these different technologies, and where in the value chain are mostly employed.

Table 1: New and emerging technologies in the steel industry

PHASE OF THE IRON AND STEEL VALUE CHAIN	TECHNOLOGY	DESCRIPTION	IMPACT
Manufacturing Innovation			
Midstream and downstream	Additive Manufacturing/ 3D printing	Additive layer manufacturing describes a manufacturing process in which a digitally controlled head with a laser deposits a fine layer of raw material to construct a three-dimensional object.	Minimises waste, enhances production flexibility, and reduces lead time, fostering sustainable production.
Automation and AI			

PHASE OF THE IRON AND STEEL VALUE CHAIN	TECHNOLOGY	DESCRIPTION	IMPACT
Midstream, downstream, and consumption and end use	Artificial Intelligence (AI)	Optimises production through machine learning, predictive analytics, and automation.	Improves quality control, predicts market demand, and reduces energy consumption.
Midstream and downstream	Advanced Robotics	Robots, cobots, and autonomous systems automate tasks to reduce human exposure and improve precision.	Improves precision manufacturing, quality inspections, and work in hazardous environments.
Visualisation and Simulation			
Midstream and downstream	Augmented Reality and Virtual Reality (AR/VR)	Enables real-time visualisation of complex production processes to improve efficiency and decision-making.	Enhances safety training, design visualisation, and process simulation.
Data Management and Analytics			
Midstream, downstream, and consumption and end use	Big Data Analytics	Integrates data-driven solutions to manage production data for better decision-making.	Improves supply chain management, process optimisation, and predicts equipment failures.
Through the value chain	Blockchain	Creates immutable records of transactions to track materials from raw sourcing to final products.	Supports product traceability, inventory tracking, GHG emissions monitoring, and smart contracts.
Through the value chain	Cloud Computing	Manages large amounts of production data in real time via cloud platforms.	Optimises workflows, reduces costs, and improves supply chain management.
Sustainability and Green Steel			
Upstream and midstream	Cleantech	Integrates low-carbon technologies like hydrogen-based reduction to reduce emissions.	Enhances sustainability by improving processes, waste management, carbon capture, and water conservation.
Connectivity and Real-Time Monitoring			
Midstream and downstream	Connectivity Technologies	Enables real-time data exchange to improve operational efficiency.	Facilitates machine-to-machine communication, remote operation, and real-time data sharing.
Midstream and downstream	Internet of Things (IoT)	Uses connected sensors and equipment to gather real-time data from machinery and environmental factors.	Enhances equipment monitoring, energy management, and inventory control.

Source: Adapted from Manning and Fruehan 2001; Poojitha n.d.; Shyam Metalics 2024; StartUs Insights 2024; Steel Technology 2023; Cunningham 2022)

Upstream

In the upstream segment of the steel value chain, which primarily focuses on sourcing raw materials such as iron ore, scrap, and coking coal, several technologies are being used. These include clean technologies like green hydrogen direct reduced iron for sustainable production, cloud computing for data storage, resource planning, remote monitoring and control, and collaborative work.

Blockchain technologies are also being employed for product traceability, inventory tracking, greenhouse gas (GHG) emissions monitoring, and smart contracts. In addition, advanced robotics is automating tasks such as loading and unloading raw materials, reducing the need for human intervention. This not only enhances safety but also lowers labour costs and increases efficiency.

Mid-downstream

In the midstream and downstream phases of the steel value chain, which primarily involve primary and secondary steel production, various technologies are also employed. These include 3D printing, AI, augmented and virtual reality, big data analytics, blockchain, cleantech, cloud computing, connectivity technologies, IoT, and advanced robotics. These technologies serve multiple purposes, as detailed in Table 1. In this phase of the value chain, technologies can be categorised into two main groups: those that enhance operational efficiency and those that support improved decision-making.

Technologies used to boost operational efficiency in the mid-downstream

The following technologies are used to boost operational efficiency in steel firms: 3D printing, cleantech, advanced robotics, and connectivity technologies.

Additive Manufacturing/3D printing

Additive manufacturing, commonly known as 3D printing, is used to produce complex shapes and sizes that are difficult or impossible to achieve with traditional steel manufacturing methods. Innovative technologies in this space, such as laser powder bed fusion and direct energy deposition, help minimise material waste, increase production flexibility, and reduce lead times, all contributing to more sustainable steel manufacturing processes.

Cleantech

Cleantech solutions, such as carbon capture technologies, energy efficiency technologies and scrap metal recycling, are driving the adoption of more sustainable practices in steel manufacturing. Carbon capture technologies (although not commercially viable yet due to high investment risk as is new technology) address the challenge of climate change by capturing and storing carbon dioxide emissions produced during steelmaking. In some cases, captured carbon can even be used as a valuable resource in the production process. Meanwhile, scrap metals are recycled through electric arc furnace (EAF) processes, a method of secondary steelmaking. This process is energy-efficient, conserves natural resources, and helps reduce carbon emissions. Steel produced from recycled materials only requires 1/8th of the energy needed to produce steel from iron ore (ABB 2022). Green hydrogen and renewable energy are also seen to have potential for reducing energy use and boost energy efficiency in the production of steel – through improving of current processes and materials (ABB 2022).

Advanced Robotics

Automation and robotics have been driving forces in the steel industry for many years, and recent advancements in these technologies are set to further accelerate this trend, with continued growth expected in the future. By automating tasks such as loading and unloading feedstock for further processing, without human intervention, automation improves safety, reduces labour costs, and enhances efficiency. Automation also helps improve quality control by minimising human error in critical tasks, streamlining material handling, and reducing waste. These advancements contribute to more precise, sustainable, and cost-effective steel production processes.

Connectivity Technologies

Connectivity technologies play a crucial role in enhancing operational efficiency by enabling real-time data exchange across various systems and processes. These technologies facilitate machine-to-machine communication, allowing devices and equipment to share information seamlessly. They also support remote operation, enabling operators to monitor and control machinery from a distance, which improves flexibility and responsiveness. Real-time data sharing enhances visibility across the entire value chain, enabling more informed decision-making. By providing instant access to critical data, connectivity technologies help optimise processes, improve productivity and reduce downtime. In addition, they empower better decision-making by offering timely insights that can drive proactive adjustments, leading to increased efficiency and more effective management of resources.

Technologies used to enhance decision-making in the mid-downstream

Compared to technologies aimed at boosting operational efficiency, there are more technologies focused on enhancing decision-making. These include AI, augmented and virtual reality, big data, and analytics, blockchain, cloud computing and IoT.

Artificial Intelligence

Artificial intelligence (AI), through machine learning, analyses vast amounts of data generated by sensors and other equipment to detect patterns and make accurate predictions about equipment failures and maintenance needs. This technology optimises production processes, enhances efficiency, and contributes to quality control. Additionally, AI helps predict market demand, improve decision-making, and reduce energy consumption, making it a valuable tool for improving both operational performance and sustainability in the steel industry.

Augmented Reality and Virtual Reality

In the steel industry, augmented and virtual reality (AR/VR) technologies enable real-time visualisation of complex production processes, providing a dynamic and interactive view of operations. These technologies enhance efficiency by allowing operators to monitor and manage production lines remotely, identify potential issues, and optimise workflows. By offering precise, real-time data visualisation, AR/VR improves decision-making, enabling quicker responses to challenges and better coordination across teams. In addition, AR/VR can be used for training purposes, allowing employees to simulate complex tasks in a safe, controlled environment, which improves skills and reduces the risk of errors on the production floor. Ultimately, these technologies contribute to higher precision, greater operational efficiency, and more informed decision-making throughout the production process.

Big Data Analytics

The steel industry generates vast amounts of data daily, and big data analytics can be leveraged to transform this data into valuable insights. By analysing detailed information such as production volumes, quality control metrics, and energy consumption, companies can identify patterns and trends that help optimise production processes and reduce costs. Big data analytics also plays a crucial role in improving supply chain management by enabling better demand forecasting. This allows companies to adjust production schedules based on anticipated demand, ensuring they meet requirements while minimising waste and inefficiencies. Ultimately, big data analytics enhances decision-making, drives operational improvements, and boosts overall efficiency across the steel production value chain.

Blockchain

Blockchain technology helps create immutable records of transactions, enabling steel manufacturers to track materials from raw sourcing to the final product and ensure accountability at every stage of the value chain. This technology enhances product traceability, inventory management, and the tracking of GHG emissions, ensuring greater transparency and sustainability throughout the production process. (See Box 1. Adopting technology for MRV systems – A South African Case Study: Looking into the CSIR Greenhouse Gas Observatory).

Cloud Computing

Cloud platforms enable steel manufacturers to manage vast amounts of production data in real time, optimising workflows, reducing costs, and enhancing supply chain management. This technology supports resource planning, remote monitoring, and control, and facilitates collaborative work, allowing teams to coordinate more effectively and make informed decisions from anywhere.

Internet of Things (IoT)

IoT connects a network of devices and sensors that collect and share data in real time. In the steel industry, IoT is used to monitor tools and equipment during production processes, helping to identify abnormalities and improve operational efficiency. It also plays a crucial role in maintaining production planning by providing real-time insights into equipment performance and process status.

Consumption and end-use

In the consumption and end-use phases, data-driven technologies are primarily employed to understand consumer patterns and optimise production. Technologies such as cloud computing and blockchain are key in enhancing supply chain management, process optimisation, equipment failure detection, market demand prediction, and energy consumption reduction. In addition, advanced robotics are increasingly used to automate tasks like loading and unloading finished products without human intervention. This automation improves safety, reduces labour costs, and boosts overall efficiency across the production and distribution processes.

2. DRIVERS OF TECHNOLOGICAL CHANGE

The global steel industry is shaped by various factors. According to Steel Technology (2023), five major drivers influence technological change in the steel industry globally: technological advancements, sustainability and green steel, the shift towards high-strength, lightweight steel, changing global trade dynamics and increasing demand from emerging markets amid population growth and urbanisation.

Climate change policies are also an important consideration as these have led to protective measures such as the introduction of border carbon adjustments and tariffs, which impact the steel industry worldwide. This section focuses on the key drivers of technological change in the steel sector.

Technological advancements are significantly transforming steel production processes, enhancing efficiency, and reducing costs. For example, smart sensors and automation are improving predictive maintenance, minimising downtime, and optimising production lines. These technologies enable steel manufacturers to predict potential issues and streamline operations, leading to increased productivity and reduced waste and cost.

The growing threat of climate change and rising greenhouse gas emissions has spurred interest in low-carbon technologies and sustainable products. This has led to an increased focus on producing sustainable and green steel. In response to these environmental concerns, industries such as automotive and aerospace are seeking to improve fuel efficiency and reduce emissions, driving demand for high-strength, lightweight steel. Advanced high-strength steel and Ultra high-strength steel are gaining popularity due to their superior strength-to-weight ratios. These materials are crucial for producing lighter vehicles and structures without compromising safety or durability.

Another key driver of technological change in the steel industry is the evolving global trade landscape, influenced by geopolitical tensions such as the China-US trade dispute and the Russia-Ukraine war. These tensions have significantly impacted steel prices and availability, prompting shifts in technological strategies within the industry.

Furthermore, the industrialisation of emerging economies, particularly in Asia and Africa, is fuelling the demand for steel (although in South Africa this is a concern). Rapid urbanisation and industrialisation in countries like India, Indonesia, and Nigeria are driving increased construction and infrastructure development. This growing demand from emerging markets is a critical factor in the expansion of the global steel industry.

3. TECHNOLOGICAL CHANGES IN THE STEEL INDUSTRY

Technological changes are taking place in the global steel industry, but the extent of this transformation in the Global South remains uncertain. According to Steel Technology (2023), the industry is undergoing significant changes, particularly in production methods, with a shift toward low-carbon and sustainable practices.

The future of the steel industry depends largely on its ability to adopt sustainable production methods. Transitioning to low-carbon and eventually zero-carbon steel production is critical to meeting global climate goals. Hydrogen-based steelmaking, which substitutes hydrogen for carbon in the reduction process, shows great promise. If scaled up commercially, it could significantly reduce the industry's carbon footprint.

In addition to hydrogen-based production, recycling and circular economy practices are expected to play an increasingly key role in the steel industry. Using more scrap steel in production can reduce the reliance on virgin raw materials and lower energy consumption. Advancements in recycling technologies and improved techniques will be essential for achieving sustainability targets.

The steel industry is also embracing circular economy principles. This involves designing products for longevity, reuse, and recyclability. By minimising waste and maximising resource efficiency, the industry can reduce its environmental impact and open up new business opportunities.

Product-as-a-service models, where steel products are leased rather than sold, are gaining traction. This approach encourages manufacturers to design durable products that can be easily maintained and recycled, promoting a more sustainable and resource-efficient industry.

In the Global South, urbanisation and infrastructure development are rapidly advancing. As populations grow and cities expand, the demand for residential, commercial, and industrial infrastructure will rise. Steel will continue to be a vital material for building structures, bridges, railways, and other critical infrastructure. Governments are investing in large-scale infrastructure projects to boost economic growth and improve living standards. These initiatives, including smart cities and sustainable transportation systems, will further drive the demand for steel.

Technological innovation in materials science will continue to propel the steel industry forward. Researchers are developing new steel alloys with improved properties, such as higher strength, increased corrosion resistance, and better formability. These advanced materials will be essential for industries such as construction and aerospace, where durability and performance are paramount. Additionally, nanotechnology is expected to revolutionise steel production. Nano-engineered steels could offer superior strength, toughness, and wear resistance, making them ideal for extreme environments and high-performance applications.

Digital transformation is another key trend shaping the steel industry. The adoption of digital technologies, including AI, IoT, and big data analytics, will continue to optimise production processes and supply chain management. Predictive analytics will help manufacturers anticipate market demand and adjust production schedules, reducing excess inventory and minimising waste. Furthermore, blockchain technology has the potential to enhance transparency and traceability within the steel supply chain. By providing secure, immutable transaction records, blockchain can help prevent fraud, ensure product quality, report on GHG emissions in the steel industry and streamline logistics.

4. TECHNOLOGICAL TRENDS IN SOUTH AFRICA'S STEEL INDUSTRY

This section focuses on technological trends in South Africa's steel industry. It begins by examining the adoption of technologies within the sector and then highlights the institutional support provided by the government to foster technological adoption in the steel industry.

4.1. Technological changes in the South African steel value chain

In South Africa's steel value chain, technological adoption has primarily focused on enhancing decision-making in the mid- to downstream segments rather than boosting operational efficiency. Technologies designed to enhance operational efficiency – particularly those accelerated by the necessity of adopting new technologies during the COVID-19 pandemic – are still being explored, with investments starting to flow in this direction. However, significant progress remains necessary, especially given the increasing demand for lightweight and high-performance materials.

South Africa's steel production is increasingly dominated by mini-mills, which primarily use electric arc furnaces technologies to recycle scrap to produce steel. In contrast, the primary steel producer, ArcelorMittal South Africa (AMSA), is struggling to adjust to these structural shifts with the recently announced closure of its long steel operation in Newcastle. This shift towards secondary steelmaking, which mainly uses electric arc furnaces, is reshaping the industry. Despite these challenges, AMSA took significant steps in 2022-2023 as the push towards sustainable development intensified. The company entered into a collaboration with Sasol to explore the revitalisation of its Saldanha Steel Midrex facility (currently under care and maintenance) at the Saldanha Works plant, as part of its decarbonisation roadmap (AMSA 2023). This initiative aims to produce and export green steel using green hydrogen and other sustainable processes. As the demand for green steel grows globally, the rise of border carbon adjustments especially in Europe (UK and EU) has become a critical factor, imposing taxes on the production of "dirty" steel. These adjustments are pressuring global steel producers to invest in technologies for monitoring, reporting, and verifying GHG emissions.

In response to these global shifts, South African industries, including steel, are investing in technologies to track and report GHG emissions as a start. In particular, the Council for Scientific and Industrial Research (CSIR) is developing systems for monitoring, reporting, and the verification of GHG emissions, incorporating technologies such as blockchain and metering. These innovations are crucial for enhancing decision-making across the steel value chain, enabling producers to comply with new regulations and improve sustainability practices.

Box 1. Adopting technology for MRV systems – A South African Case Study: Looking into the CSIR Greenhouse Gas Observatory

Rasool et al. (2024) highlighted that a 2021 Boston Consulting Group survey of executives from 1290 organisations across nine major industries worldwide revealed that approximately 86% of respondents still monitor and account for GHG emissions manually. The adoption of innovative technologies, such as AI, automation, and digital platforms, offers firms an opportunity to track embedded emissions while saving time more accurately.

In South Africa, progress is being made in this area. For instance, the CSIR Centre for Robotics and Future Production is developing a greenhouse gas observatory. This observatory will collect and manage real-time data, providing accurate GHG emissions data at the product level for exporters required to report emissions to jurisdictions with strict reporting standards. The platform will be a digital solution built on blockchain technology, ensuring reliable data management and analysis (CSIR Centre for Robotics and Future Production, 2024).

Currently in its pilot phase, the platform's ecosystem allows for the installation of hardware such as energy meters and Raspberry Pi devices. These devices collect real-time data on energy consumption, which is then used to calculate GHG emissions for each product at every stage of the production process. The data is summarised using blockchain technology, and the platform generates dashboards and product-specific GHG emission reports. These reports can be used to comply with emissions reporting requirements for customers in the European Union or other regions implementing border carbon adjustments.

In addition to the exploration of blockchain technologies in the steel industry, researchers in South Africa are actively advancing laser powder bed fusion (LPBF) techniques for the metal and steel industries – a technique used in 3D printing. For instance, a team at CSIR is developing a laser powder bed fusion process designed to reduce costs by increasing build rates while maintaining structural integrity. Globally, LPBF technology is gaining traction among firms; however, its adoption remains constrained by production speed, the size of the build envelope, and the maximum part size that can be manufactured (Makoana et al., 2018).

As highlighted in an innovation report published by the HSRC (2024), manufacturing businesses in South Africa continue to invest in IoT and business intelligence technologies to enhance decision-making capabilities. However, investment in other technologies, such as those aimed at improving operational efficiency, is often hindered by funding constraints or the high costs associated with innovation.

4.2. Institutional and government support

The Department of Trade, Industry and Competition (the dtic) supports technological change as part of its industrial development support and improving global competitiveness of South African firms. Its programme aims to raise South African industries (such as steel) to embrace the use of technologies such as robotics, artificial intelligence, nanotechnologies, and quantum computing.

In addition to the dtic, several research centres are promoting research and innovation within South Africa's steel industry. Notably, Mintek, a national mineral research organisation under the Department of Mineral Resources and Energy (DMRE) and the Department of Science and Innovation (DSI), plays a key role in supporting the sector. Established in 1934, Mintek specialises in research and development (R&D) related to mineral processing, extractive metallurgy, and related fields. Mintek has engaged in various projects within the steel industry, including the development of low-nickel austenitic stainless steels (Hercules™) and innovative stainless steel rock bolts (Smartbolt™).

The DSI, alongside its agency, the CSIR, also provides R&D and innovation support for the steel industry. As highlighted in Box 1, the CSIR is actively assisting industries affected by border carbon adjustments in South Africa, demonstrating the technological capabilities and readiness of local industries. Also, the CSIR is exploring the use of 3D printing especially in the use of laser powder bed fusion for the steel industry in South Africa.

CONCLUSION

The global steel industry is undergoing a significant technological shift. While the South African steel industry faces challenges in adopting these technological changes, it must address critical issues such as inadequate infrastructure, exposure to geopolitical risks, weak demand and the urgent need to transition to greener production methods. These factors place growing pressure on local producers to innovate and adopt innovative technologies, despite the lack of financial resources.

This report has highlighted the emerging technological trends shaping the steel sector, offering a comprehensive analysis of both proven and experimental innovations. By exploring the drivers of change, it provides valuable insights into the possible future direction of steel production. As South Africa's steel industry navigates these shifts, understanding the potential disruptions and adopting innovative technologies will be crucial for its continued competitiveness and sustainability in an evolving global market.

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