MANUFACTURING AND THE CIRCULAR ECONOMY

A more competitive South African manufacturing sector through a circular economy

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EXECUTIVE SUMMARY

The circular economy is a concept gaining widespread traction globally as an effective approach to achieving a sustainable, resource efficient, and low-carbon economy, with added potential to unlock new jobs and businesses. According to the South African government, the circular economy represents a new growth opportunity for South Africa. The implementation of which will require an innovative, transdisciplinary, science, technology and innovation-based strategy, to reduce costs, and create jobs and industries that benefit the economy, citizens and the environment.

In this regard, the CSIR initiated a study to evidence South Africa's transition towards a more circular economy. The study aims to identify opportunities offered by the transition towards a circular economy, by addressing the following research questions:

1. What is the current development path for the South African manufacturing sector?
2. What could a circular development path for the manufacturing sector look like?
3. What are the business opportunities presented by a circular development path?

An overview of the circular economy concept and key underlying principles are discussed in this report from a manufacturing perspective. A synopsis of the current status of the South African manufacturing sector, as well as challenges and opportunities are presented. This is followed by the proposal of specific circular economy interventions through which the resilience, competitiveness and growth of the South African manufacturing sector can be improved. A range of circular economy related business opportunities within the South African manufacturing sector are also highlighted as a means for the sector to embrace circular economy thinking and practices and grow existing businesses.

The methodology employed included an initial desktop study aimed at understanding the relevance of the circular economy to the manufacturing sector. This was followed by a more in-depth study which involved collating secondary data through literature review, gathering primary data through stakeholder engagements, survey questionnaires, and stakeholder workshops / focus group discussions. The combined outcomes of the desktop study, data collection and stakeholder engagements allowed the project team to answer the research questions from a manufacturing sector perspective.

The analysis of the current development path of the South African manufacturing sector confirms its strong dependence on the access to resources such as energy, water, and materials, making it highly vulnerable to insecurity in supply. The South African economy is heavily dependent on the export of un-beneficiated minerals and unwrought base metals linked strongly to resource extraction from the mining sector. There is also a strong dependence on the import of finished products due to a lack of value addition and localisation in the South African manufacturing sector.

An evaluation of circular economy principles and practices, including an assessment of global case studies, highlighted the potential for the circular economy to transform the sector in terms of resilience, competitiveness and sustainability, with the added potential for economic growth and job creation in line with global trends.

Stakeholder engagement provided valuable insights into the current status of the sector with respect to the circular economy, revealing a relatively mature level of development and implementation in certain industries, but much room for expansion and scaling of circular economy interventions overall. The extent of sectoral readiness in embracing circular interventions varies widely, with some measures at a more advanced stage (e.g. material looping; resource efficiency and cleaner production; and renewable energy technologies) while certain interventions are considered to be at a lower level of readiness (e.g., green steel manufacturing, chemical leasing, circular design and manufacturing, circular business models, and bio-based fuels / materials) and will require greater action to fast-track.

Stakeholders also highlighted the challenges the sector faces in attempting to roll-out circular economy interventions, including the lack of awareness; the cost of implementing and the lack of sustainable financing mechanisms; lack of appropriate skills and local case studies / demonstration projects; and the lack of available markets.

The stakeholder feedback provides an important industry perspective regarding the South African manufacturing sector's circular economy development path, measures already implemented or planned, as well as opportunities to grow circular economy interventions within the sector.

The evaluation provides clear evidence that the circular economy offers the sector opportunities to enhance its sustainability in terms of resource utilisation, water and energy consumption, greenhouse gas emissions reduction, and waste valorisation, all of which would contribute to the sector and economy as a whole in achieving climate and sustainability goals.

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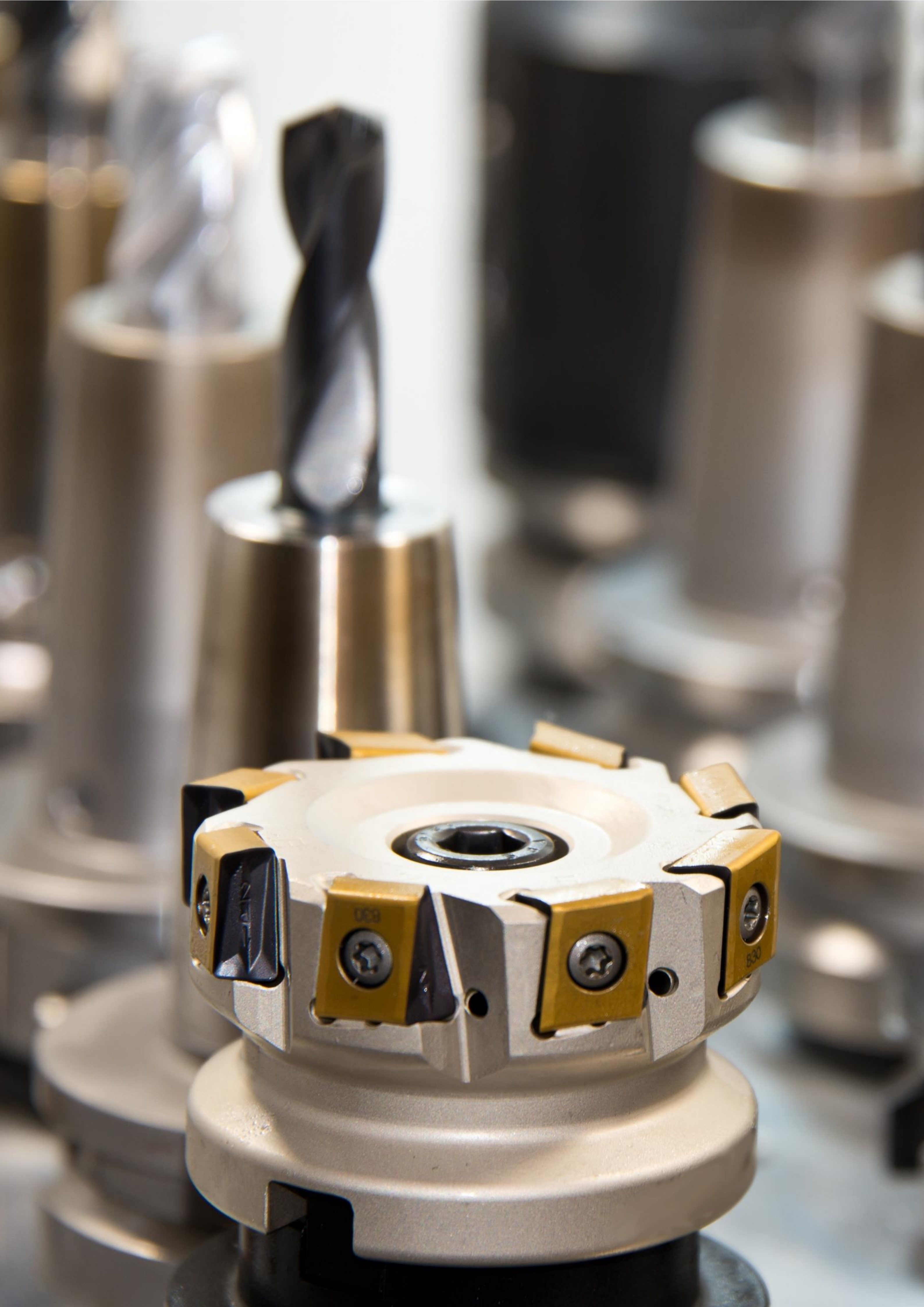
ACRONYMS

4IR	Fourth Industrial Revolution
ACEN	Africa Circular Economy Network
AEDA	Advanced electronic design automation
AM	Additive manufacturing
AR	Augmented reality
CE	Circular Economy
CEIs	CE Interventions
CO_2	Carbon Dioxide
DSI	Department of Science and Innovation
EMF	Ellen MacArthur Foundation
EPR	Extended Producer Responsibility
ESCO	Energy Service Companies
EU	European Union
EV	Electric vehicle
FCEV	Fuel cell electric vehicles
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IS	Industrial Symbiosis
IoT	Internet-of-Things
LCA	Life Cycle Analysis
NACE	National Advisory Council on Innovation
NCPC	National Cleaner Production Centre
OEM	Original Equipment Manufacturer
PGM	Platinum Group Metals
RECP	Resource Efficient and Cleaner Production
SAMS	South African Manufacturing Sector
SDG	Sustainable Development Goals
SEZ	Special Economic Zone
SMME	Small, medium, micro enterprise
STI	Science, Technology and Innovation
UNEP	United Nations Environment Programme
VCA	Value Chain Analysis
VRPs	Value-retention processes
WEEE	Waste electrical and electronic equipment
WEF	World Economic Forum
WISP	Western Cape Industrial Symbiosis Programme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1 Introduction

1.1 Background

The Circular Economy (CE) is a concept gaining widespread traction as an effective approach for achieving a sustainable, low-carbon economy, with added potential to unlock new job opportunities and business enterprises. Decarbonising the global economy is a necessary transformation for mitigating environmental challenges due to population growth, carbon-intensive technologies and the predominant linear 'take-make-waste' economic model.

The Department of Science and Innovation's (DSI) White Paper on Science, Technology and Innovation (STI), approved by Cabinet in March 2019, is one of the first South African policy documents to consider the circular economy in terms of its long-term economic growth potential (DST, 2019). The National Advisory Council on Innovation (NACI), an entity of the DSI, listed the circular economy as one of nine priority STI domains for South Africa.

According to the DSI, the circular economy represents a new trajectory for South Africa, the implementation of which will require an innovative, transdisciplinary, STI-based strategy to reduce costs, create jobs and industries that benefit the economy, citizens and the environment. According to the DSI's Deputy Director-General, Mr Patel, "*the circular economy is a very important element of a concept we are taking forward in the innovation policy space, namely innovation for transformative change. It is aimed at a deep-seated change that re-orientates societies to a much more sustainable, fairer world.*" (DSI, 2019).

1.2 Objectives

In this regard, the CSIR initiated a study to evidence South Africa's transition towards a more circular economy through STI. The study aims at mapping an appropriate development path for the local economy and, to identify business opportunities offered by the local transition towards a circular economy. A strong evidence base, combined with circular technological and social innovations, is intended to inform good policy- and strategy-making for both government and the private sector, and support the local transition to a more circular economy. The first phase of this study focussed on three key industrial sectors, namely mining, agriculture and manufacturing.

Circular economy related business opportunities are explored within each sector as well as cross-cutting activities between these sectors. This report presents the findings on the role of the South African manufacturing sector (SAMS) in a circular economy.

The following research questions were addressed:

1. What is the current development path for the South African manufacturing sector?
2. What could a circular development path for the manufacturing sector look like?
3. What are the business opportunities presented by a circular development path for the sector?

An overview of the circular economy concept and key underlying principles are discussed in this report from a manufacturing perspective. A synopsis of the current status of the South African manufacturing sector, challenges and opportunities are then presented. This is followed by the proposal of specific circular economy interventions (CEIs) through which the resilience, competitiveness and growth of the South African manufacturing sector can be improved. A range of circular economy related business opportunities within the South African manufacturing sector are also highlighted as a means for the sector to embrace circular economy principles and practices, grow existing businesses, and unlock new business opportunities.

1.3 Methodology

The methodology employed to answer the above research questions, included an initial desktop study aimed at understanding the relevance of the circular economy to the manufacturing sector. This culminated in the publication of a short, introductory briefing note entitled "*Supporting the development of a globally competitive manufacturing sector through a more circular economy*" (Fazluddin *et al*., 2021). The initial concepts of the research that were documented in the briefing note were presented at the CSIR Circular Economy project launch held in November 2021 and published by the CSIR in a book entitled "*The circular economy as development opportunity*" (Godfrey, 2021). This was followed by a more in-depth study which involved collating secondary data through literature review, gathering primary data through stakeholder engagements, survey questionnaires, and stakeholder workshops / focus group discussions, which allowed the project team to answer the above research questions for the manufacturing sector.

1.3.1 Circular economy interventions for the South African manufacturing sector

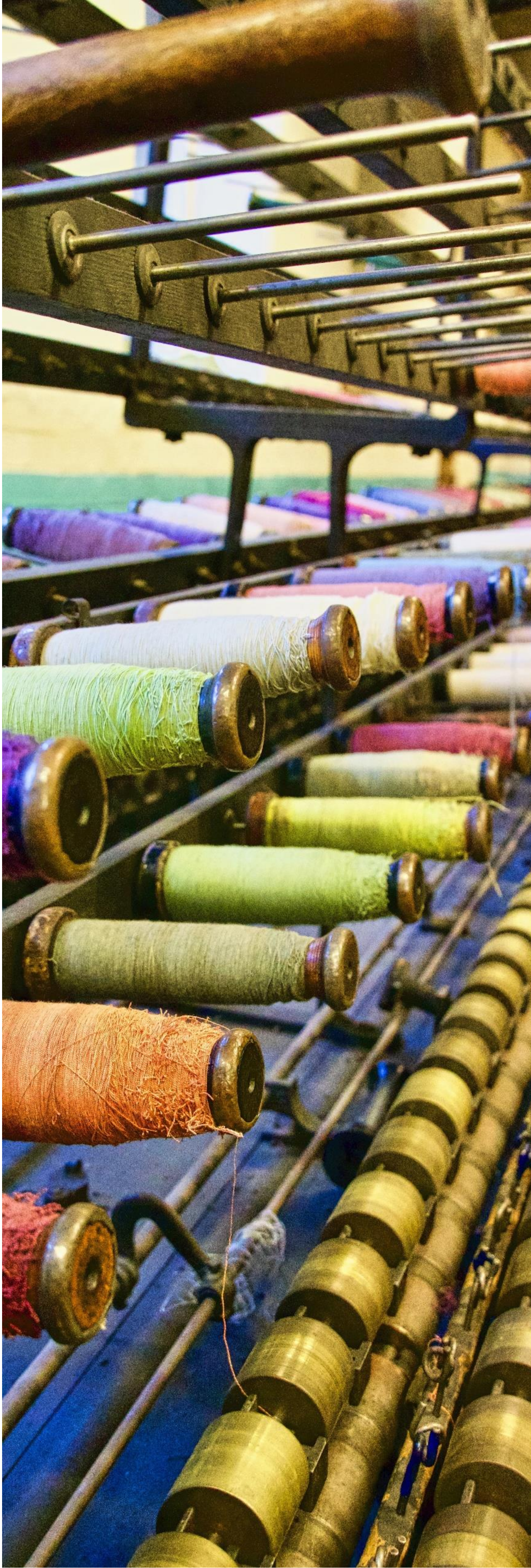
In order to assess the validity, or relevance of the proposed interventions, an external stakeholder survey was conducted whereby an online questionnaire was designed using LimeSurvey. Following a team review and approval of the questionnaire, the online survey went live on the 25 January 2022, and remained active until the 18 February 2022. A selected list of key, external stakeholders were invited to participate in the survey based on their role and experience in the sector. A total of 65 external stakeholders were invited to participate, spread across the private sector, government and non-governmental organisations (NGOs).

The survey questionnaire was divided into 3 parts: Part 1 capturing respondent demographics, Part 2 capturing prior/current involvement with circular economy related projects including affiliations to organizations such as the African Circular Economy Network (ACEN), African Circular Economy Alliance (ACEE), Ellen MacArthur Foundation (EMF), etc. Part 3 assessed stakeholder opinions on the proposed circular economy interventions. Participants were also prompted for more detailed comments on specific questions to gain further insights and opinion.

In parallel with the online survey, participants were invited to a virtual webinar-based workshop entitled "*Circular economy interventions for the South African Manufacturing Sector*" held on the 24 February 2022. A key focus of the workshop was a presentation of the survey results, with the aim of further assessing the relevance of the proposed circular economy interventions, the perceived sectoral readiness to implement these measures, and a gauge of the extent to which stakeholders considered specific interventions already implemented, or in progress of implementation.

Based on the combined outcomes of the survey responses and workshop participation, a shortlist of 14 key stakeholders were invited for one-on-one interviews aimed at gathering more detailed insight regarding circular economy opportunities in the South African manufacturing sector. Of the total invited, six stakeholders accepted the invitation and were interviewed. Pertinent points arising from the one-on-one discussions are discussed in Section 4.

This report is presented in three sections. Section 2 reviews the current development path for South African manufacturing sector. Section 3 presents an outline of the circular economy from a manufacturing perspective. The final section, Section 4 explores the circular economy development path for the South African manufacturing sector.



2 Current development path for South African manufacturing sector

2.1 Overview of the sector

The South African manufacturing sector (SAMS) has suffered from de-industrialisation over the past two decades, mimicking global trends (Buchholz, 2020). There is a need for systemic shifts in production and consumption patterns so as to enable effective resource utilisation to achieve sustainable economic growth, preserving natural capital and improving socio-economic wellbeing. However, the local manufacturing sector continues to operate predominantly on the linear 'take-make-dispose' economic model, plagued by excessive resource demand, unsustainable production and consumption patterns, and high levels of wastage (Nahman *et al.*, 2021).

Various policy and economic drivers have resulted in a declining demand from South Africa's main export markets, which has seen the sector's GDP contribution fall from over 20% in 1993 to 13% in 2020 (IDC, 2021). The SAMS, despite its decline, remains a sizeable contributor to national greenhouse gas (GHG) emissions, largely through the sector's fossil-based energy use, and liquid fuel demand (DFFE, 2021). The heavy economic dependence on resource extraction in favour of exports is well recognised (Khan *et al.*, 2022). Despite massive inputs of natural resources, productivity within the manufacturing sector remains low, while significant volumes of waste and pollution are generated (Von Blottnitz *et al.*, 2021).

2.1.1 Economic significance of the sector

The SAMS ranks fourth in GDP contribution, embodying a diverse list of sub-sectors, each demanding a broad range of resources, processed materials and finished products. The main sub-sectors by contribution (%) are as follows (StatsSA, 2018):

- food and beverages (26%)
- petroleum and chemical products (including plastics and plastic products) (24%)
- basic iron and steel (19%)
- wood products, paper and printing (11%)
- motor vehicles, parts and accessories (7%)
- glass and non-metallic mineral products (4%)
- textiles and clothing (3%)
- furniture and other manufactured products (3%)
- electrical machinery (2%)

The three largest sub-sectors account for over two thirds of manufacturing activity (IDC, 2021). Despite the sectoral GDP doubling since 1994, its contribution to national GDP has declined, forcing labour migration towards the services industry (Buchholz, 2020).

The manufacturing sector has high resource demands, relying strongly on primary and secondary processing of extracted resources (e.g. base metals) and other feedstocks. These finite resources face increasing risk from over-exploitation (Khan *et al.*, 2022). Moreover, the country mostly exports un-beneficiated ores and unwrought base metals, apart from motor vehicles, and associated spares and accessories.

The lack of local beneficiation is exacerbated by high levels of manufactured imports (>80% in 2020), comprising (IDC, 2021):

- motor vehicles, parts and accessories (13.6%)
- machinery and equipment (11.9%)
- chemical products (8.9%)
- basic chemicals (5%)

In addition, the sector draws 52% of national energy demand (DoE, 2019) (Figure 1) and 3% of the national water allocation (Figure 2) (GreenCape, 2021). Electricity costs have outpaced inflation for over a decade, exceeding R9Bn by Q3 2019 for the iron and steel subsector alone (Creamer, 2019). Blackouts have led to production losses, rising costs, reduced competitiveness and investment. Over 80% of sectoral energy is sourced from coal-fired utilities, a major source of GHGs for South Africa (USAID, 2021).

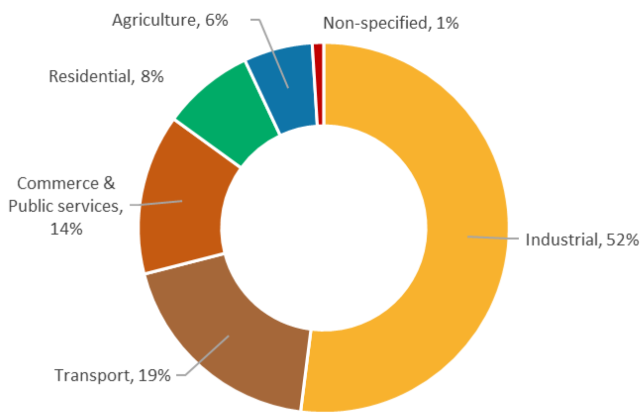


Figure 1. Energy demand in South Africa (DoE, 2019)

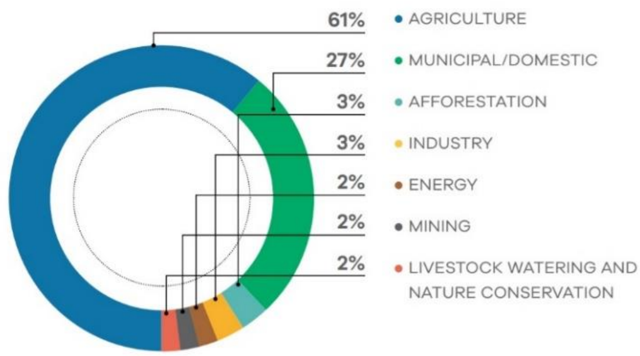


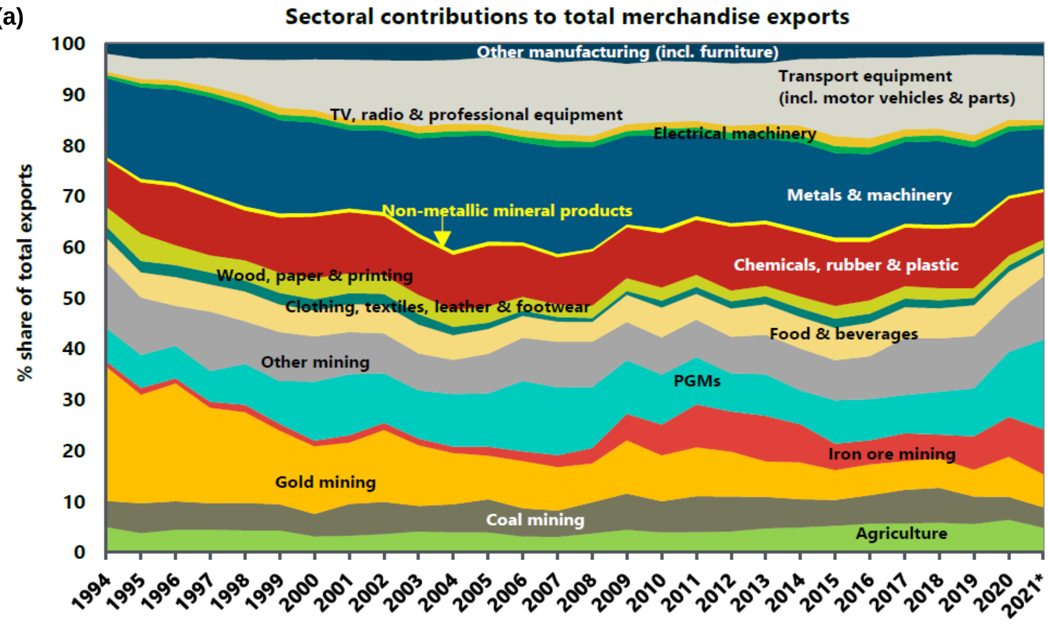
Figure 2. Water allocations in South Africa (GreenCape)

2.1.2 Historical trends and resource demands

The strong dependence on resource extraction and base metal exports is a long-standing issue as reflected by the multi-decadal trends shown in Figure 3. It is evident from these trends (Figure 3) that metals and mining have collectively contributed the major share of South Africa's total export basket for several decades, with a decline in output of gold but an increase in iron ore and PGMs over this period (IDC, 2021). It is important to note that the extraction of resources under 'other' mining includes additional minerals such as ferrochrome, manganese, vanadium and titanium-bearing ores. Some differentiation is also necessary given the fact that PGMs include smelted and base metals (unwrought), which are essentially under-beneficiated. Iron and steel, as well as other base metals are included under 'metals and machinery' and are exported as unwrought product.

Thus, sectoral exports are strongly dependent on resource extraction exported without significant local beneficiation. Figure 3 also confirms this as a long-standing historical issue with PGM exports appearing to have returned to pre-1994 levels. Demand is likely to exceed these levels due to global demand for PGM base metals for a wide variety of applications such as catalysts, transport, telecoms, etc. (Khan *et al*., 2022). The export of 'Other Mining' products also shows a rising trend signifying a rise in export demand for these minerals.

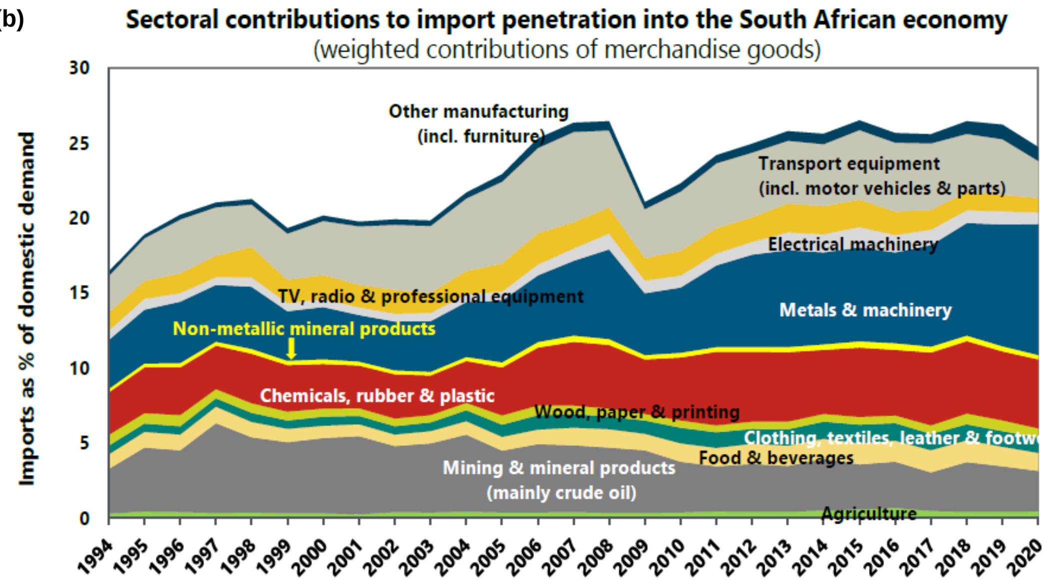
(a)



Source: IDC analysis, compiled using SARS data

Note: * January to April 2021

(b)



Source: IDC analysis, compiled using Quantec, SARB data

Figure 3. Sectoral contributions (a) % of exports; (b) imports (% of demand) (IDC, 2021)

A positive trend which cannot be ignored is the massive growth in the export of transport equipment, the bulk of which is made up of motor vehicles, parts and accessories. Whilst this has contributed positively to the growth of the South African manufacturing sector, it is important to note that almost all of the motor vehicle exports are driven by overseas-based Original Equipment Manufacturers (OEM) and their respective markets.

Sectoral imports since 1994 highlight the strong dependence on petroleum, chemicals, machinery and transport equipment. It is clear that the growth in the export of transport equipment has corresponded somewhat with a growth in the import of transport equipment, parts and accessories. This is likely to relate to the local, OEM based manufacture of motor vehicles for which import of parts are a requirement. Metal and machinery imports also grew notably, signifying a heavy dependence on base metals, including wrought metal products for manufacture of finished goods, particularly where the local manufacture of such materials may be limited or non-existent. The trends also indicate a growing dependence on imports of machinery and equipment needed for the local manufacturing sector. The import of 'mining and mineral products' refers mainly to crude oil and appears to have been stable over the period shown.

2.2 Current economic status and resource demands

The provincial contribution to manufacturing is represented in Figure 4. The figure highlights the dominant role of mining in geographically endowed provinces and the significant contributions to provincial GDP from the financial and government services sectors. An evaluation in terms of provincial sectoral contributions reflects again the heavy dependence on resource extraction driven by the dire economic need to generate revenue and balance fiscal deficit. Manufacturing is surprisingly strong in some less urbanised provinces which enjoy contributions from the automotive industry (Eastern Cape) and, Paper & Pulp industry (Mpumalanga). The performance of the manufacturing sector remains curtailed by the low demand in South Africa's main export markets in the developed world (TIPS, 2021).

The manufacturing sector labour intensity is indicated in Figure 5. The largest sub-sector in terms of employment, is the food and beverage sub-sector, followed by chemicals and petroleum, and metals and metal products. Notably, the metals sub-sector exceeds both these in terms of employment, an indication of a higher labour intensity for this sector. Importantly, the automotive sector employs fewer workers but exceeds the metals and metal products sub-sector with respect to income, highlighting the economic significance of the transport segment.

Despite GDP doubling since 1994, growth has largely been outside of manufacturing with the sector suffering persistent decline across sub-sectors and corresponding job losses. The resultant loss in manufacturing jobs has had a serious impact with labour shifting to the services industry and unwanted de-industrialisation. The end of the super-commodity cycle, global steel glut, and poor policy-making has seen sectoral GDP falling from over 20% in 1993 to about 13% in 2021 (TIPS, 2021).

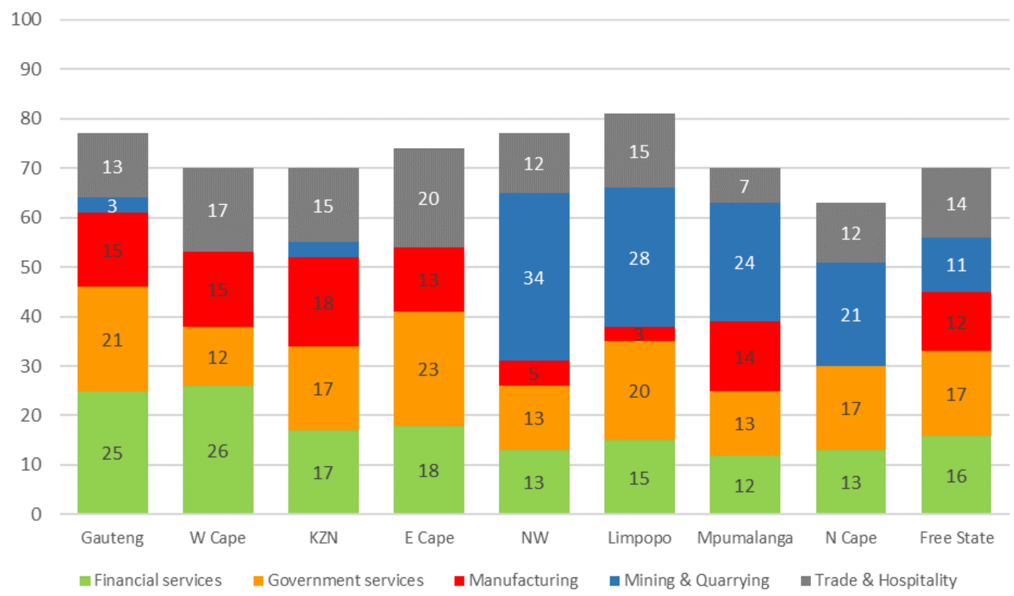


Figure 4. South Africa's provincial contribution to manufacturing sector (red) (% Revenue, RBn) (TIPS 2021)

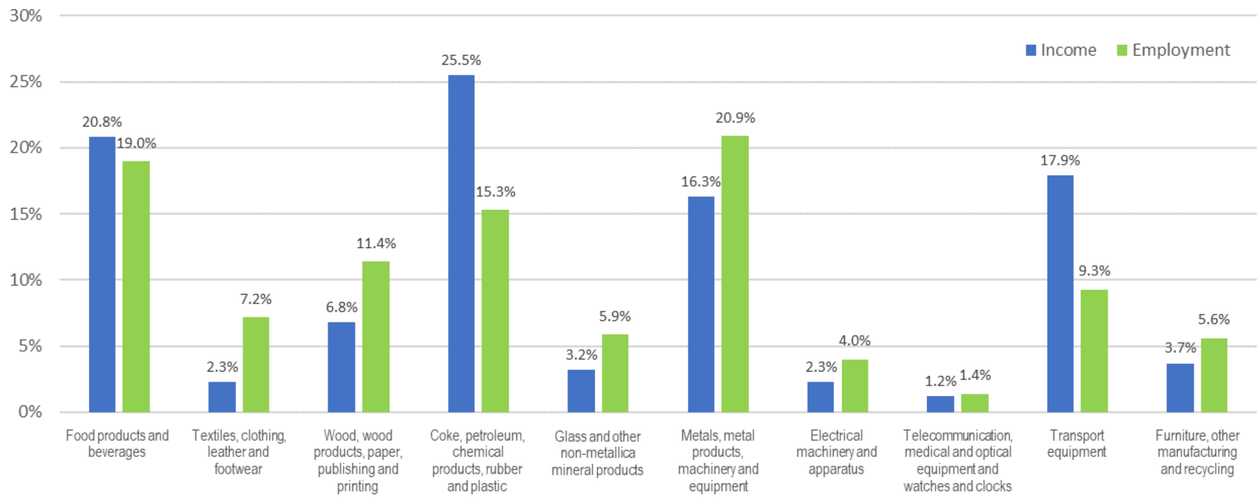


Figure 5. Manufacturing sub-sector contributions to income and employment, Q4 2019 (SAMI, 2019)

The manufacturing export basket has changed over the years, with notable growth in motor vehicle exports, including parts and accessories. This sub-sector contributes a third of sectoral GDP and produced over 500,000 vehicles on an annual basis by 2020. The main destinations are Asia, Eurozone and USA, but Africa represents the biggest export market for SA-manufactured goods, with Botswana, Namibia and Zambia as key SACU members. Whilst the strength of auto exports is viewed as an indicator of international competitiveness, there is underlying risk given that sectoral investment is mainly from foreign-based OEMs, whose global outlook is veering sharply towards Electric Vehicles (EVs) and Fuel cell electric vehicles (FCEVs).

Under-utilisation of manufacturing capacity has also been a challenge due to weak economic demand, persistent causes being insufficient demand, a shortage of raw materials, and labour. Increasing levels of imports may also contribute to under-utilisation due to a reduction in the need for local manufacturing. Energy supply and security remains a critical challenge as costs have outpaced inflation over the past decade. Electricity costs in the basic iron and steel subsector exceed R9Bn, and R2Bn in the basic non-ferrous metals industry. Blackouts contribute to lost production, raising costs and lowering competitiveness which has dampened investment in the sector. Despite recovery, trends remain volatile, due to fluctuating input costs, increasing fuel and energy costs, impending carbon border-taxes and exchange rate volatility. There is a skills shortage, regarding education levels and required mix of soft and hard skills the industry demands (Creamer, 2019).

2.3 Policy landscape

In shifting local industry towards the circular economy, numerous government policies, industry master plans, and strategic plans need to be considered. According to Creamer (2019), industrialisation coupled with increasing investment are a key focus of government policy, focusing on sectors with greatest potential for growth: automotive, textiles, leather and footwear, gas, chemicals and plastics; renewable energy, including steel and metal fabrication. Massive potential for job creation is foreseen in small- and medium-sized enterprises which must be included in manufacturing value chains. Circular economy opportunities arise based on the call towards enhanced localisation, energy efficiency coupled to GHG mitigation and fossil-fuel abatement, waste reduction and recycling.

In May 2018, government released the 10th Industrial Policy Action Plan (IPAP) (dtic, 2018), designed to tackle the decline in manufacturing and focus on transformation. Since inception, the IPAP has seen notable success, doubling production and job creation in the automotive sector, reviving the ailing tooling industry and boosting the clothing, textiles, leather and footwear sectors. Importantly, the IPAP exploits public procurement by designating certain sectors or products for local procurement based on preferential procurement regulations, viz. rail rolling stock, transformers and power pylons, transport equipment and vessels. The Black Industrialists Scheme (BIS) launched under IPAP (2015) has realized over 100 projects, R13Bn in private investment and 9000 jobs. Circular economy opportunities also reside in the development of Special Economic Zones (SEZ Act, RSA 2014) given the massive investment and job creation potential. Eleven SEZs have been designated nationwide, some of the more pertinent zones being the following: OR Tambo SEZ announced recently for the manufacture of fuel cells; Platinum Valley SEZ (Bojanala, NW) is earmarked for auto-catalyst manufacture and platinum recycling; Northern Cape SEZ (solar PV and renewables) and Tshwane Automotive SEZ. The Coega SEZ has developed into the largest with 43 operational investors worth R10Bn and 8000 direct jobs created. The Dube TradePort (KZN) is forecast to attract R18Bn of investment in its second phase of expansion, generate 12,000 jobs and R3Bn in private investment (Creamer, 2019). The African Continental Free Trade Agreement (AfCFTA) came into effect from May 2019 creating the largest global free-trade zone with a consumer market exceeding a billion consumers. South Africa is thus uniquely positioned to benefit from the increased continental trade and deeper regional integration. A priority is the listing products to be covered under AfCFTA, and 'rules of origin' as to what qualifies as a locally manufactured article.

The launch of several industry Master Plans presents further opportunities for sectoral growth and enablers towards a more circular economy. A strategic mandate of the Master Plans is localisation driven by preferential government procurement and security of raw materials, chemicals and equipment supply for local industry. The Steel Industry Master Plan (dtic, 2021) mandates locally manufactured primary steel for all key infrastructure programs including value-chain development in capital equipment, construction, transport equipment and automotive, including a Transnet roadmap for procurement of rolling stock for rail infrastructure. Cross-border carbon taxes will penalise local manufacturing, unless applied equally to imported products, hence the target for local industry on carbon neutrality by 2050. Particular emphasis is placed on power-intensive industries such as steel mills, foundries, and smelters typically reliant on fossil-fuels. Increasing use of renewable power, gas, coupled to water efficiency, waste reduction and recycling, and the hydrogen economy form a collective part of the circular economy initiatives.

Emerging manufacturing development in the green-tech market (estimated at R30Bn) presents circular economy opportunities as well. NERSA exemption on self-generation up to 100MW enables embedded generation projects under a revised IRP, addressing not only energy security through regenerative approaches, but also making local solar panel, wind tower and turbine manufacture feasible. This provides opportunities for the development of circular products in renewable energy, water recycling and desalination plants. This transition will be accelerated by a more agile government trade and industrial policy framework to lower the embedded carbon in manufactured exports. The plans call on national R&D organisations to assist in developing the green industry and "*implement circular processes*."

2.4 Summary

The South African manufacturing sector has seen a decline over recent decades in line with global trends however this has been exacerbated by several additional factors within the sectoral context. A heavy reliance on the export of un-beneficiated mineral resources and base metals, coupled with a weak demand for South African manufactured finished products as well as poor policy making, instability of energy supply, and lack of skilled labour. Long-term sustainability of the local manufacturing sector remains an ongoing challenge particularly given its predominant linear economic manufacturing approach. These factors have had a compounding effect in promoting under-utilisation of manufacturing sector capacity as well.

The sectoral contribution to GDP is dominated by three main sub-sectors, namely food and beverages (including tobacco), petroleum products and chemicals (including plastics and rubber), and metals, metal products, machinery and equipment. These being the largest in terms of both revenue and employment making up over 60% of the total sectoral contributions. The metal and metal products sub-sector exceeds both the former sectors with regard to number employed. The particular economic significance of the transport (automotive) sector was noted based on the higher relative contribution to sectoral GDP against number employed. This possibly relates to a higher level of automation and mature technologies adopted by foreign OEMs that are incentivised to manufacture motor vehicles locally.

Importantly, the sectoral overview reveals that despite the weakened status of the South African manufacturing sector relative to other economic sectors such as finance, there are growing opportunities to improve the status quo via a circular economy approach. The IPAP calls for enhanced beneficiation of local resources and localisation of manufacturing capability to address ongoing socio-economic and sustainability issues, disregarding the fact that its implementation has already seen notable progress towards revitalising local manufacturing, driving preferential procurement policy and supporting black industrialists. The establishment of SEZs has also seen substantial investment towards manufacturing. The thematic manufacturing setup within these designated zones opening up substantial scope for implementation of circular economy principles, as a means of enhancing resilience and competitiveness, creating sustainable jobs, and at the same time achieving climate and sustainability goals.

Coupled to these policy interventions promoting circular economy are various industry Master Plans and the drive by government towards the greening of the manufacturing sector and economy as a whole. The emphasis on security of supply of raw materials, preferential local procurement and infrastructure development towards locally established manufacturing value chains offer strategic levers by which a vibrant South African circular economy can be established. To cap these circular economy offerings in the making, developments in the renewables energy industry present a myriad of additional options for the application of circular manufacturing processes aimed at recycling, remanufacturing materials and components within the solar and wind energy sector, and decoupling of fossil-based energy demand via the hydrogen economy, including the adoption of EV's and FCEV's.

3 The Circular Economy - A manufacturing perspective

3.1 Introduction

Circular solutions can be leveraged locally to fulfil national development objectives, climate obligations and Sustainable Development Goals, with emphasis on economic growth, poverty alleviation, infrastructure development and job creation (WEF, 2021). The manufacturing sector has a pivotal role to play in driving re-industrialisation and the transition to a more circular economy. Indeed, the manufacturing sector, in close collaboration with other economic sectors, is centrally placed to design and implement the circularity of resources, with positive impacts on the economy, society and the environment. Manufactured products, chemicals, plastics and industrial machinery play a key role in the productivity and growth of both upstream and downstream economic sectors, such as mining, agriculture, mobility, energy, and water. Applying circular principles from the design of products, manufacturing companies can influence the production process, and indeed the entire product life cycle, including usage and end-of-life scenarios.

3.2 Key principles

The World Economic Forum (WEF, 2021) defines a circular economy as:

> *"...an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems, and business models."*

The circular economy is based on three key principles which collectively provide a systemic approach to addressing the challenges of resource extraction and demand, waste and pollution, as well as economic growth, helping to achieve economic resilience in the local manufacturing sector, as noted below:

1. *Designing out waste and pollution*: redesign manufacturing processes and products to enhance resource efficiency, coupled with sharing economy business models.
2. *Keeping materials in use*: remanufacture, refurbish, repair and recycle materials and products across value chains.
3. *Regenerating natural systems*: transition to green energy (solar, wind, hydrogen) and decouple resource utilisation.

It is important to differentiate circular economy thinking from the more well-known ideas of the green economy, waste recycling, etc. Conventional approaches to addressing environmental challenges (GHGs, climate change, habitat destruction, etc.) tend to focus on reducing impacts based on predominant linear production and consumption systems. Typical examples are improving production efficiencies and reducing material impacts to mitigate GHGs and improve resource utilisation. This overlooks systemic flaws in the 'take-make-dispose' linear model, viz. product design and use, material choices, through to low utilisation and recycling rates of products and their component materials at end-of-life. Tight product cycles are a key differentiating factor of the circular economy, circumventing the loss of embedded energy, resources and labour that occurs with simple recycling and disposal (Figure 6).

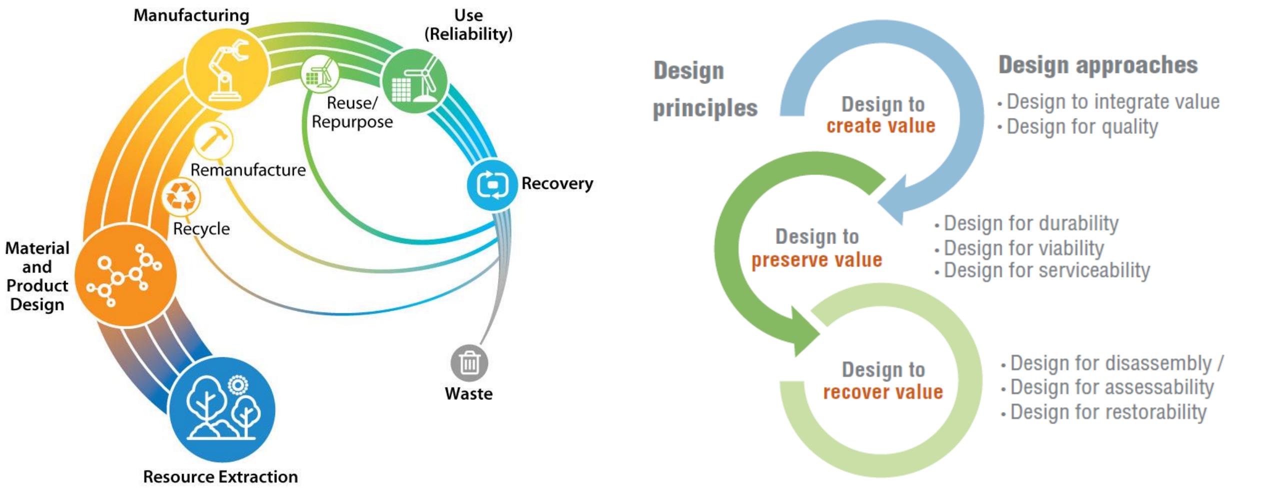


Figure 6. Integration of circular economy into manufacturing (NREL)

Preservation of natural capital by controlling finite stocks and balancing renewable resource flows is key. The circular economy model further distinguishes between technical and biological cycles, where biological materials (food, wood, etc.) are designed to feed back into the system via processes like anaerobic digestion and composting, regenerate living systems, such as soil or the oceans, which in turn provide renewable resources for the economy. Technical cycles recover and restore products (e.g. appliances), components (e.g. printed circuit boards), and materials (e.g. steel) through strategies like reuse, repair, remanufacture or recycling. Ultimately, the circular economy aims to optimise resource use by constantly circulating products, components, and materials at their highest utility in both cycles (Valencia, 2017).

An ideal circular economy aims to benefit business, environment and society collectively, maintaining natural resources at highest value ensuring re-entry into the economy, *never ending up as waste*. This implies a fundamental shift in thinking by regenerating natural capital, designing for zero waste and using renewable energy and resources. This idealised model demands co-ordination across value chains, including public and private sectors to achieve the desired transformation.

The transition to a circular economy relies on a new approach to product and system design, founded on three requirements:

- The ability to create value
- The ability to protect and preserve value
- The ability to easily and cost-effectively recover value

The way products are designed, produced, sold, used and re-used, collected, and reprocessed must be re-invented by design to distribute value across the entire industry, enabling a systemic approach to mitigate the growing challenges of resource extraction and consumption, waste generation and environmental impacts.

3.3 Global trends

Global trends demonstrate that the circular economy offers a framework for sustainable economic growth and human prosperity, as well as a means to enhance innovation and competitiveness. Local and international case studies highlight the benefits reaped by many countries that have implemented circular economy programs as part of national policy and economic framework. The newly adopted EU Circular Economy Action plan is one example, forming one of the main anchors for a regional, sustainable growth agenda in the form of the European Green Deal. The plan focuses on *design and production* for a circular economy ensuring that resources are continuously recirculated within the economy (EC, 2021). Additional examples are the Euro Commissions' Circular Economy Package (2016), Netherlands' nationwide program for a circular economy (2016) and China's 13th 5 Year Plan (2017).

The following sections highlight three disruptive global trends in the manufacturing sector:

- Remanufacturing
- Renewable energy technologies
- 4IR technologies

3.3.1 Remanufacturing

The UNEP report on remanufacturing (IRP, 2018) calls for a revolution in the way of producing and consuming, so as to move away from resource-intensive production and consumption models, towards low carbon, efficient processes, where innovation will be the motor of change. Remanufacturing and refurbishment are intensive, standardised industrial processes that provide an opportunity to add value and utility to product service life. Repair, refurbishment, and arranging direct reuse represent maintenance processes that typically occur outside of industrial facilities, providing the opportunity to extend the products useful life. The report views this as essential for achieving the Sustainable Development Goals, specifically Goal 12: Sustainable Consumption and Production, given the contributions of such processes to climate goals.

The report showcases the merits of value-retention processes (VRPs) such as remanufacturing, refurbishment and reuse within three industrial sectors, and the benefits relative to the original manufactured product. Requirements for VRPs and VRP products must be built-into early-stage product specifications, planning and business case development, well before product designers are involved in the process. For the circular economy to thrive, industry members must focus on design practices that create, preserve, and enable the recovery of value. In this manner, the material requirement, the energy used, the waste, but also the costs and the generation of jobs can be measured through first hand data from selected industries.

Relative to virgin production, VRPs require less new material and energy, generating less production waste and emissions per-unit. Studies suggest that at product-level, remanufacturing and comprehensive refurbishment can reduce GHG emissions between 79% - 99% in relevant sectors. Material savings via VRPs is also significant such that remanufacturing can reduce new materials required by 80% - 98% whilst direct reuse does not require any new materials input. Cost advantages of VRPs range, conservatively, between 15% - 80% of the cost of an OEM version of the product. VRPs rely on high-quality, durable products and components as inputs: there will always be a need for original manufacturing activity alongside VRPs and other circular economy practices.

Caterpillar's (CAT) remanufacturing program returns components at end-of-life to same-as new condition, reducing carbon, waste and raw material inputs. Caterpillar has developed a unique set of world-class salvage techniques and are able to remanufacture to the latest performance specifications, which is a crucial differentiator in the sector. Profit margins on remanufactured goods, up to 40%, can make this commercially viable, depending on the product. A challenge to the uptake of remanufacturing can be the lower cost of original goods (disregarding embedded costs). In some cases, repair, remanufacturing requires subsidisation as incentive.

3.3.2 Renewable Energy Technologies (RET)

A truly circular economy demands a comprehensive approach to resource efficiency, one that not only addresses the use of raw materials, but also energy sources. It is important to note the significant investments being made towards renewable energy technology (RET) projects in sub-Saharan Africa, as listed in Table 1 below (Hundermark, 2021):

Dealing with the end-of-life waste that will emanate from these large-scale RET developments is an important future challenge. In this regard, important lessons for Africa reside in EU developments in the area of RETs. Whilst the EU considers RETs essential for Europe's transition to climate neutrality, there are notable challenges. Deployment, maintenance and replacement of this infrastructure requires significant resources, including many substances included in the EU's list of critical raw materials (CRMs). Waste arising from end-of-life clean energy infrastructure is projected to grow up to 30-fold over the next 10 years, presenting significant opportunities to reduce the consumption of scarce raw materials by recycling metals and other valuable resources back into production systems (Figure 7). Circular economy approaches such as repair and upgrading of equipment and recycling of end-of-life infrastructure can underpin the sustainability credentials of the renewable energy transition (EEA, 2021).

Table 1. Current investments in RET Projects (sub-Saharan Africa)

Country	Source	Scale (MW)	Description of RET Development Project
Ghana	Solar	10-100	Government and Bui Power Authority announced plans to construct eight solar plants in Ghana (10MW-100MW size).
DRC	Solar	200	SNEL, state-owned utility signed power purchase agreement for two solar plants (100MW each) in copper belt region (> $300m)
Botswana	Solar	100	Shumba Energy secured $950k of $80m, 100MW solar project in Botswana - full funding expected by Q2 2022.
South Africa	Solar	100	Pele Green Energy-EDF Renewables consortium to construct 100MW plant as part of Anglo Platinum's broader strategy to integrate renewable energy with mining operations.
South Africa	Solar, wind	1000 wind 1600 solar	DMRE awards 5th bid of Renewable Energy Independent Power Producer Procurement Program (REIPPP).
Namibia	Green H2	5000	HYPHEN Hydrogen Energy selected as preferred bidder for first-ever large-scale green hydrogen project. (valued at $9.4Bn)

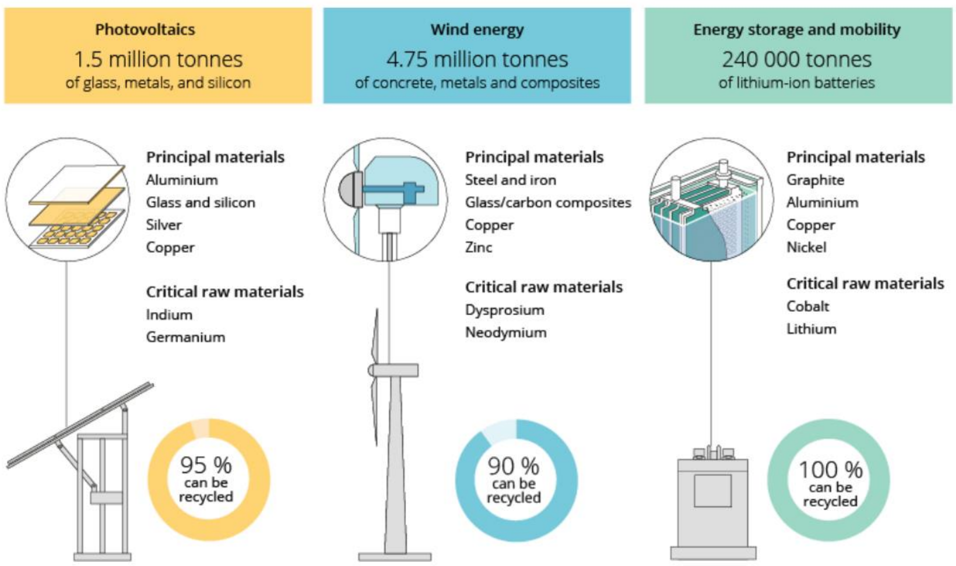


Figure 7. Material recovery opportunities from clean-energy sector by 2030 (EEA 2021)

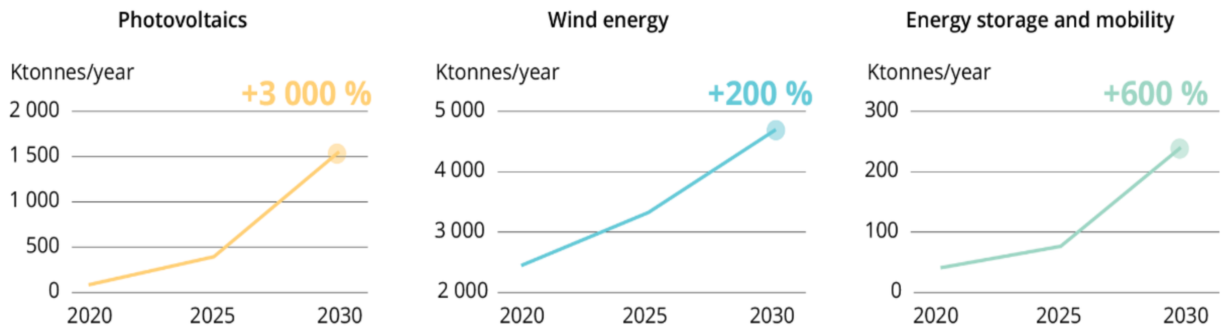


Figure 8. Expected growth of waste materials from the clean-energy sector (EEA, 2021)

Waste generation in the renewable energy sector is expected to undergo a dramatic increase in future (Figure 8) and will require attention from policy-makers. This increase will be challenging to manage, as end-of-life products may be widely distributed geographically. However, there are strong benefits as much of the wastes arising either belong to established recycling systems (e.g. steel, glass, aluminium); or are high-value critical raw materials.

The recovery of materials from renewable energy technologies and their reintroduction to production cycles, presents challenges such as (EEA, 2021):

- processing difficulties due to: use of composite materials; presence of hazardous substances; and low concentrations of more-valuable elements;
- equipment not designed to facilitate end-of-life/recyclability aspects;
- under-developed recycling capacity and technologies;
- market conditions do not properly price externalities of using virgin materials vs recycled;
- logistical issues due to remote locations, scale, and safety requirements on infrastructure.

Implementing innovative circular business models is often impeded because the ecological and climate benefits of using recycled materials are not yet fully accounted for in the costs of the materials. Therefore, suitable secondary materials regularly have to compete on price with primary materials that are often cheaper. Timeframes are also important in developing policies and protocols for dealing with the future wastes generated by this sector. Much of the infrastructure being installed will have a relatively long service life, and as such provisions are required to plan now for the environmental and financial impacts of dealing with these wastes as they arise in future.

Applying circular economy principles in the design, manufacturing and application of renewable energy technologies will mitigate the impacts by:

- applying circular business models to maintain producer responsibility
- designing infrastructure in a circular manner to facilitate reuse of components
- supporting the development of recycling to maximise recovery of materials

3.3.3 4IR Technologies

The Fourth Industrial Revolution (4IR) presents unique opportunities for innovation in advanced manufacturing, while enhancing company competitiveness and contributing to the fulfilment of societal and environmental commitments. Scaling circular manufacturing will require disruptive, as well as digital technologies such as Internet-of-Things (IoT), digital twinning, big data, and blockchain, which allow for advanced tracking and monitoring of resource utilisation and waste.

A study by WEF (2019) on 4IR technologies in the Indian state of Andhra Pradesh identified six 4IR related interventions that could unlock $5Bn a year of sustainable value for its fast-growing automotive and electronics sectors. The Andra Pradesh manufacturers envisage 200,000 new jobs being created, thanks to existing and upcoming projects across various automotive segments. In the US State of Michigan, four 4IR technologies show potential to add $7Bn annually to its automotive sector. Andhra Pradesh and Michigan State are hubs for the Indian and US automotive sectors.

The WEF (2019) study showed that new mechanisms are being developed to facilitate the adoption of 4IR technologies by bringing key stakeholders together to exchange knowledge and launch new public-private partnerships. The platforms would be integrated in a *Global Centre for Sustainable Production* that would provide further strategic guidance, encouraging innovative action that makes manufacturers more competitive and manufacturing more sustainable. The next step is to drive on-the-ground action and facilitate the implementation of 4IR technologies for competitiveness and sustainable growth.

Three technologies were specifically identified for the automotive sectors (Andra Pradesh, Michigan):

- *Cobotics 2.0 (collaborative robots):* Robots designed to collaborate with human beings to execute tasks are used in manufacturing to remarkable efficiency gains
- *Augmented workforce:* Augmented reality (AR) layers computer-generated graphics on top of an existing reality to deliver information. In AP's automotive sector, AR/VR could help to skill the 200,000 employees predicted to join the sector
- *Bio-based plastics:* Heavy metal and plastic components can be replaced with high-performance elastomers, thermoplastics and composites made partially or wholly using plant feedstock and nanotechnologies making vehicles lighter and more fuel-efficient

For the electronics sector (Andra Pradesh), the following technologies were identified:

- *3D-printed electronics:* 3DP components with metal substrates allows designers to build faster prototypes, reducing time to market and using resources more efficiently.
- *Digital traceability of minerals:* Blockchain-enabled software for precious and industrial metal markets can prevent "conflict minerals" from entering the value chains of electronic products.
- *Advanced electronic design automation (AEDA):* Simulation of electronics design that predicts material and component performance to optimise designs, in combination with machine learning can increase both design and production efficiency.

According to WEF (2019), these six technologies have the potential to create more than $5 billion in annual value whilst also supporting commitments to sustainability and circularity. There are however some risks associated with the adoption of 4IR technologies, some having a high energy footprint; others may lead to unemployment. Businesses must account for such potential negative externalities before implementing the technologies.

Additive manufacturing (AM) as a 4IR technology has clearly disrupted traditional manufacturing processes (machining, casting, injection moulding) enabling reductions in development costs, resource utilisation, waste and energy consumption. Its on-demand, digitally distributed manufacturing, allows for reduced physical inventories and more resilient supply chains. This enabling reductions in development costs and time to market, resource utilisation, waste and energy consumption, with the potential to substitute or even replace traditional processes. These unique capabilities and the rapid product design and manufacture capability without the need for centralised facilities, independent of geographic location can support the circular economy in numerous ways. These advantages are highlighted in Figure 9.

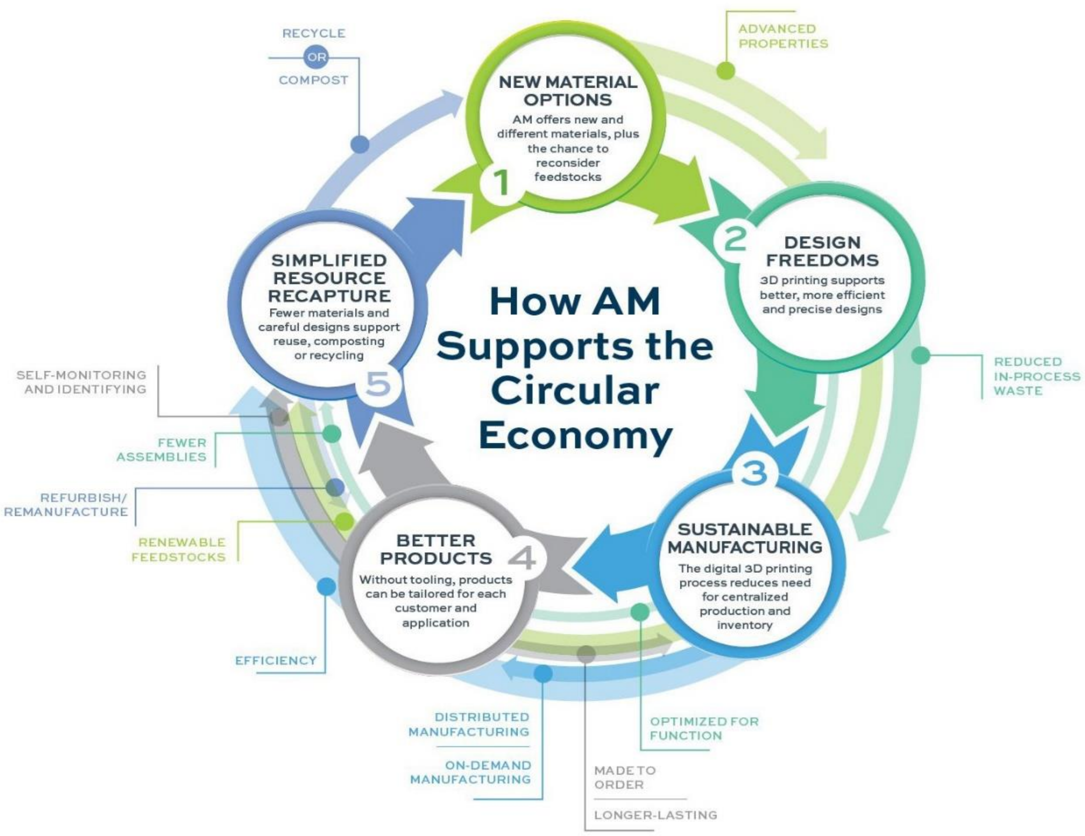


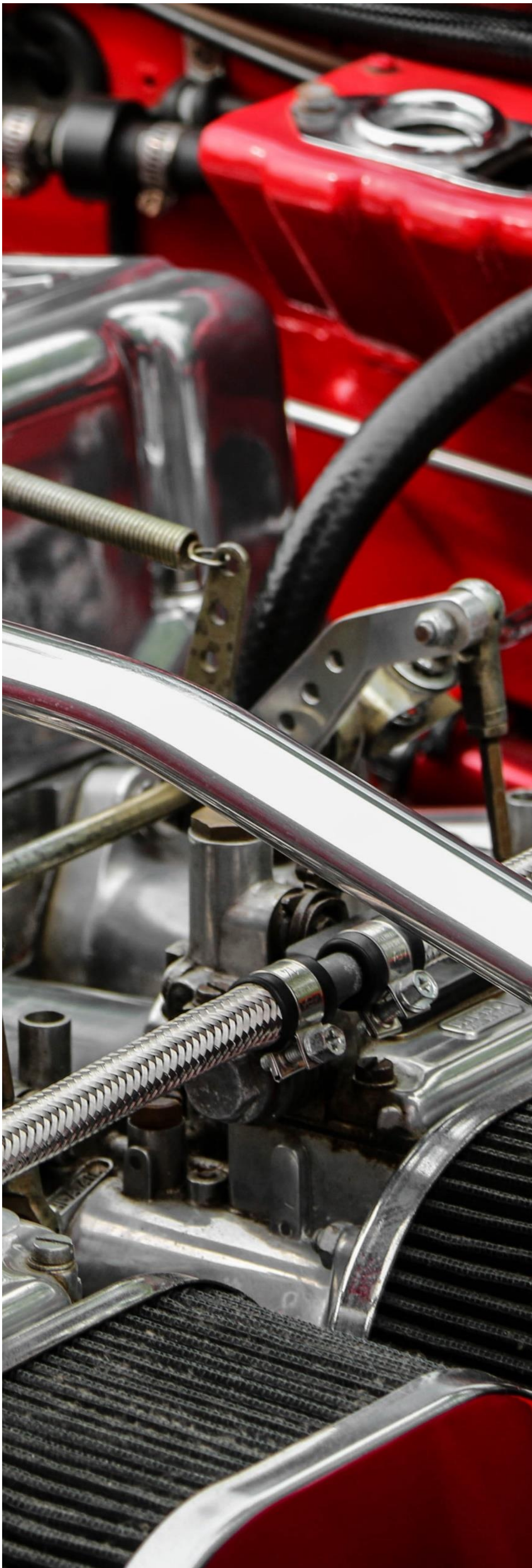
Figure 9. How Additive Manufacturing supports a circular economy (Hendrixson, 2020)

According to Hendrixson (2020), "*The circular economy needs additive manufacturing as no other method offers the design freedom, or has the ability to produce in as small a footprint, spread around the globe, sending products through numerous small supply chains. Perhaps no other method is so capable of turning production on its head, and forcing manufacturers, designers, inventors and even consumers to think differently about what gets made, bought and used*"

Some key benefits of AM that support a circular economy include (Hendrixson, 2020):

- *New material options:* Ability to manufacture with renewable feedstock (recycled metal powder or bio-polymers)
- *Design freedoms:* Allow complex geometries without moulds or other incumbent tooling, parts can be designed using less material, reducing or eliminating in-process waste, and processing time. Consolidated assemblies save time and labour in production.
- *Sustainable manufacturing:* Digital platform offers more sustainable and efficient manufacturing, avoiding the incumbent costs of conventional manufacturing such as mould tooling, jigs and fixtures, oversized stock material, etc. On-demand manufacturing allows for reduced stock held in inventory with potentially smaller footprint than conventional injection moulding or machining; this fact along with the easy mobility of digital files makes distributed manufacturing possible.
- *Smarter products:* Customised parts incorporating sensors, monitoring devices, RFID tags and QR codes to identify and monitor product over lifecycle.
- *Simplified resource:* Consolidated assemblies simplify material recovery and reuse. Recycled materials from other processes, scrap metal, etc. can be transformed into 3D printing feedstock.

AM products provide added value for responsible manufacturing, offering lightweight designs, functional integration and product designs able to solve complex manufacturing challenges, while still minimising waste. Studies also show the potential to reduce energy and carbon emissions using AM in place of conventional methods. Energy consumption of 3D printing technologies is significantly lower than conventional machining (Digital Alloys, 2019). The CO_2 emissions between AM and conventional machining are important for carbon taxes. In Europe, this is currently about $30/ton or $0.02/lb of emissions which are not yet significant to manufacturing process selection. However, any future increase renders metal additive manufacturing even more valuable against energy-intensive conventional manufacturing processes (Digital Alloys, 2019).



3.3.4 Circular textiles design and manufacturing

Currently, less than 20% of textile waste is recycled globally despite a massive environmental burden posed by current manufacturing processes. Over 1Bn tonnes of CO_2 is emitted annually from textile production, 100M tonnes non-renewable resources and 100Bn m^3 of water consumed, with over 80% of waste fibre landfilled or incinerated ($100Bn in value lost). Added to this negative environmental burden is the consumption of some 340M barrels of oil per year for plastics-fibre production, 200k tonnes of pesticide and 8M tonnes of fertilizer use for cotton production.

The textiles industry presents valuable circular economy trends from which important lessons can be derived for other industries or manufacturing sub-sectors. The value chain approach towards implementing circular economy interventions within this industry is noteworthy in the manner in which this seeks to address all three circular economy principles. In so doing, the industry seeks to ensure its sustainability, minimise waste and emissions to ecosystems, whilst simultaneously developing materials that are more eco-friendly and re-usable or recyclable (EMF 2017).

Collaborative efforts across the value chain, involving private and public sector actors, are vital for transforming the way clothes are designed, produced, sold, used, collected, and reprocessed. The burden can be mitigated via circular economy interventions that phase out hazardous substances, increase utilisation, implement renewable resources, and radically improve recycling along the value chain.

3.3.5 Circular business models

The shift to a circular economy is encouraging companies to adopt new business models in which the *performance and the service component* of products provide the added value to customers. Performance-based business models facilitate take-back, reuse, refurbishment and recycling, improving product design and manufacturing for greater use and longevity, helping to reduce resource consumption and waste and emissions. At the same time, these models can contribute to greater cost-efficiency for businesses. ENEL (2022) describes the circular economy as a strategic ally of sustainable development with a shared vision on redesigning how we address resource scarcity, global warming and waste management.

Circular business models are playing an increasingly important, and disruptive role towards the circular economy transition globally. Their significance cannot be over-emphasised given their importance toward manifesting the full potential of a circular economy transition. Some of the more commonly adopted circular economy business models (product-as-service, sharing platforms and circular supplies) are described in Figure 10. Circular economy business models, such as "product life extension" and "product-as-service" can help manufacturers tap into a $4.5 trillion global economic opportunity, but requires new technologies and processes. By developing new 4IR-enabled capabilities around the sustainable design, manufacture and servicing of products, manufacturers can grow revenues by accessing new markets and customers with new business models (WEF, 2021).

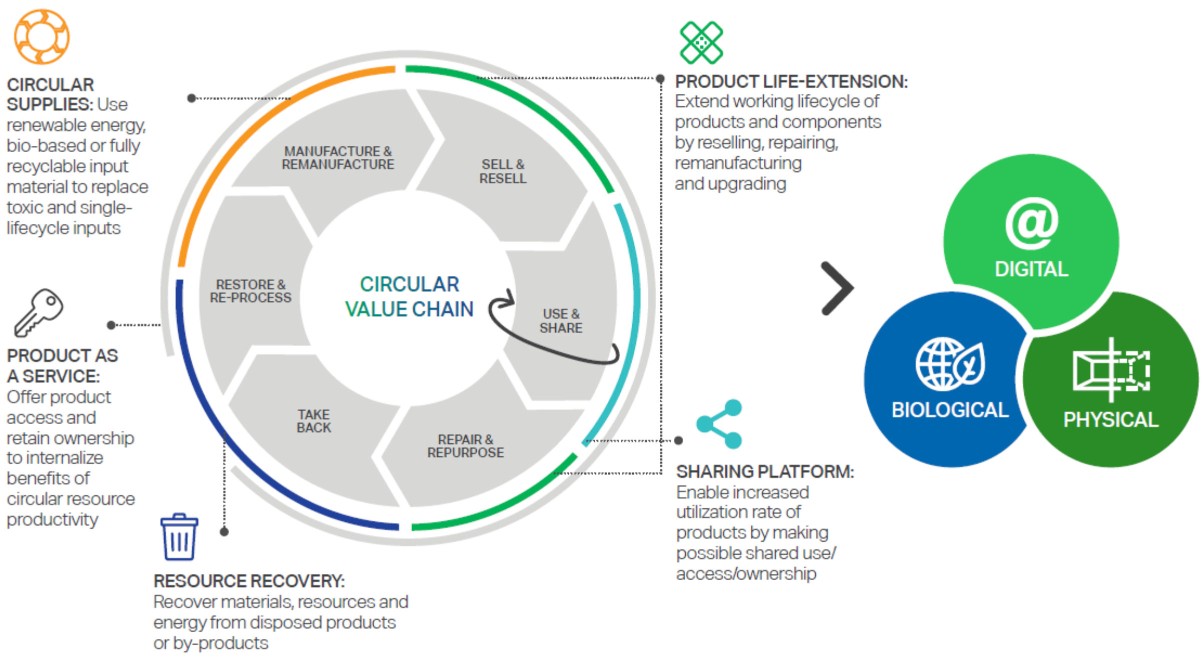


Figure 10. Circular economy business models and associated disruptive technology (WBCSD, 2017)

Chemical leasing is a state-of-the-art circular economy business model which targets more efficient use of chemicals in the production process, redefining the business relationship between chemical user and supplier. This business model has been implemented by UNIDO since 2004 and has grown substantially internationally but does not appear to feature significantly within the local industry. Chemical users are mainly interested in ensuring that the chemicals deliver the best solutions for their product and/or processes**.** By shifting focus to the performance, the user only pays per functional unit of chemical employed, thus reducing the chemical footprint along the value chain. The life cycle of chemicals is prolonged, waste is minimised, and resources used more efficiently. Application of this business model often leads to reductions in the use of other resources such as water and energy, contributing to the achievement of circular economy goals. Supplier and user both benefit because less chemicals are used when payment is linked to the functions performed. This changes the business paradigm, i.e. *the utility of a chemical and desired performance of a process/product become the centre of the buying process*.

Example include: a producer of automotive parts uses solvents to clean and degrease and pays the chemical supplier based on the per part cleaned to requisite quality levels, not volume of solvent used. An automaker needs surface protection for its parts, i.e. car body pre-treatment, surface activation and the application of a system of coatings, and by chemical leasing pays per car body protected not amount of chemicals used. Chemical leasing can be applied in many industries and processes, ranging from the textile industry to car manufacturing to agriculture.

Industrial Symbiosis (IS) is a circular economy business model wherein unused or residual resources of one company are recovered for use by another company thereby creating opportunities for keeping materials in use. By utilising waste or by-products of an industry or industrial process as raw materials for another, the model allows materials to be used in a more sustainable and efficient way. IS can support economic development and service delivery by lowering costs for waste and effluent management and creating opportunities for SMME's.

In developing circular economy business models, the importance of specific modelling and/or analytical tools such as Life Cycle Analysis (LCA) and Value Chain Analysis cannot be overlooked. Both tools form an important part of circular economy modelling and analysis. LCA, for example, can assist brand owners understand the environmental footprint of their product and make smarter choices across its entire lifecycle, including early-stage material choices and end-of-life options (UNEP, 2021).

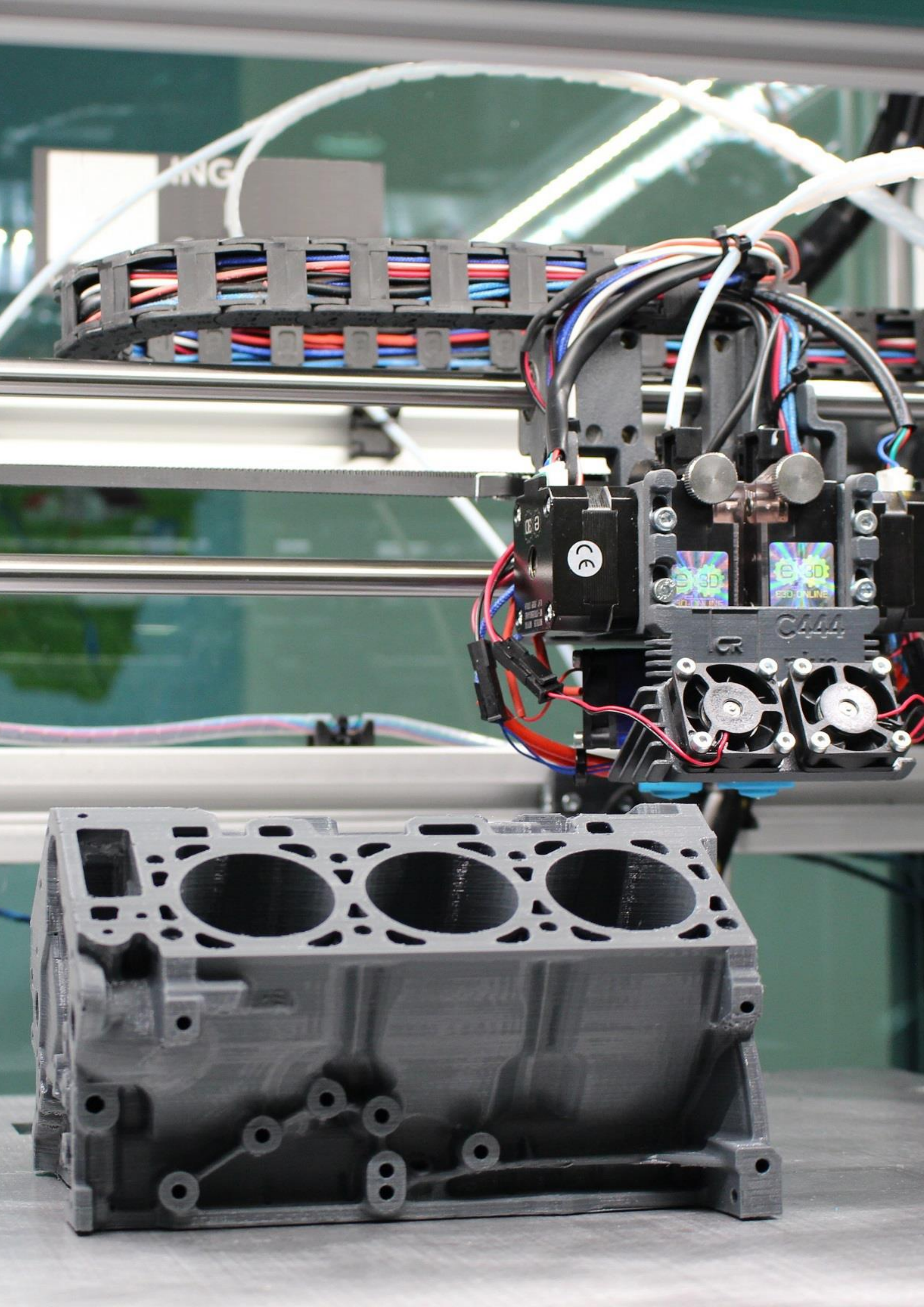
3.4 Summary

The manufacturing sector has the potential to play a pivotal role in transitioning South Africa to a more circular economy. Based on its diversity of resources and products, the manufacturing sector is centrally placed towards the attainment of effective resource decoupling, with positive impacts on the economy, society and the environment. Applying circular principles in the design of products, manufacturing companies can influence the production process, and indeed the entire product life cycle, including usage and end-of-life scenarios.

A review of global trends identified a variety of innovative circular economy interventions with the potential to disrupt the sector. These include remanufacturing of machinery and equipment, a relatively well-established methodology in the automotive sector. Remanufacturing, together with other value-retention processes (VRPs) such as refurbishment and reuse, create, preserve, and enable the recovery of value. Other trends include the substantial investments towards the development of large-scale renewable energy technologies across the sub-Saharan region as a means to counter climate change and decouple from fossil-based fuels, mainly coal. However, studies highlight the longer-term challenge regarding the end-of-life waste projected from these clean energy technologies, which creates significant circular economy opportunities for reducing consumption of scarce raw materials by recycling back into production systems, and repair and upgrading of equipment.

Unique opportunities for innovative circular economy interventions also lie in the adoption of disruptive 4IR technologies such as digital twinning, big data and blockchain, cobots in the workforce, the exploitation of augmented reality for training and operations, and the application of bio-based materials in the manufacture of advanced, lightweight components. Included in the suite of 4IR technologies advancing circular economy implementation is additive manufacturing, which creates opportunities to reduce energy consumption, development costs, resource utilisation and wastage. Its on-demand, digitally distributed manufacturing, allows for reduced physical inventories and more resilient supply chains.

Chemical leasing and Industrial Symbiosis are two important circular economy business models that have been adopted globally, helping to achieve more sustainable resource and energy use and waste reduction. Importantly, 4IR-enabled capabilities around sustainable design, manufacture and servicing of products, can help producers grow revenues by accessing new markets and customers with new business models.



4 Circular economy development path for the manufacturing sector

This section explores the development of a circular economy path for the South African manufacturing sector. In so doing, the study attempts to address specific questions regarding appropriate circular economy interventions (CEIs) for the sector; the sector's readiness to adopt the envisaged CEIs; obstacles towards their implementation in South Africa; and potential business opportunities arising from the implementation of the CEIs. Each of the research questions is distinctly addressed in the following sections below based on engagement with sector stakeholders.

4.1 Circular economy interventions

Based on the current status of the local manufacturing sector and the associated challenges, as well as a survey of circular economy practices, global case studies, and emerging trends, several CEIs were identified as relevant to the manufacturing sector. These interventions are based on the ability to decouple resource demands from growth, their impact towards improving sectoral resilience and competitiveness, meeting climate and sustainability commitments, as well as growth in revenue and sustainable jobs. The identified CEI's are listed in Table 2 below.

Each of these CEIs have been discussed in some detail in the preceding section. Their merits have been highlighted on the basis of local and international case studies as embodying the key principles of circular design and manufacturing, material looping, and regeneration, as well as considering innovative circular economy development opportunities.

It was important to assess the relevance of the proposed CEIs, their sectoral readiness and obstacles towards their implementation, amongst other considerations, based on independent feedback from external stakeholders. The validity of the stakeholder assessment thus forms an important weighting factor based on the survey demographics, having targeted experienced, senior, sector stakeholders.

The response to the survey therefore represents a very important outcome given the strong representation from Senior Management / Executive (66% of respondents). In addition, 68% of the respondents had over 10 years of experience in the manufacturing sector, with 42% of participants having more than five years of prior or current experience in circular economy related projects (see Appendix 1). External stakeholders have therefore brought a deep understanding of the South African manufacturing sector, and the potential for circular economy interventions, to the discussion. In addition, these are stakeholders that have the ability to drive and influence change in the manufacturing sector and unlock circular economy opportunities.

Table 2. Proposed circular economy interventions (CEIs) for South African manufacturing sector

CE Intervention	Description & Benefits
4IR Technologies	Fusion of technologies: AI, robotics, IoT, quantum computing, etc
Additive Manufacturing	Making of products by adding consecutive layers of material (3D printing)
Bio-based fuels / materials	Renewable fuel or materials derived from biomass feedstock, e.g. wood
Chemical Leasing	Value-addition model where client pays per functional unit of chemical used
Circular Business Models	Manages product lifecycle and associated costs by changing usage patterns
Circular Design & Manufacturing	Optimise material use, durability & repairability to design out waste
Circular Textiles Design & Manufacturing	Use durable, eco-friendly textiles & processes to avoid harmful chemicals
Green Steel Manufacturing	Use of renewable energy to generate hydrogen to replace fossil fuels
Industrial Symbiosis	Processing waste/by-products of one process as raw material for another
Material Looping	Converting products/materials to new products whilst retaining properties
Remanufacturing	Optimise resources by recirculating products/materials at highest utility
Renewable Energy Technology	Energy production via renewable sources (solar, wind, hydro & biomass)
Resource Efficient & Cleaner Production	Integrated approach to enhance efficiency of process, product & service

4.2 Appropriateness of circular economy interventions for South Africa

This section highlights the outcomes of the stakeholder engagement process which was aimed at assessing the appropriateness of the proposed CEIs for the South African manufacturing sector. Select comments and observations from stakeholders on the appropriateness of CEIs are also included below.

4.2.1 Stakeholder engagement

When asked to what extent stakeholders agree that these CEIs can benefit the South African manufacturing sector, the results showed a high level of agreement for most of the interventions, with an emphasis on the more commonly practiced interventions. High levels of agreement on the benefit of CEIs were noted for Resource Efficiency & Cleaner Production; Materials Looping; Renewable Energy Technologies; and Circular Design & Manufacturing (Figure 11). There was some level of uncertainty with regards to the less familiar CEIs such as Chemical Leasing; Industrial Symbiosis; Additive Manufacturing; and Circular Textiles Design & Manufacturing (Figure 11). The level to which stakeholders agreed that specific interventions are appropriate, i.e. will benefit the sector, directly corresponded with their level of familiarity with specific interventions, this being most evident for chemical leasing where over 75% of respondents were unfamiliar with the concept, suggesting that chemical leasing is a relatively new concept to the sector. Green steel manufacturing was another CEI for which stakeholders had a generally low level of familiarity (Appendix 1).

Stakeholders agreed (93% of respondents) that the SAMS is strongly dependent on access to resources such as energy, water, and materials, making it highly vulnerable to insecurity in supply. There was strong agreement (81% of respondents) that the South African economy is currently heavily dependent on imports of finished goods and high value products, and adversely affected by un-beneficiated material exports (80% of respondents). As noted by a participant "*there is a need for policy against imports. High-value imports work against South Africa, since cheap imports are encouraged whilst valuable materials are exported.*" There was overwhelming agreement (97% of respondents) on the need for CEIs to improve sectoral competitiveness and resilience. Similarly a high level of agreement (87% of respondents) that the implementation of CEIs in the South African manufacturing sector could lead to inclusive growth and decent jobs, while also mitigating environmental pollution (97% of respondents).

There was some debate around the issue of 'green steel' and its consideration as a circular intervention. It was reconfirmed that green steel relates to the use of green hydrogen as a substitute for carbon-based resources and fuels in steel manufacturing, as well as the use of renewable energy across the steel manufacturing value chain. Waste steel also has very high levels of circularity through reuse and recycling.

A key point raised by stakeholders was the need for a common, and improved, understanding of the circular economy and the need to work across sectors. A need was stressed that this CSIR study move stakeholders towards a Circular Economy Roadmap or strategic pathway that is cross-cutting and that can directly benefit the South African manufacturing sector.

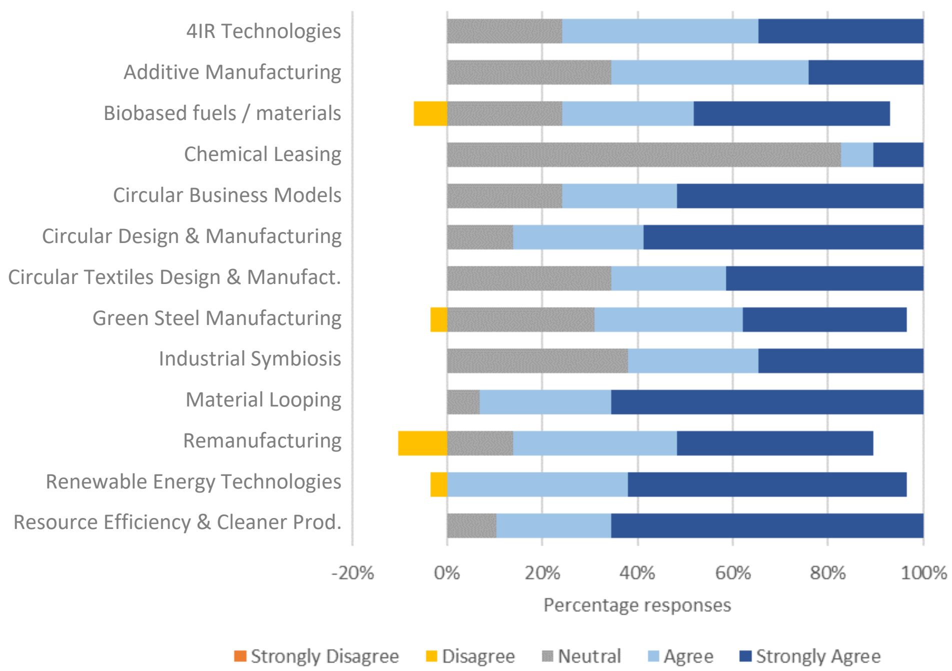


Figure 11. Extent to which circular economy interventions can benefit the South African manufacturing sector

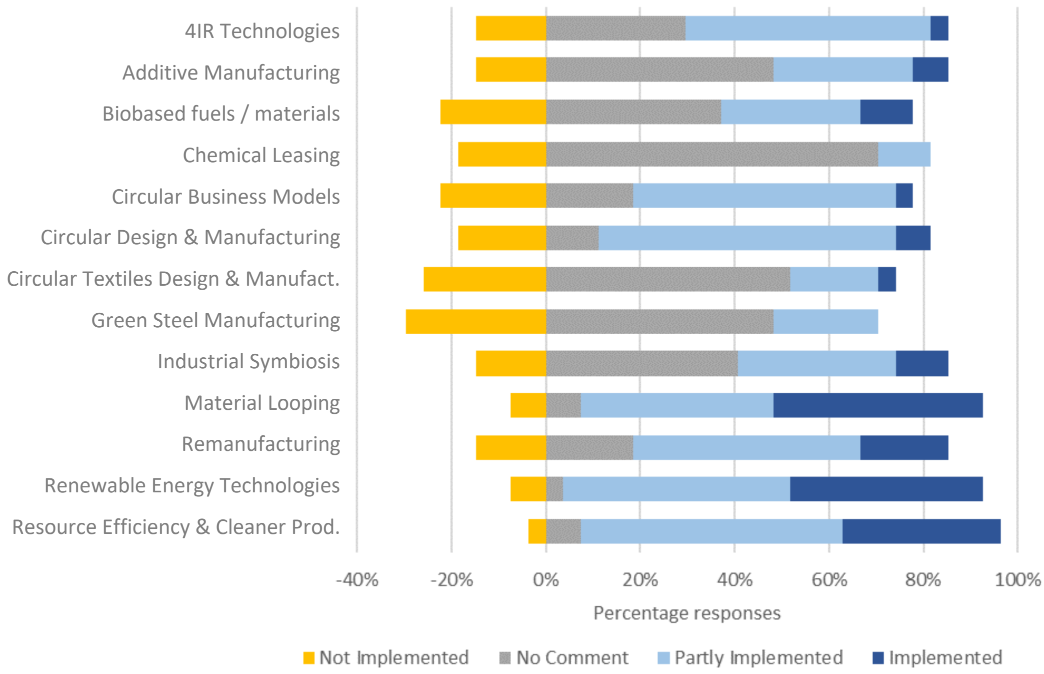


Figure 12. Level of implementation of circular economy interventions in South African manufacturing sector

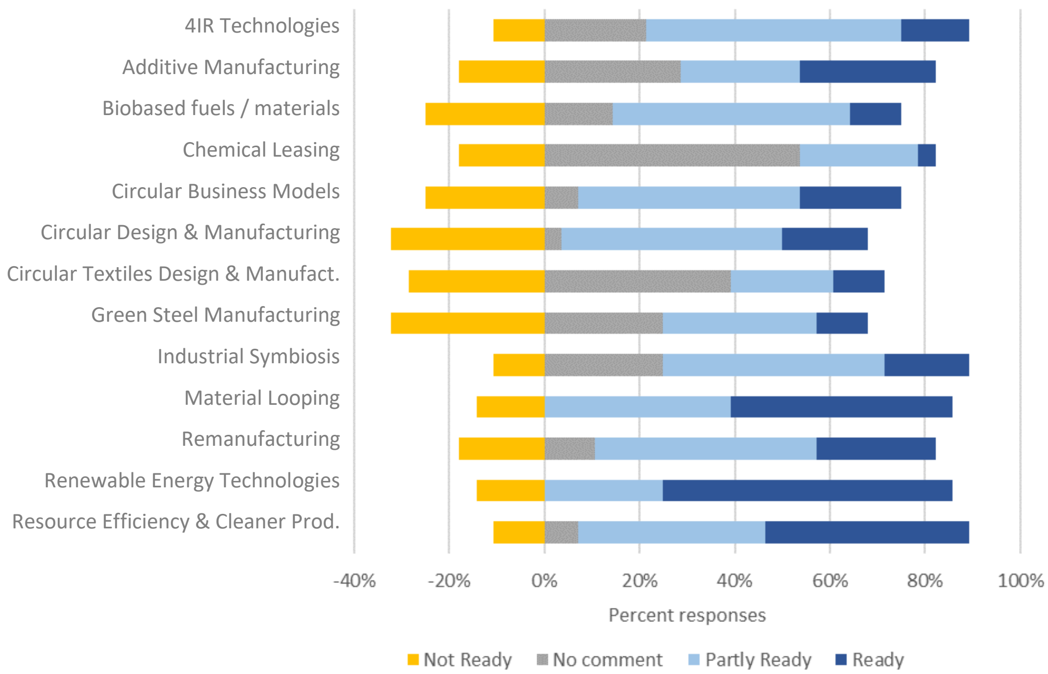


Figure 13. State of readiness to implement circular economy interventions in South African manufacturing sector

4.3 Readiness to implement these interventions

Many circular economy interventions have found application in the global north, but are yet to find scale or application in developing countries that face their own unique circumstances. Stakeholders were asked to rate the current level of implementation of the proposed CEIs in South Africa (Figure 12) and the sectoral readiness to implement these interventions (Figure 13).

4.3.1 Stakeholder engagement

The results showed high levels of implementation for Materials Looping; Renewable Energy Technologies; and Resource Efficiency & Cleaner Production (Figure 12) in the SAMS. These are well known interventions with South Africa having established a relatively successful materials recycling industry over the past 40-50 years for e.g., metals, plastic, paper, etc. (Godfrey & Oelofse, 2017). Renewable energy technologies have emerged in response to South Africa's loadshedding, climate commitments and policy interventions, while the National Cleaner Production Centre (NCPC-SA) has been successfully implementing Resource Efficiency and Cleaner Production programmes in the South African Manufacturing Sector for the past two decades (NCPC-SA, 2020). Importantly, the extent to which respondents considered specific CEI's already implemented suggests that there is significant room for strengthening and scaling these CEIs given that the bulk of the responses were 'partly implemented' as opposed to 'implemented'.

Similarly, the sector showed a high level of readiness to implement Materials Looping; Renewable Energy Technologies (RETs); Resource Efficiency & Cleaner Production; and Remanufacturing (Figure 13). The notably high readiness ranking by respondents on RETs was unexpected given this sub-sector has only come to the fore in recent years. The reason may lie in the fact that many companies are investing in RET's for business efficiency (energy security), but price remains a constraint for many. The relatively high readiness to implement 4IR technologies was also surprising given the apparent lack of sectoral familiarity with the technology.

CEIs such as Green Steel Manufacturing, Circular Design and Manufacturing, Circular Textiles Design & Manufacturing, and Bio-based fuels / materials, were seen to be at lower levels of readiness. Perhaps as longer-term interventions, more will need to be done to raise the level of awareness regarding these interventions and prepare the sector for the adoption of these technologies, including piloting / demonstration.

A number of constraints were highlighted as obstacles to fast-tracking the implementation of CEIs in the South African manufacturing sector. These included:

- Lack of *awareness* of circular economy opportunities and associated business case
- *Cost* of implementing CEIs, especially for SMMEs, many of whom are operating in 'survival mode'
- Lack of *sustainable finance mechanisms*, investment *incentives* and unattractiveness of South Africa as an investment destination
- Difficulty in accessing *funding*
- Long lead time to obtain management *approval* and necessary capital *investment*
- Lack of *skills*, knowledge and capacity on CEIs
- Lack of case studies or *demonstration* projects on successful projects that have improved business (including the cost of such demonstration)
- Lack of an enabling *legislative* environment
- Lack of access to export *markets* that drive CEIs
- Lack of downstream infrastructure and *markets* to absorb secondary materials (waste)
- Poor understanding of *life-cycle impacts* of products
- Local industries have not invested in updated technologies for several decades

As noted by one stakeholder "*Most business owners in South Africa don't have the luxury to explore change.*" Despite having some of the leading scientists and engineers in South Africa, there has been a failure to implement CEIs in South Africa.

There were also obstacles to specific CEIs. As noted by a representative from the foundry industry with respect to Additive Manufacturing "*We have invested in a small production unit, but we have seen the constraint brought about by limited embracing of the technology by our people. We are examining the possibility of producing patterns for the foundry using additive manufacturing and produced castings and recognise the opportunity of printing moulds and cores, but the costs of the capital equipment are prohibitive*". Despite additive manufacturing being recognised as a significant growth industry globally.

One idea put forward in the sector engagement to address many of the listed obstacles, was to establish local technical support services / institutions for industry, based on the model of Energy Service Companies (ESCOs) that support uptake of energy efficiency interventions.

The detailed stakeholder responses indicate a diverse range of opinions, ideas and recommendations concerning the appropriateness of the proposed CEI's, and the sectoral readiness to implement. Many valuable insights have been captured regarding the readiness and the perceived obstacles towards an effective roll-out of a circular economy approach within the South African manufacturing sector. At the same time, these obstacles present certain opportunities for improvement, growth and innovation in circular economy, including business opportunities.

4.4 Business opportunities to implement circular economy solutions

The overview of the circular economy principles and their application across local and international markets, and the various interventions identified, highlight a diverse range of interventions that offer the local economy a basket of potential business opportunities. These offer the means to address ongoing sectoral challenges in terms of resilience, competitiveness, unemployment, and export dependence. This section provides a more in-depth view of the potential circular economy related business opportunities for the manufacturing sector, as aligned to the key circular economy principles below.

4.4.1 Design out waste and pollution

Circular ***business models*** have come to the fore in recent years, e.g. product-as-service, product sharing, remanufacturing and circular supplies. Changing usage patterns via the sharing economy and product-as-service models can realise significant economic and environmental gains. Tata Steel and the Indian Steel Authority set up *mjunction*, for example, an e-market for steel waste, allowing traders transparent access. *mjunction* has evolved into the world's largest e-market for steel, with trade volumes increasing from $13.8m in 2002 to $9.45Bn in 2016 (WBCSD, 2016).

By selling product functionality or services rather than products *per se*, companies can manage an entire product life cycle, and associated costs, by developing closed material flow loops (EMF, 2017). Renault, for example extends and optimises the EV battery lifecycle by selling it as a service. Since starting, battery leasing is now preferred by over 90% of customers. Renault further extended its EV battery lifecycle by cascading to energy storage applications (WBCSD, 2016).

In the case of chemical leasing, this circular model shifts focus from increasing sales volumes to value-addition, where the client pays per functional unit, ensuring that both supplier and end-user achieve reductions in chemical use (UNIDO, 2016)

Manufacturing ***product design*** must consider optimising materials, durability, and repairability to design out waste. In the *textiles industry*, there is increased focus on design of more durable, re-usable and eco-friendly textiles. Natural fibre development can help avoid use of harmful chemicals in the textiles value chain, a global problem. Improved textile design would reduce the level of hazardous chemicals and micro-fibre waste entering ecosystems (EMF, 2017). In the *plastics industry*, the South African Plastic Pact calls for zero waste by redesigning problem packaging such that 100% of plastics are reusable, recyclable, or compostable by 2025 (SAPP, 2020).

Improved ***resource efficiency*** in manufacturing is critical to the South African manufacturing sector's global competitiveness. The NCPC-SA, tasked by the dtic, fulfils a vital role in helping reduce energy, water and materials use across various manufacturing sub-sectors. Over the period 2010-2020 the NCPC's industrial energy efficiency program has worked with 274 large companies and 180 manufacturing SMEs, saving over 6500 GWh in energy and R5.275 Bn in direct costs (NCPC 2021). The recent NCPC I-GO (Integrated Greening Operations) initiative, facilitated on behalf of UNEP aims to scale-up resource efficiency efforts of SMEs in Africa. Scaling up resource efficiency and cleaner production (RECP) measures across the local manufacturing sector is an urgent requirement, that provides significant business and labour opportunities.

4.4.2 Keep products and materials in use

A circular economy aims to optimise resource yields by constantly circulating products, components, and materials at highest utility. Tight product cycles are a key circularity trait, circumventing a loss of embedded energy, resources and labour from simple recycling and disposal.

The ***remanufacture*** of industrial equipment by Value Retention Processes (VRPs) can reduce virgin material usage by 80-98% and cost by 15-80% over Original Equipment Manufacturer (OEM) products (IRP 2018). Globally, remanufacturing is dominated by the automotive and aerospace sectors, as well as construction, electrical equipment, heavy machinery and medical devices. However, local uptake remains low due to a lack of infrastructure, supply chains and investment in remanufacturing technologies (Nasr, 2018). Remanufacturing of internal combustion (IC) engines is a well-established industry within the local automotive sector. In contrast to simple reconditioning, local ICE remanufacturers adopt industry standards to guarantee used engines are returned to OEM approved specifications through an extensive and audited process. Remanufactured engines provide levels of performance, reliability and lifespan that equal, and, in many instances exceed the original (REMTEC, 2021). Scaling South Africa's remanufacturing capability, as a buffer to manufacturing sectors at risk, e.g. the local automotive industry, needs to be further explored.

Caterpillar, the global heavy machinery OEM has been remanufacturing components since 1973. Caterpillar's dedicated remanufacturing arm (CAT Reman) is now a leader in developing value recovery processes and technologies, profitably growing to nine locations worldwide (>3500 employees) based on its component recovery business model. Durable parts enjoy repeated remanufacturing, e.g. gearboxes, drivetrains and brakes (IRP, 2018). The circular framework of designing for multiple remanufacturing cycles has been increasingly used by CAT given that major costs lie in materials (65%).

Local manufacturing features an established ***recycling*** industry across various sub-sectors, although the need to scale this is recognised. The South African *metals sector* has established a mature scrap metal recycling industry, achieving a recycling rate of 80% (DEA 2018). Continued recycling is necessary to maintain steel scrap in a constant loop, and to supplement primary steel production, given the insufficiency to satisfy rising world demand. Almost half of EU steel originates from secondary processes and end-of-life (EoL) scrap (Eurofer, 2015). A strategic value chain with opportunity for closing resource loops is the primary processing of local platinum group metals (PGMs). The reliance on exports of unwrought PGM base metals mandates the need for local beneficiation. Dedicated SEZs for fuel cell and auto-catalyst manufacture present opportunities for refurbishment and recycling of components at EoL, enabling beneficiation and retention of extracted precious metals within the local economy.

The South African *plastics sector*, despite implementing voluntary Extended Producer Responsibility (EPR) two decades ago, has only achieved a 43% collection rate (input), with much lower recycling (output) rates. Plastics recycling is an important local industry with opportunity for businesses to actualise the SA Plastic Pact target: all packaging to contain 30% recycled content with 70% of packaging effectively recycled by 2025 (SAPP, 2020). New EPR regulations for paper and packaging, e-waste and lighting are expected to significantly scale up the collection, reuse, repair and recycling of these goods in line with mandated targets (DFFE, 2021).

The *clothing and textiles sector* requires significant circular interventions given its impacts in terms of resource demand and resultant wastage. Currently, less than 20% of textiles are recycled globally, despite a massive environmental burden. As a developing country, end-of-life clothing in South Africa often finds reuse opportunities driven by high levels of poverty and unemployment. Locally, organisations such as *The Clothing Bank*, and *Rewoven*, have partnered with major local retailers to drive greater textile reuse of excess stock, customer returns, store damages, end-of-season and bulk rejections. The textile sector can phase out hazardous substances, enhance resource utilisation, adopt renewable resources and inputs, and radically improve recycling along the value chain via circular interventions. Cascaded recycling allows re-use of textiles in lower value applications (insulation, cleaning materials, etc) (EMF, 2017). NCPC-SA has partnered under the UNEP's InTEX project in developing Innovative Business Practices and Economic Models across the local textiles value chain (NCPC, 2020).

As noted by an industry stakeholder *"textile recycling and re-processing is still in the pilot phase in South Africa and limited to one fabric base. There is potential to scale up if all CTFL-Masterplan participants get on board."*

NCPC and GreenCape have championed ***Industrial Symbiosis*** (IS) to close resource loops, with opportunities to scale up and lower material input costs, whilst addressing resource scarcity and waste (WCG, 2021). Over the period 2015-2020, NCPC assisted 80 companies through IS, diverting 215,000 tonnes of waste resources from landfill and saving R17.7m in landfill diversion (NCPC, 2020).

Case studies from India and China (IRP, 2017) highlight the environmental impact from fossil-based energy and material use in cement and steel production, including resource depletion and air pollution by particulate matter (PM). This can be reduced through beneficial exchange and reuse of materials across energy and construction sectors focusing on two key material exchanges (a) reuse of fly ash from power plants in lieu of cement (beyond current reuse levels) in the construction sector, (b) reuse of steel slag that enables both heat recovery and material substitution of cement. Low polluting construction materials such as green bricks and green cement avoids PM2.5 emissions from brick and cement factories.

4.4.3 Regenerate natural systems

In addition to the manufacturing sector adopting more renewable energy solutions, the emerging green energy market (estimated at R30Bn) offers new circular manufacturing opportunities for South Africa. NERSA's exemption on self-generation (up to 100MW) renders embedded generation via local solar panel, wind tower and turbine manufacture feasible. A 1GW/yr solar PV market is sufficient for five manufacturers to set up local facilities of 200MW each, providing opportunities for circular renewable energy products (Creamer, 2019). Policies call on national R&D organisations to assist in developing a green, circular industry (DTIC, 2018). Bio-based energy and materials, including bio-catalysis, can also help in moving away from fossil-based resources.

The REIPP program was highlighted in the previous section indicating the level of investment towards solar, wind, hydro in the sub-Saharan region. This commitment brings with it the challenges identified from EU studies on the EoL waste to be generated from RETs and the requisite measures to be put in place to manage the broad spectrum of materials and products to be recovered, re-used, or recycled including some CRMs.

It is clear that the application of circular economy principles is not new to the South African manufacturing sector, with activities being driven locally, regionally and internationally to decouple growth from resource consumption and transition to alternative circular economy business models. However, while many of the underlying principles are already being applied in the local manufacturing sector, more needs to be done in achieving the scale required for meaningful impact. Collaboration at all levels is vital, and companies can employ the ReSOLVE framework (regenerate, share, optimise, loop, virtualise, exchange) to navigate the complexities in transitioning to a circular economy (McKinsey, 2016).

Scaling circular manufacturing will require disruptive technologies, including digital technologies such as Internet-of-Things (IoT), big data, and blockchain, which allow for advanced tracking and monitoring of resource utilisation and waste capacity. Additive manufacturing for instance, has disrupted traditional manufacturing processes (machining, casting, injection moulding) enabling reductions in development costs, resource utilisation, waste and energy consumption. Its on-demand, digitally distributed manufacturing, allows for reduced physical inventories and more resilient supply chains.

4.5 Potential for climate change mitigation

Various CEIs in the manufacturing sector have the potential to reduce GHG emissions. These include (a) changes in energy usage (energy efficiency, fuel switching, combined heat and power, use of renewable energy), (b) more efficient use and recycling of materials. However, as noted by stakeholders, many companies are committed to Science Based Targets (SBTi) to achieve a net-zero target by 2050, and might become overly focused on addressing emissions without necessarily understanding that many CEIs can support emissions reduction. *"Time and resources get devoted to 'traditional' GHG emissions mitigation interventions with little consideration for circular economy interventions."*

The *electrotechnical sector* , for example, is one of the fastest growing sectors globally, with high resource demands and high levels of waste electrical and electronic equipment (WEEE). Since 2014, e-waste has grown by 9Mt globally. Currently, <10% of locally generated WEEE is recycled, mostly pre-processed with export for metal recovery, resulting in the loss of resources. Increasing the local WEEE recycling rate would provide local job opportunities (DEA 2018), but also, GHG mitigation potential through recycling common industrial materials and products.

It is recommended that further modelling be undertaken to quantify the climate mitigation potential of CEIs in the South African manufacturing sector, as a driver for supporting a circular economy transition. This may also create an opportunity to access climate finance to finance circular economy initiatives in the South African manufacturing sector.

4.6 Summary

Based on the stakeholder engagements, the evaluation of the local manufacturing sector in terms of circular economy practice, as well as a survey of global trends and case studies, it is evident that the implementation of the circular economy within the South African manufacturing sector presents both opportunities and challenges. The sectoral analysis along with stakeholder inputs clearly indicates that there are numerous circular economy related measures that have already been implemented. In addition, there are a multiplicity of ongoing activities within private companies, government, NGOs/NPOs specifically dedicated to circular economy. In many instances, there is notable collaboration within the industry or sub-sector regarding circular economy practices.

Immediate circular economy related business opportunities lie in the extension and scaling of current activities within the sector. This study provides substantial evidence by way of data gathered, global trends and benchmark studies of the collective benefits that the proposed CEIs would afford the sector. Each of the CEIs evaluated presents significant potential for local manufacturers to unlock new business opportunities, and enhance existing processes in terms of efficiency, waste management, resource use and emissions. As noted in the report, some of these interventions have already developed to a relatively mature stage, e.g. Materials Looping; Renewable Energy Technologies; and Resource Efficiency & Cleaner Production, and can now be scaled to achieve greater impact in terms of the benefits that the circular economy approach offers.

Disruptive technologies associated with 4IR (IoT, Additive Manufacturing, digital twinning, etc.) are helping to achieve impact in the implementation of innovative manufacturing process and business models. Global trends indicate a rapid uptake of 4IR related technologies to enhance manufacturing capability, productivity and efficiency, enabling massive gains in resource optimisation, reducing energy and material consumption, upskilling of the workforce, and tracking of materials and waste throughout the circular economy value chain. These technologies present notable opportunities for the South African manufacturing sector to enhance its competitiveness and sustainability.

Notwithstanding the positive outlook presented above, it is clear from the engagement with stakeholders that significant challenges remain towards enhancing the implementation of circular economy within the sector, as well as scaling of circular economy measures across the sector and broader economy. Many of the obstacles to circular economy implementation raised by stakeholders appear to be common with those experienced in other countries, and in other sectors, e.g., agriculture. A vital issue for effective circular economy roll-out at scale is clearly collaboration across all sectors of the economy from government, private sector and supporting organisations. Stakeholder concerns highlight the need for increased support for SMMEs within the local context, improved infrastructure for waste handling and recycling, and access to markets.

Funding for CEIs was a key issue raised by many stakeholders who noted that financial institutions and models currently are not geared towards funding CEIs, in part due to a lack of awareness and understanding of the business case. Similarly, companies may be reluctant to fund circular economy projects due to a lack of awareness of the business case, or more so this not being clearly defined at the outset. There was strong agreement on the need for policy interventions, which is a global trend with circular economy implementation, as well as the need for incentivising companies that promote circular economy.

5 Conclusion

This study has addressed the main research questions by showing that the current development path of the South African manufacturing sector is still dependent on resource extraction, export of base metals and minerals, and imports of finished products, notwithstanding its predominant linear 'take-make-waste' economic approach.

Detailed evaluation of the circular economy principles and practices, including global trends and case studies clearly shows that the circular economy approach can help the South African manufacturing sector mitigate many of its challenges regarding resource extraction, efficiency, productivity, competitiveness, waste and emissions.

Based on the review of global trends and case studies, as well as engagement with key sector stakeholders, it can be concluded that most, if not all, of the proposed circular economy interventions outlined in this study can benefit the South African manufacturing sector, and are appropriate for transitioning the sector towards a circular economy. Uncertainty regarding the benefits of chemical leasing, industrial symbiosis, remanufacturing and bio-based fuels / materials to the local manufacturing sector are noted, although this may have more to do with lower levels of familiarity than with the technology. Highlighting the need for improved awareness regarding the circular economy opportunities and their benefits to the South African manufacturing sector.

The extent of sectoral readiness in embracing these circular interventions varies widely, with some measures at a more advanced stage (e.g., material looping, resource efficiency and cleaner production, and renewable energy technologies) while certain interventions are considered to be at a lower level of readiness (e.g., green steel manufacturing, circular design and manufacturing, circular business models and bio-based fuels / materials) and will require greater action to fast-track.

The stakeholder engagements provided valuable insights regarding the current status of development of the sector with respect to the circular economy, revealing a relatively mature level of development and implementation in certain industries, but much room for expansion and scaling of circular economy interventions overall. Stakeholder feedback also highlighted the extent of challenges and obstacles the sector faces in attempting to roll-out circular economy initiatives, especially for smaller manufacturing businesses that struggle to access funding.

The obstacles and challenges noted by stakeholders were very similar to those observed in other economic sectors, e.g., agriculture. Major obstacles to transitioning the South African manufacturing sector to a more circular economy, and unlocking associated benefits, included lack of awareness of circular economy interventions and the associated business case; the cost of implementing and the lack of sustainable financing mechanisms; lack of appropriate skills; lack of local case studies or demonstration projects; lack of available markets for circular products and services. In principle, an increased awareness and understanding, upgrading of skills and knowledge base, creation of support platforms and organizations, and collaboration across all sectors of the economy appear to be universal challenges to effective circular economy implementation.

Apart from the more conventional circular economy practices, a circular development path for the South African manufacturing sector would need to embrace a host of innovative, disruptive technologies (e.g., 4IR) in order to achieve maximum benefit and ensure sustainability and competitiveness in the long-term. In this regard, the localisation of manufacture of materials, products and components for the emerging local markets in renewable energy technologies (solar panels, wind towers), electric vehicles and hydrogen fuel cells (including FCEVs) presents an important opportunity for the sector to leverage the circular economy. Remanufacture, re-use and refurbishment of end-of-life materials and components from these applications can enable the sector to retain materials within the local economy, prevent the export of valuable, un-beneficiated resources, whilst ensuring that climate and sustainability commitments are met. In particular, high value critical raw materials (CRMs) would also be recovered, an important consideration in the beneficiation of local resources such as platinum group metals (PGMs).

It is also evident from the study outcomes that there is significant opportunity for research and development into innovative manufacturing processes and materials that enable resource decoupling, energy and water savings, including reduced waste and emissions. Light-weighting and innovative design via processes like additive manufacturing open up new avenues for resource optimisation, supply chain resilience, zero inventories and waste minimisation, not to mention rapid, lower cost product development. The local industry has already seen some investment in additive manufacturing with CSIR hosting the national programs in Additive Manufacturing, providing an important platform from which to enhance additive manufacturing capability that supports the transition to a more circular, efficient and competitive South African manufacturing sector.

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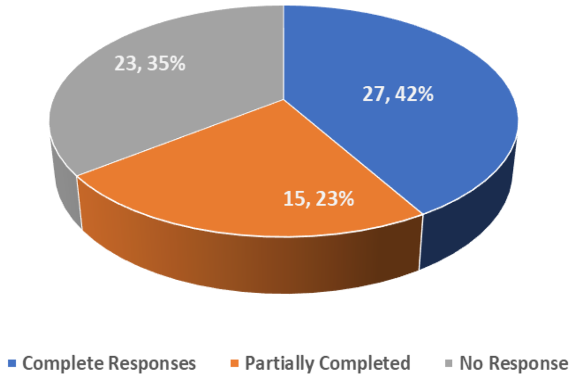
Appendix 1: Analysis of Survey Response Results

The response to the survey is summarised graphically in the figure below in terms of the number of complete responses, partially complete and non-respondents. Importantly, the partially completed questionnaires were used in gathering any data on questions completed and added to the overall results. The survey results are provided in this section.



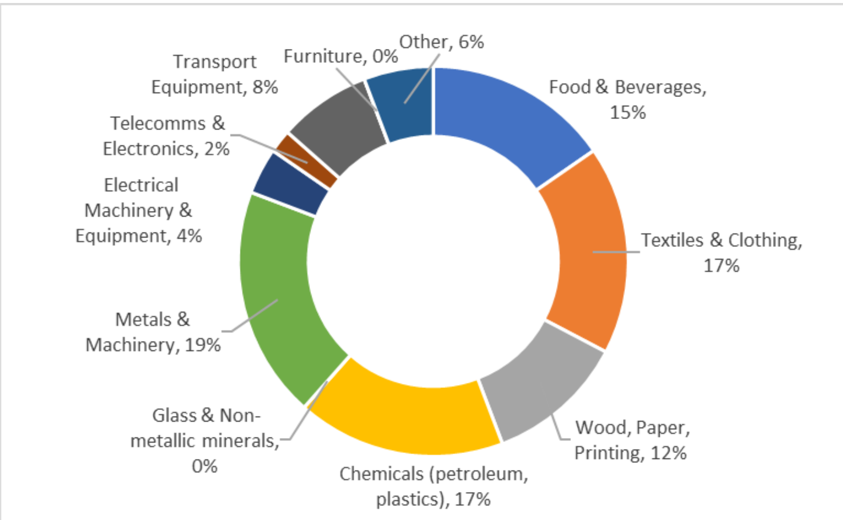
In terms of the demographics of the survey, the following points were noted:

1. 42% completed the survey, while 23% completed partially and 35% abstained.
2. Over 80% of participants had >10 years within the SAMS and >75% held senior management to executive positions in their respective companies.
3. In terms of their sub-sectoral involvements, there was a good spread across sub-sectors.
4. Years of experience and involvement in CE Projects did not correspond with any affiliation to CE organizations such as ACEN, EMF, etc.

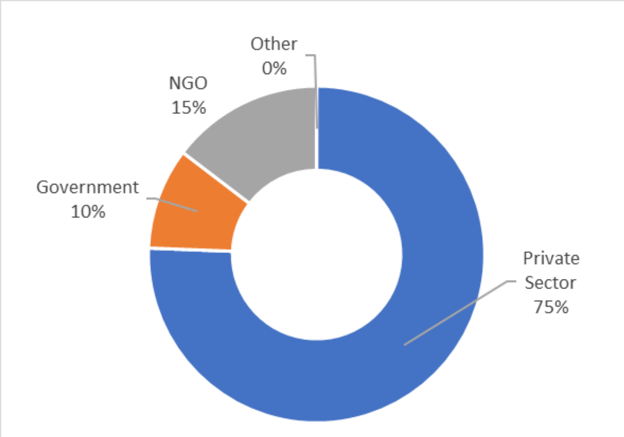
Regarding prior experience with Circular Economy related initiatives or projects, the survey results revealed the following perspective:

1. Over 2/3rd of respondents were, or are currently involved in CE related projects or interventions.
2. Over 80% of respondents ranked their knowledge of CE from working to excellent with over 50% rating their know-how as good to excellent.
3. Over 2/3rd of the participants had CE related experience in excess of 3 years with over 30% having more than 5 years of CE related experience.
4. Surprisingly, the level of affiliations of the companies represented by the respondents to CE related organizations, most of whom work in the private sector, was only 41%. This indicated that the involvement in CE related initiatives and years of experience are not necessarily linked to organizational affiliations. This may suggest that private companies are already driving CE initiatives within their own business environment.

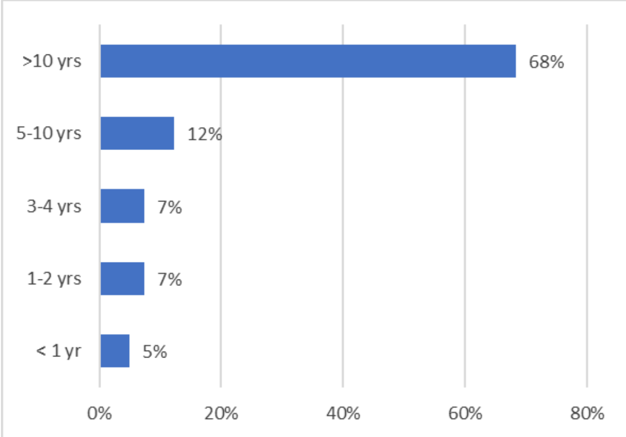
Question 1.1. Please indicate which manufacturing sub-sector you are currently active in.



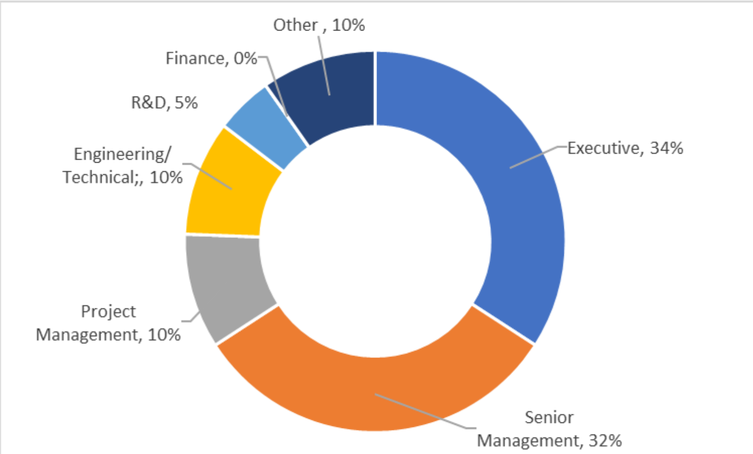
Question 1.2. Please select the category to which your organization belongs.



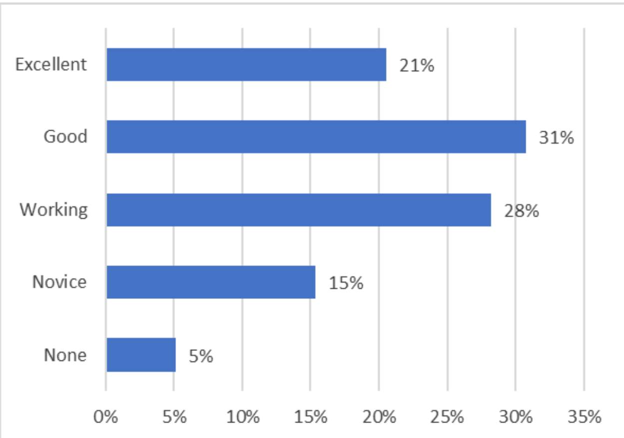
Question 1.3. How many years of experience do you have working in the manufacturing sector?



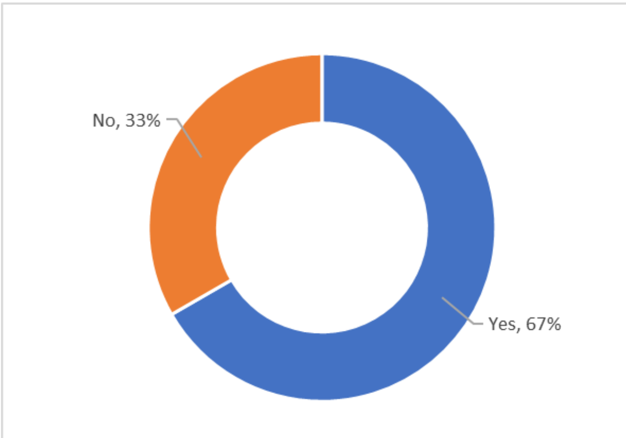
Question 1.4. Please indicate your main level of responsibility within your organization



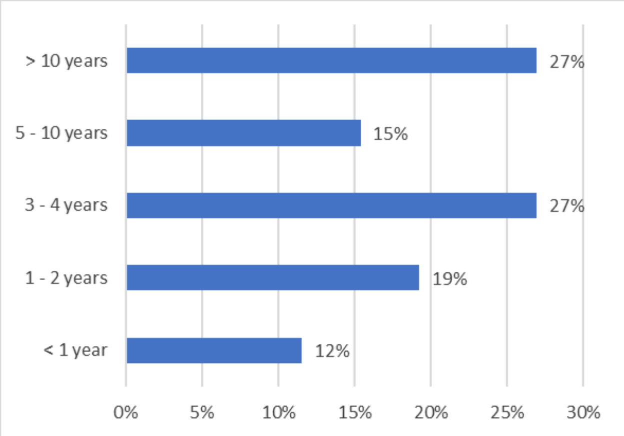
Question 2.1. Please rate your personal knowledge of the Circular Economy (CE).



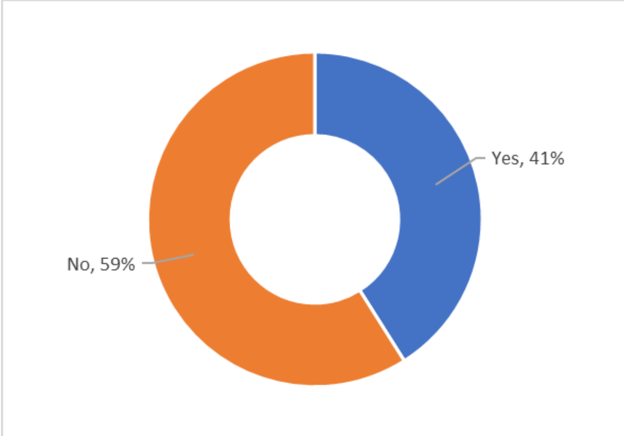
Question 2.2. Are you currently (or have previously been) involved in Circular Economy related projects and/or interventions?



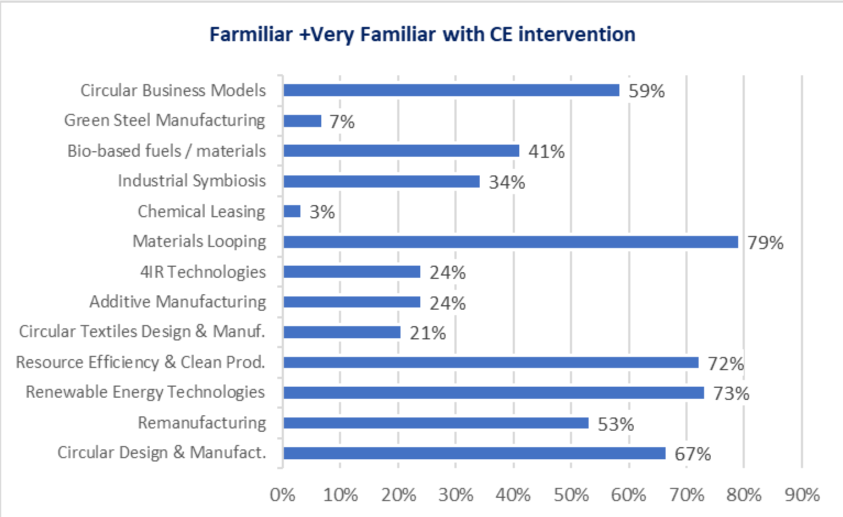
Question 2.3. How many years of experience do you have with CE related projects?

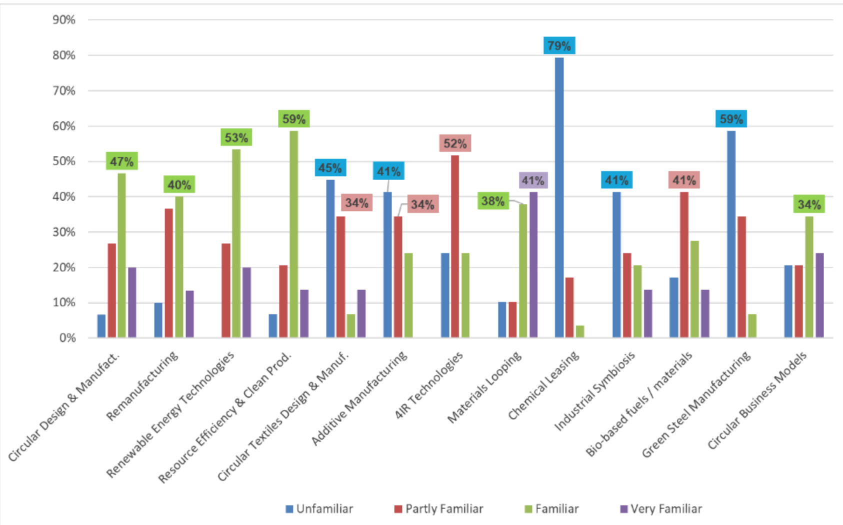


Question 2.5. Is your company affiliated with any Circular Economy related organizations

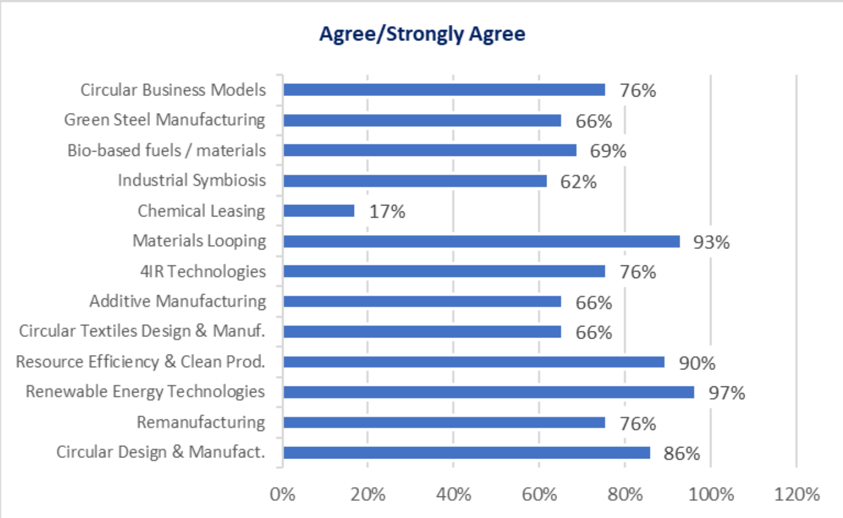


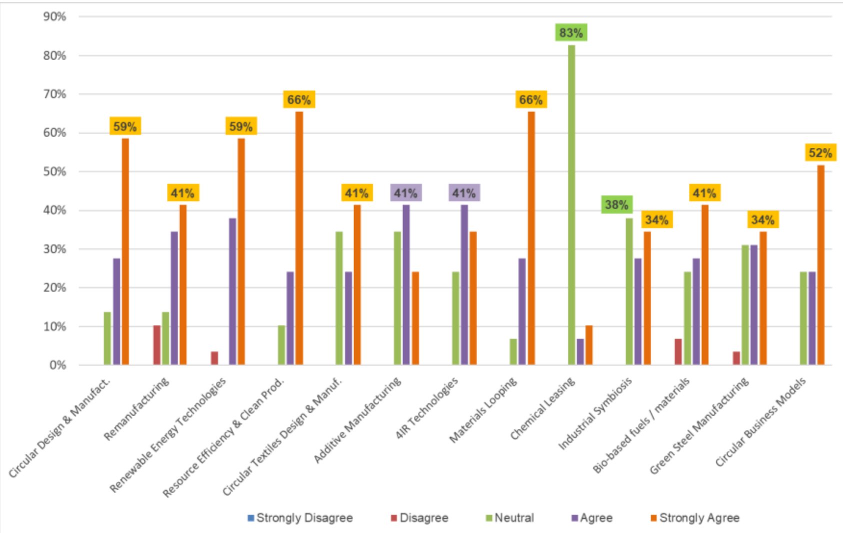
Question 3.1. Which of the following Circular Economy Interventions are you familiar with?



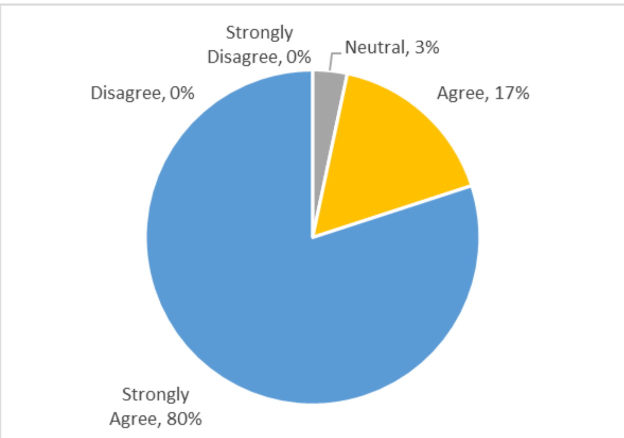


Question 3.2. To what extent do you agree that the following Circular Economy interventions can benefit the South African manufacturing sector?

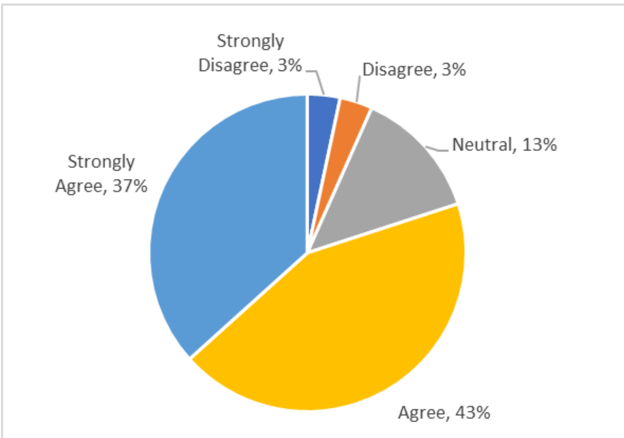




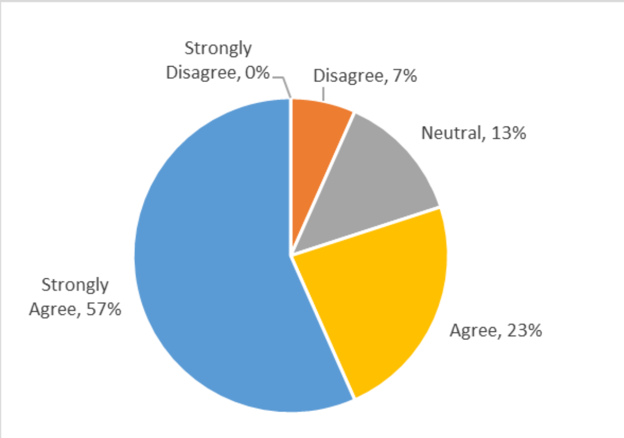
Question 3.3. The South African manufacturing sector is in need of CE interventions to improve resilience and competitiveness of the sector



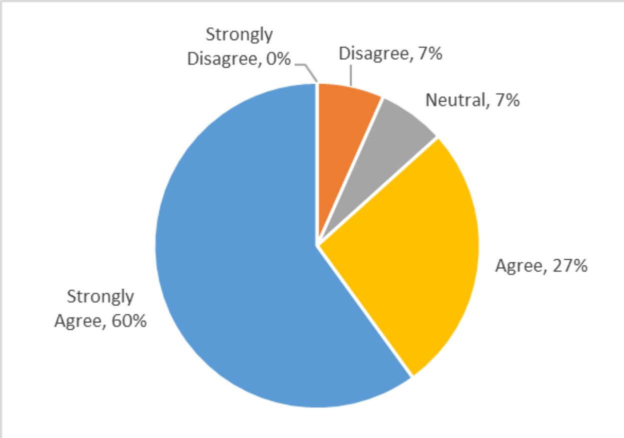
Question 3.4. The implementation of CE interventions within the South African manufacturing sector would lead to inclusive growth and decent jobs



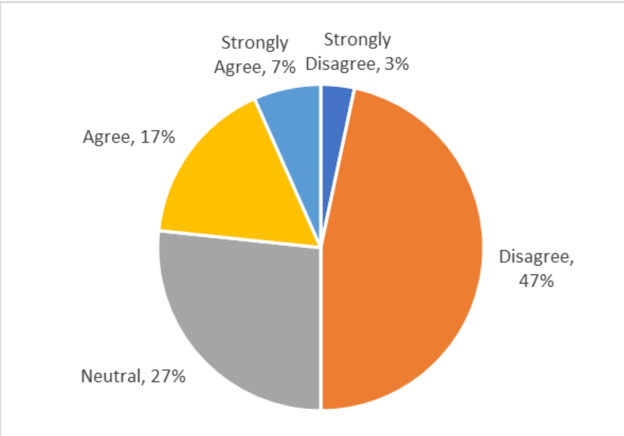
Question 3.7. The South African manufacturing sector is adversely affected by the export of un-beneficiated raw materials



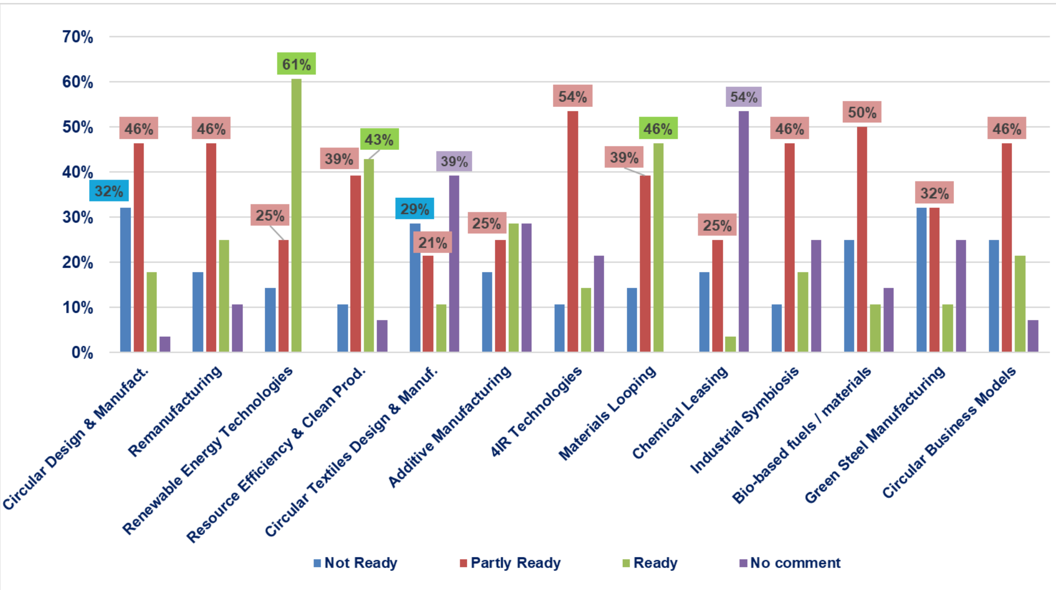
Question 3.8. The South African economy is strongly dependent on imports of finished goods and high value products



Question 3.9. The SA manufacturing sector has a good understanding of what the Circular Economy is and potential benefits for the sector.



Question 3.10. How would you rate the South African manufacturing sector in terms of readiness towards implementing the proposed Circular Economy interventions listed below? Please elaborate on your response above, particularly where you consider the sector is not ready



Question 3.11. Which of the listed Circular Economy interventions would you say are already being implemented within the South African manufacturing sector or broader economy? Please elaborate, particularly where you consider any interventions are already implemented