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BUSINESS CASE FOR THE CONTINUED INVESTIGATION OF CARBON CAPTURE AND STORAGE IN SOUTH AFRICA

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EXECUTIVE SUMMARY

This report explores the business case for continued investigation into carbon capture and storage (CCS) in South Africa. The timeframe considered covers an investment and development period between 2017 and 2030, followed by an implementation period from 2030 to 2050.

The findings of this study indicate that largescale CCS deployment in South Africa is economically viable under specified conditions, and as a result, the technology has the potential to play a transitional role in mitigating national CO2 emissions and contribute to socio-economic development. A number of components were evaluated in the course of the analysis (Figure 1). The evaluations provide an iterative basis upon which the conclusions are drawn.

Figure 1: Evaluation process used in CCS business case study

The rationale for CO2 emission reductions is well established in the context of South Africa’s commitments to respond to climate change. Social and economic transformation may be increasingly hampered by climate change impacts. Ambitious and well planned measures, such as the largescale rollout of CCS, are therefore required to respond accordingly.

The study builds on a suite of comprehensive research studies in the examination of the transport logistics and storage potential. Current research indicates that a trunkline approach, which comprises a common pipeline to transport CO2, is the most economical and feasible way to implement a CCS network on a national scale. Further research is required to establish which state CO2 should be transported (e.g. dense or gaseous phase) as well as how to overcome the various logistical constraints (e.g. natural geography; CO2 source locations and more). The Orange, Bredasdorp and Durban Zululand basins are identified as the preferred sites for storage as they allow for higher well injection rates of CO2, which presents cost saving opportunities as fewer wells are required to store the same quantity of CO2. The Durban Zululand basin is particularly attractive as it is closer to CO2 emission sites than the other basins located in the Western Cape.

Industries where CCS would be most viable are identified as the liquid fuels industry (refineries and coal to liquids), coal-fired power stations, cement and iron and steel industries. CCS is the only option for a number of industries with unavoidable process emissions such as the cement and iron and steel production.

The investment in the development of CCS technology is anticipated to be in the range of 1.7 – 9.8 billion Rand. The techno-economic analysis component of this study finds that technology costs, economic structure, growth rate and carbon price are the key drivers of the viability of CCS. The low carbon price scenarios, where the discounted monetary saving between 2030 and 2050 is between R 4.76 – R 8.27 billion, therefore appear to present no material monetary benefit above the investment in the development of CCS technology. However, the monetary saving in the low carbon price scenario is not greatly lower than the investment in development. There is thus little risk associated with investing. Conversely, under the high
carbon price scenario, the potential monetary saving of between R 1 683 – R 2 319 billion is orders of magnitude larger than the investment in CCS development. Thus, these monetary savings figures represent large opportunities to benefit from developing CCS technologies. They also represent an equivalently large risk of missed opportunities if CCS is not developed.

The study finds that South Africa stands to gain a large opportunity to benefit in a future characterised by high carbon prices. South Africa could however risk forfeiting these large potential gains should the country not invest in the development of CCS technologies. The uncertainty of the future price of carbon represents a much larger risk and needs to be monitored regularly and from a variety of different perspectives.

The analyses demonstrate that the carbon price can play a significant role in the uptake of CCS technologies. High carbon price scenarios may see many industries implement CCS where the carbon price exceeds the cost of implementing CCS. Low carbon price scenarios may only offer this opportunity to selected industries where the cost of CCS implementation is relatively low, such as liquid fuels production. Under low carbon price trajectories economic gains would be relatively small compared to the investment in the development and implementation of CCS. Similarly, the emissions reductions would be substantially smaller than those achieved under a high carbon price. The timing of such investments is key, considering the long lead times associated with the development of the regulatory environment and subsequent infrastructure expansion.

Substantial CCS uptake and significant emissions reductions are expected under high carbon price scenarios, providing room in the Peak, Plateau and Decline budget for other sources of GHG emissions. Industries may be significantly less inclined to take up CCS under the low carbon price scenarios. In such a future, the country will not meet its commitments to the current Peak, Plateau and Decline trajectory. This failure may have subsequent repercussions related to other international commitments, which could affect the country's international bargaining powers and competitiveness.

If, as this study concludes, CCS is deemed essential to meeting the Peak, Plateau and Decline trajectory, the technology will need to be supported through policies and measures in addition to being driven by a high carbon price. The measures will need to be cognisant of the costs of CCS development and implementation within different industries. Regulation of CCS for each industry will need to be timed appropriately with the emerging carbon price to be economically efficient. The implementation of regulations related to carbon limits, which also specify the use of CCS, would need to be considered in the context of international cap and trade mechanisms to provide the necessary incentives for companies to invest in the technology. The regulation of CCS would need to carefully consider the implications for the eligibility criteria for participating in international emissions trading schemes.

At this stage there is sufficient evidence to suggest that CCS development should continue to the next phase of piloting a test injection of CO₂. The business case for CCS technologies in South Africa should be reassessed on the culmination of the test injection to determine whether further investment in a demonstration injection should be conducted.
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1 INTRODUCTION

Carbon capture and storage (CCS) is a technology whereby carbon dioxide (CO₂) is captured from the exhaust of industrial or energy processes, transported to a storage site and stored for the long term. CCS allows carbon intensity to be decoupled from energy intensity. In a country where the nature of the economy is energy intensive, such as the extraction and beneficiation of mineral resources in South Africa, CCS provides a mechanism to reduce the carbon intensity of the economy without changing the economic structure. This report considers the business case for continued investment into CCS in South Africa.

1.1 BACKGROUND

The South African economy is reliant on coal. This is true not only for power generation but also for around one third of our liquid fuels production and the mineral beneficiation industries (IEA, 2014). Electricity generation and liquid fuels collectively account for over three quarters of the country’s greenhouse gas (GHG) emissions. This is shown in Figure 2.

![Figure 2: South Africa’s GHG emissions (IEA, 2014)](image)

The South African Government has committed to reduce GHG emissions by 34% by 2020 and 42% by 2025 below the business-as-usual trajectory, subject to the provision of adequate international financial, technological and capacity-building support.

South Africa’s coal based economy has to be transformed to a low carbon economy in the next 2 to 3 decades. Whereas there is general consensus that a move away from coal is an obvious solution, there is also
an option to soften the transition away from coal through the utilisation of carbon capture and storage (CCS) technology as a transitional phase towards a low carbon economy. If CCS technology can be proved to be economically viable and efficient, it can potentially form part of the longer term solution to South Africa’s energy challenges.

The South African Centre for Carbon Capture and Storage (SACCCS) was established during March, 2009 as a division of the South African National Energy Development Institute (SANEDI) to facilitate the development of CCS technology and its application. CCS has been identified as a National Flagship Priority Programme and the CCS Roadmap has been endorsed by Cabinet.

A Pilot Carbon Dioxide Storage Project is being planned. This will use the outcomes of a South African Carbon Dioxide Geological Storage Atlas. The pilot project is a “proof-of-concept” for CCS in South Africa as well as being a platform for capacity building.

It is appropriate at this point to address the technical and economic rationality of continuing with the development of CCS in South Africa.

1.2 OBJECTIVES

This business case for the continued investment into CCS in South Africa aims to, inter alia, inform policy and decision makers on future investment into CCS.

The objectives include:

- Analysis of the conditions under which CCS would need to contend;
- Identification of the techno-economic parameters applicable to CCS;
- Determination of the extent to which CCS can reduce CO₂ emissions within a national GHG mitigation programme; and
- Analysis of the risks related to the continued investment into CCS in South Africa.

The resources committed to CCS should be in support of South Africa’s needs to transform its economy to a low carbon economy.
1.3 METHODOLOGY

The approach to the business case is illustrated in Figure 3 and described in the following text.

- **Assessment of current emissions, legislation and policy frameworks**
  An assessment of the current state of national emissions considers the latest published National Emissions Inventory. The national legislative and policy frameworks are reviewed to determine the relevance to CCS and other initiatives relevant to GHG mitigation. International efforts and agreements are also considered;

- **Assessment of the drivers and constraints impacting the uptake of CCS**
  Long term drivers of carbon emissions and the need for CCS are uncertain. Scenarios are used to provide the range of conditions under which CCS may need to be implemented. Existing scenario studies are used to inform the assessment of the CCS business case;

- **Projection of growth of key emitting industries**
  Projections of growth within major emitting industries (energy transformation, cement and iron and steel) are estimated for the drivers identified in the scenario studies considered;

- **Evaluation of storage potential**
  The carbon storage potential is evaluated based on existing studies conducted by the SACCCS and used as an input into the techno-economic analysis of the business case;

- **Quantifying the cost of capture, transport and storage of CO₂**

Figure 3: Approach to developing the CCS Business Case

The approach to developing the business case includes:

- **Assessment of current emissions, legislation and policy frameworks**
  An assessment of the current state of national emissions considers the latest published National Emissions Inventory. The national legislative and policy frameworks are reviewed to determine the relevance to CCS and other initiatives relevant to GHG mitigation. International efforts and agreements are also considered;

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  Projections of growth within major emitting industries (energy transformation, cement and iron and steel) are estimated for the drivers identified in the scenario studies considered;

- **Evaluation of storage potential**
  The carbon storage potential is evaluated based on existing studies conducted by the SACCCS and used as an input into the techno-economic analysis of the business case;

- **Quantifying the cost of capture, transport and storage of CO₂**
A review of the literature is used to determine the various costs within the CCS value chain. The costs for carbon capture within the electricity, liquid fuels, cement and iron and steel industries, CO\(_2\) transport and storage are derived from existing studies;

- **Evaluation of the CCS business case**
  The potential for CCS and the timing of its implementation are derived based on costs of CCS technologies, storage potential and drivers from the scenario studies. The impacts of implementing or not implementing CCS in the context of the scenario forecasts are compared; and

- **Evaluation of the risks associated with CCS**
  A risk analysis is conducted considering the output of the techno-economic analysis and other social factors which may impact on the implementation of CCS.

### 1.4 Scope

The target audiences for the Business Case for Continued Investment into Carbon Capture and Storage in South Africa are: government; policy makers; industry decision makers; potential funders; and stakeholders in the climate change arena.

The general approach is to consider CCS from a South Africa Incorporated perspective i.e. the social costs of carbon emissions (and subsequent climate change) are carried by the whole of society and the cost to mitigate these emissions are also carried by society.

The focus is on the techno-economic evaluation of the business case but social and environmental aspects are considered qualitatively. Some of the related aspects are being considered by other concurrent studies such as the Carbon Capture and Utilisation project and the Transportation of CO\(_2\) project commissioned by SACCCS. These topics are considered from the average costs from existing studies in this analysis. The emphasis in this report is on the higher level economic evaluation of CCS.

### 1.5 Structure of Document

The rational for CO\(_2\) emissions reduction, presented in Section 2, provides an international and national context including international commitments. Section 3 considers the potential for carbon capture and storage in South Africa. The emissions from various industries and the amount of CO\(_2\) which can be captured are evaluated. The potential transportation limits of CO\(_2\) and the storage potential are also evaluated. CCS technology costs and benefits are provided in Section 4 and considers the development and implementation costs. Local and international scenario studies are reviewed in Section 5 to inform drivers of CCS used to provide context for the evaluation of the business case in uncertain circumstances. Projections of the key drivers are used in an analysis of scenarios to determine the impact CCS may have on the national emissions inventory in Section 6. A risk analysis of CCS within the context of the analysis is presented in Section 7.
2 RATIONALE FOR CO₂ EMISSION REDUCTIONS

Extensive, long-term research has concluded that climate change is linked to humankind’s use of fossil fuels. This approach has resulted, in some sectors of the world, in accelerated industrial, technical and social development. The unintended consequence of this development path has led to, among others, increased levels of GHGs in the atmosphere which increased average global temperatures and impact on our climate.

The impacts of climate change are increasingly affecting communities, economies and countries in a negative manner. In the near future, Southern Africa is expected to become much hotter and drier than the global average, should the world continue on the current emissions trajectory. The region’s developmental status exacerbates the risks associated with climate change, particularly risks related to water, agriculture, health and infrastructure.

While South Africa has a relatively small emissions profile compared to the likes of the United States, China, India and the European Union, the country’s per capita emissions are similar to those of industrialised countries. In 2010 the country’s emissions were reported to be 518 239 tCO₂e, an increase of 22% compared to levels in 2000 (Department of Environmental Affairs, 2014a).

The increased consumption of coal and other fossil fuels is the main driver of South Africa’s increased emissions levels. The energy sector contributed 80% of the country’s GHG emissions in 2010 (Department of Environmental Affairs, 2014a). Electricity generation accounts for approximately 56% of the energy sector and 45% of the country’s total emissions. A summary of South Africa’s most recently published national GHG inventory is presented in Figure 4.

![Figure 4: Summary of South Africa's National GHG Inventory (2010)](image)

The energy and industrial sectors give rise to the greatest proportion of GHG emissions in South Africa’s inventory. South Africa has committed to a 34% reduction in GHG emissions by 2050.
South Africa’s ambitions to reduce emissions are framed within the context of developing the country’s socio-economic profile. In particular, sustainable development is a key priority for the country’s growth. South Africa’s development is particularly vulnerable to the impacts of climate change on account of high levels of poverty in the country. Poorer communities lack the safety nets of spare resources and sophisticated or even adequate infrastructure. The risks associated with climate change are therefore disproportionately high for the poorer segments of South Africa’s society, which make up the vast majority of the population. The public and private sectors have a responsibility to implement measures that safeguard our current and future generations.

The Sustainable Development Goals framework is one of the most recent international measures that support such aims, where the overarching goal is to balance global environmental, social and economic needs. In particular, the first of the 17 goals focusses on the eradication of poverty; worldwide and on a permanent basis. The National Development Plan 2030 (National Planning Commission, 2012) echoes this sentiment on a local level as it embodies the country’s main strategies to eliminate poverty and reduce inequality by 2030. The Plan’s focus on sustainable growth therefore incorporates various climate change mitigation goals and proposed actions to meet the country’s environmental and resilience needs, in addition to South Africa’s international and local emission reduction commitments and goals.

South Africa is considering a suite of measures with which to meet its climate goals. These range from company-level carbon budgets to the upcoming carbon tax and investigations into the feasibility of CCS. These measures are guided by high level policies. The National Climate Change Response Policy in particular lists CCS as one of the eight Near-term Priority Flagship Programmes, given the nation’s current dependence on coal. The flagships are considered the frontrunners or ‘game-changers’ in South Africa’s climate action in key sectors (Department of Environmental Affairs, 2011).

The CCS Flagship Programme has a programme level governance structure. The South African Centre for CCS was established in 2009, in partnership with national and international stakeholders. It is the leading authority for CCS in the country and acts as a ring-fenced division within the South African National Energy Development Institute (SANEDI), which in turn reports to the Department of Energy. Some of the public, private and international partner organisation include; Eskom, Norwegian entities, SANEDI, Sasol, Alstom, AFD, Anglo American, Exxaro, PetroSA, Total and Xstrata (SA CCCS, 2015). The centre is supported by the South African Bureau of Standards Technical Committee 265 which mirrors the work of the ISO Technical Committee 265.

The actual implementation of the CCS Flagship Programme is governed by the South African CCS Roadmap. The CCS Roadmap details steps for the commercial scale rollout of CCS comprising five phases, each phase requiring a major decision. The roadmap covers the period
from 2004 to 2025. The five phases of the CCS Roadmap are described in

![Figure 5: Five phases of the CCS Roadmap (SACCCS, 2016)](image)

Phases 1 and 2 of the Roadmap have been completed. The phase 3 Pilot CO₂ Storage Project, scheduled for implementation in 2017, is contingent on a number of factors relating to the exploration programme. The pilot project entails the injection of approximately 10 000 tonnes of CO₂ per year into a selected geological storage site. This will be the first ever CO₂ injection into a South African geological formation.

The demonstration plant (phase 4) will test an integrated operating system under local conditions, forming an essential link between feasibility trials and a full scale commercial plant. The magnitude of the demonstration plant is in the order of hundreds of thousands of tonnes of carbon dioxide per year.
The planned commercial operation (phase 5) is dependent on the successful outcome of the demonstration plant but is not expected to be a part of the South African Centre for Carbon Capture and Storage. The magnitude of the commercial scale operation is in the order of millions of tonnes of carbon dioxide per year.

In addition to the outlined envisaged in the CCS Roadmap, the commercial rollout of CCS in South Africa is also influenced by developments in the international environment. These are important because they give context to domestic emission reduction strategies and ambitions, and can also provide a basis for the analyses of risks pertaining to CCS, which extend to CCS emissions reductions in subsequent sections.

2.1 South Africa’s Climate Change Obligations

South Africa’s high level approach to climate change is characterised by continuous endeavours to balance the national developmental priorities with the global necessity to reduce GHG emissions associated with human activity. Understanding the country’s sources of emissions and respective mitigation opportunities is key to developing national emission reduction scenarios. Such scenarios form the basis of South Africa’s domestic and international commitment. The aim of this report is therefore to investigate what part CCS plays in the country’s emissions mitigation strategy, locally and abroad.

The country’s current overarching mitigation strategy is based on the “peak, plateau and decline” emissions trajectory (Figure 6), which was formalised internationally in South Africa’s Copenhagen Pledge in 2009. According to this commitment, South Africa’s emissions will range between 398 and 614 Mt CO₂e by 2025. The emissions are expected to plateau for about a decade thereafter and then decline in absolute terms. The Copenhagen pledge amounted to a conditional commitment to reduce emissions by 34% below business as usual by 2020 and 42% by 2025.

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1 The plateau, peak, decline trajectory is expected to be recalculated in the near future.
In order to achieve its emission reduction goals, South Africa has mapped out various emissions projection scenarios in the Mitigation Potential Analysis (MPA) (Department of Environmental Affairs, 2014a). (The marginal abatement costs from the MPA of various technologies are shown in Figure 7.) This document was built on work undertaken in the National GHG Inventory for the period of 2000-2010 and the Long Term Mitigation Scenarios. The development of the national emission projections and trajectory options is however iterative in nature, and plans are ongoing to update the projection and trajectory scenarios.
Due to the global nature of climate change, South Africa’s response and approaches are influenced by developments in the international community and must be considered within the context of international obligations.

2.1.1 International obligations

Global average temperature is directly related to the concentration of GHGs in the atmosphere. As per the country’s role in the recent climate change negotiations in Paris in December 2015, South Africa has reconfirmed its commitment to working with global counterparts to limit global temperature increases below 2°C above pre-industrial levels, and ideally to 1.5°C.

The adoption of the Paris Agreement (UNFCCC, 2015) is considered a landmark for international climate policy because for the first time, a global pledge was made to curb emissions, strengthen resilience and act internationally and domestically to address climate change. Countries committed to unprecedented levels of emissions mitigations in their respective Intended Nationally Determined Contributions², which were subsequently formalised as Nationally Determined Contributions. These Nationally Determined Contributions are to be reconsidered every five years in a ‘global stock-take’, with a view to increasing the level of ambition of the various contributions.

The Paris Agreement declared that industrialised countries should have absolute targets, while developing countries should progressively move towards economy wide reduction or limitation targets. In this regard, South Africa is firmly committed to shifting the country’s economy to a low-carbon basis. Such a move entails scaling-up emission mitigation activities. South Africa’s transition of its international mitigation obligation, from a relative deviation from the “business-as-usual” approach, to the “peak, plateau and decline” trajectory, is evidence of the country’s commitment to this aim.

While commitments made by South Africa and other parties to the Paris Agreement are to be commended, it is widely acknowledged that there is still a huge gap that needs to be filled in order to achieve the proposed cap on global temperatures to 2°C, as per Figure 8.

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² Provided by 187 out of 196 UNFCCC member states.
In line with the Paris Agreement and in acknowledgement that emission reduction targets need to be made more ambitious, one of the weighty strategies that South Africa has committed to pursuing is the decarbonisation of the country’s energy sector, which accounts for about 80% of the country’s emissions (Department of Environmental Affairs, 2014a). This approach is well documented in the country’s policy and strategy documents, from the National Development Plan 2030, the Integrated Resource Plan and most recently, South Africa’s Intended Nationally Determined Contribution. This strategic shift will generate significant risks and opportunities for the energy sector value chains. In particular, vast reserves of coal and existing power stations will become ‘stranded assets’, exposing the country’s economy to inadequate generation capacity, job losses in the mining sector and reduced income from coal exports.

CCS is therefore one of the proposed technology interventions that South Africa is considering, in order to fill this gap. CCS is particularly attractive because it enables significant CO₂ emission reductions while maintaining the use of fossil fuels (Herzog, 2011) and the use of coal fired power plant for their full operational life and potentially the possibility to extend their life. Furthermore CCS could also be used in industrial process to reduce CO₂ emissions which may not necessarily be related to the generation of energy.

While CCS could be, in principle, an effective measure to reduce significant volumes of CO₂ emissions from South Africa’s energy and industrial sectors, detractors of the technology point to various limitations. The (relatively) high financial implications of the CCS technology and process are particularly important.

CCS must therefore be considered in terms of its financial viability and possible niche markets, particularly in comparison to other competing technologies. There are however various international and local supporting mechanisms, which if developed alongside the CCS feasibility in South Africa, could make the technology more economically appealing.
2.1.2 Local implementation of emission reduction measures

The South African political and regulatory environments are supportive of investigations into the technical and financial feasibility of CCS in the country. The most recent development in these environments are the Draft Carbon Tax Bill (2015) and the related Draft Carbon Offset Regulations (2016). These publications are indirectly supportive of CCS in South Africa because the impacts of both will lead to the development of a carbon price in South Africa. A price on carbon may benefit CCS in two ways. The first is the development of a market need for measures that reduce or mitigate CO₂ (which is the predominant GHG in South Africa’s inventory) by companies who may be liable for the tax. The second is the opportunity for CCS activities to participate in the offset market, where credits from these activities could be sold to tax-eligible entities to reduce their carbon tax liabilities. The introduction of these fiscal and economic emission mitigation measures is discussed further in section 2.3.2.

In addition to the proposed carbon tax and offset component, South Africa has also developed a number of other supporting pieces of legislation. The National Climate Change Response Policy is the country’s overarching climate change policy. It represents South Africa’s vision for an efficient climate change response and the long-term, just transition to a climate-resilient and lower-carbon economy and society. Given the socio-economic context of the country, the policy focuses on the effective management of climate change impacts through interventions that build and sustain South Africa’s social, economic and environmental resilience and emergency response capacity. It states that mitigation actions in the country shall:

- Be needs driven and customised to meet the relevant circumstances, with specific emphasis on developing the more vulnerable communities and members of society;
- Promote GHG-reducing technologies, practices and processes;
- Be cost effective and provide substantial GHG emission reductions; and
- Result in economic growth and job creation or benefit public health and alleviate poverty (Department of Environmental Affairs, 2011).

The National Climate Change Response Policy resulted in the adoption of the peak, plateau and decline trajectory. Within this context, the policy also lists CCS in the synthetic fuels industry as one of the mitigation options with the biggest mitigation potential in the medium-term (see Figure 6 for a graphical representation of the peak, plateau and decline strategy outlined in the policy document).

The National Development Plan 2030 is another of South Africa’s landmark policy documents which supports the development of CCS in South Africa. The National Development Plan 2030 recognises the need to reduce GHG emissions and improve energy efficiency, within the context of strategies to eliminate poverty and reduce inequality by 2030. The Plan is holistic in nature; it thus recognises that the effects of climate change threaten the proposed upliftment efforts in the country. The Plan therefore aims to ensure that all sectors of society are more resilient to the future impacts of climate-change by:

- Decreasing poverty and inequality;
- Creating employment;
• Increasing levels of education and promoting skills development;
• Improving health care; and
• Maintaining the integrity of ecosystems and the many services that they provide.

The Plan’s focus on sustainable growth therefore incorporates various climate change mitigation goals and proposed actions to meet the country’s environmental and resilience needs. These include the achievement of the peak, plateau and decline trajectory for GHG emissions (with the peak around 2025) as well as the entrenchment by 2030 of an economy-wide carbon price. Furthermore, the National Development Plan 2030 strongly supports the implementation of the 2010 Integrated Resource Plan, which aims to reduce carbon emissions from the electricity industry from 0.9kg per kilowatt-hour to 0.6kg per kilowatt-hour.

South Africa’s energy and industrial sectors are particularly emissions intensive. Together they generated 87% of South Africa’s GHG emissions in 2010 (Department of Environmental Affairs, 2014a). The National Development Plan 2030 therefore supports interventions that have the potential to facilitate cleaner coal use in the long term. Cleaner coal use will impact the emission intensity of South Africa’s electricity, which is expected to reduce the country’s future grid emission factor represented in Figure 9.

![Figure 9: South Africa’s projected emission intensity (Integrated Resource Plan 2010)](image)

Given the national priorities of creating employment opportunities keeping the country’s lights on, CCS is one such technology that is specifically endorsed by the plan, on account of its potential to mitigate emissions arising from industry. CCS will also prolong the economic viability of the coal mining industry and maintain the jobs in this sector.
The *New Growth Path* is another of the country’s seminal policy documents which aims to enhance economic growth, employment creation and equity. The document’s principal target is to create five million jobs over the next 10 years. This framework reflects government’s commitment to prioritising employment creation in all economic policies. It identifies strategies that will enable South Africa to grow in a more equitable and inclusive manner while attaining South Africa’s developmental agenda.

South Africa’s *Industrial Policy Action Plan* is linked to the objectives of the *New Growth Path*, among others. It recognises the “…pressing need for structural change in the economy to break out of commodity dependence and move to a more diversified base in which increasing value-addition and export-intensity come to define South Africa’s growth trajectory” (Department of Trade and Industry, 2016).

The *Industrial Policy Action Plan* is a product of the Economic Cluster of Government and is updated annually. The most recent revision for 2016/17-2018/19 was released in May 2016 and provides updates on the key focus areas, of which green industry investments is one. Carbon capture is one of the measures considered as a potential technological innovation that could support the leveraging of South Africa’s mineral resource endowment while mitigating emissions.

The *Integrated Resource Plan*, produced by the Department of Energy, is a strategic document that contextualises the country’s strategy to reduce emissions in the context of electricity generation. The purpose of the *Integrated Resource Plan* is to provide a long-term integrated electricity system build plan to meet projected electricity demand within existing legislation and policy frameworks. The Electricity Regulation Act 4 of 2006 requires the National Energy Regulator to “issue rules designed to implement the national government’s electricity policy framework, the Integrated Resource Plan.” The *Integrated Resource Plan* is implemented through determinations made by the Minister of Energy. Furthermore, any electricity licence issued by the energy regulator requires that the licence be placed within the context of the Plan and ministerial determinations.

The *Integrated Resource Plan* uses a system approach to energy planning which aims to minimise the cost of the energy system over the time horizon of the plan (typically 20-30 years). Constraints such as availability of resources e.g. water, primary energy and emission limits, provide boundaries within which the energy system may be developed. Commodity and technology costs play a large role in this process. Due to cost minimisation more expensive technologies (even if marginally more expensive) are often excluded from a build plan, unless policy imperatives are imposed either through constraints such as imposing emission limits or through pricing. Carbon pricing is an example of the latter.

The latest approved *Integrated Resource Plan 2010* was published in May 2011. CCS does not appear as an option in the plan and it is stated that “Carbon Capture and Storage (CCS) would allow coal generation to continue to have a large presence even in a carbon-constrained world. This is still a priority for future research”. The final plan in the *Integrated Resource Plan 2010* includes emissions constraints as defined by the peak-plateau-decline requirements. These limits are adhered to by using a combination of energy efficiency and renewable energy technologies, within the planning horizon up to 2030.

The *Integrated Resource Plan for Electricity 2010-2030 Update Report 2013*, published in November 2013 (but not promulgated) considers CCS in more detail and costs are applied to technologies fitted with CCS. While the planning timeframe considered in the *Update Report 2013* extends to 2050, the document has not yet been
approved by government and does not provide conclusive direction on where the energy sector will be
directed. The update does however include application of CCS to pulverised fuel coal fired power plants,
fluidised bed combustion plants, integrated gasification combined cycle power plants and open cycle gas
turbines. The pulverised fuel plant with CCS has an 86% reduction in CO₂ emissions with a 70% increase
in the levelised costs and a 43% reduction in efficiency, compared to the same technology without CCS.
The implications for integrated gasification combined cycle are more competitive with an 87% reduction in
CO₂ emissions with a 31% increase in the levelised costs and a 29% reduction in efficiency. The cost of the
technologies with CCS, relative to the cost of alternative (renewable energy) technologies with lower or no
emissions, are too high to be competitive, particularly in the later years of the planning horizon. This is
largely due to assumptions about renewable energy technology learning, in which the cost of the
technologies decrease as more of the technology is installed.

The Integrated Resource Plan Update Report 2013 also considers the impact of carbon pricing by simulating the
proposed carbon tax. It sums up the carbon price in relation to the emissions limit: “the application of the
emissions limit… provides a more significant carbon price than the carbon tax. …The Integrated Resource
Plan modelling chooses a more aggressive decarbonisation than the proposed carbon tax.” Although pricing
of carbon and emissions limits are used in the Integrated Resource Plan Update Report 2013, options for CCS do
not feature as part of the resulting plan within its time horizon to 2030. The implementation of CCS is only
expected to materialise after 2030 due to the lead time for the technology. This will also depend on the
demand for electricity after 2030 and the scope for mitigation using alternative options.

The Integrated Energy Planning Report was produced as part of an Integrated Energy Planning process. The
Integrated Energy Plan is intended to provide an energy sector wide plan similar to the Integrated Resource Plan
but with additional scope to include other parts of the sector, such as refining capacity and demand for
other energy carriers. The purpose is to consider the impacts of demand side energy efficiency and fuel
switching, in addition to the interaction between supply side technologies within national energy planning.
Emissions from the whole energy sector are considered.

As with the Integrated Resource Plan, the Integrated Energy Plan considers CCS technologies as part of the
modelling process. The Integrated Energy Planning Report has similar findings - CCS technologies are not
selected as competitive options within the projected demands for energy and the time horizon considered.
The time period for the Integrated Energy Plan is 2012 to 2050. The time window for CCS is in the electricity
generation sector, and is defined by the life of existing and planned coal fired power plants. Most of the
current coal power plants are retired by 2040, as represented in Figure 10. This leaves scope for CCS to be
applied to Medupi and Kusile and any other new coal fired power plants that may be constructed after 2030.
2.1.3 Mechanisms to meet obligations

Countries around the world are increasingly implementing carbon budgets, targets and taxes. These measures typically set a price on carbon. Carbon prices can be used as effective policy instruments to directly tackle rising emissions, and can also spur investments in low emission technologies and markets. The carbon markets are the platforms on which carbon commodities can be traded.

In South Africa 18 companies were awarded carbon budgets in 2016 and the upcoming carbon tax is scheduled for implementation in 2017. The carbon tax in particular will have an offset component, where the price of a tonne of CO₂ is expected to be R120 (prior to the subtraction of any applicable relief mechanisms).

While companies affected by carbon budgets, targets and taxes can reduce their emissions through internal measures, it is often too expensive for these entities to meet their targets or eliminate their carbon footprint entirely with internal reductions. Additional mechanisms are required to achieve these aspirational goals.

The carbon markets comprise one such mechanism. The markets can provide certified carbon offset credits that companies can use to offset their various liabilities, depending on the specific requirements of the trading scheme or national programme under which they fall.
The Clean Development Mechanism (CDM) is the most widely recognised framework in this regard. The CDM is defined in Article 12 of the Kyoto Protocol, an international treaty which extends the 1992 United Nations Framework Convention on Climate Change (UNFCCC). The Kyoto Protocol requires party countries to limit or reduce their GHG emissions. The Protocol utilises market-based mechanisms such as emissions trading and the CDM to help countries meet their emission targets, and to encourage the private sector and developing countries to contribute to emission reduction efforts.

The CDM encourages developing countries to implement emission reduction projects to earn carbon credits or certified emissions reductions. Each certified emission reduction is equivalent to one tonne of CO₂ reduced from the atmosphere. These certified emission reductions can be sold to developed countries which can use the credits to meet their emission reduction targets. In South Africa’s context, registered CDM project activities that meet local criteria are eligible as offset projects under the imminent carbon tax.

In order to register a stand-alone CDM project, or project activity under a Programme of Activities, project developers must identify the appropriate baseline and monitoring methodology under which the amount of certified emission reductions generated by the project activity can be determined. Methodologies are classified into five categories, ranging from methodologies for large and small scale project activities, including CCS. There are however no approved methodologies for CCS project activities. Such a methodology would need to be developed and subsequently approved by the Executive Board of the CDM. In the event that such a methodology is approved, project developers may use this methodology to register CCS projects or Programmes of Activity. The lack of approved methodology for CCS is an indication of its market readiness.

There are also opportunities in the voluntary carbon market, however no registered methodologies exists in these either. Methodologies registered with the CDM could also potentially be used to register projects under the Voluntary Carbon Standard. The Voluntary Carbon Standard is the most widely used voluntary GHG programme. Emission mitigation projects registered under this standard can generate verified carbon units.

While the international market for certified emission reductions is currently very depressed, the development of the South African carbon tax (scheduled for implementation in 2017) presents various carbon offsetting opportunities. Both the CDM and the Voluntary Carbon Standard are eligible standards in terms of the local carbon tax. Emission reduction projects registered under these standards may generate offset credits which could be used to offset carbon liabilities under the proposed tax. Such projects would need to meet the various eligibility criteria defined by the tax regulations. These requirements include, among others, local sustainability development criteria, as well as the requirement that the project developers (of carbon offset projects) be outside of the South African carbon tax net.

There may be opportunities that can be leveraged within the context of reducing emissions in South Africa, however, should it not deliver on its national commitments the country may also face punitive measures in the future.
2.2 INTERNATIONAL INCENTIVES FOR GHG MITIGATION

As a non-Annex I, developing country, South Africa is not obligated to implement or achieve the mitigation targets outlined in its Intended Nationally Determined Contribution (submitted in 2015) or subsequent Nationally Determined Contributions, which are required to be progressively more ambitious in terms of emission reduction commitments. South Africa is however required by the Paris Agreement to report on progress in implementation and achievement of mitigation in its Nationally Determined Contributions. These communications summarise the country’s high level policies and strategic approach to climate change at a point in time, illustrated in Figure 11.

South Africa is continuing to implement policies that incentivise low-carbon interventions or discourage high-carbon activities. Such policies signal price changes in the economy, making low-carbon activities economically feasible. The growing trend to apply regulated or national prices on carbon (as per carbon taxes and budgets) provides an additional mechanism that can help systematically achieve emissions reductions and related targets. Applying a price on carbon provides a framework for assessing the cost benefit of various emission (CO2 equivalent) mitigation options, which typically steers resources toward the lowest cost interventions and related research and development opportunities.

The development of a price mechanism for carbon in the domestic economy is therefore likely to support the commercialisation of CCS in South Africa.

2.2.1 Impact on trade and climate finance opportunities

The upcoming carbon tax will be the primary state mechanism to drive emission reductions in the private sector in South Africa. Non-compliance with the carbon tax will result in the same form of enforcement as non-compliance with other tax liabilities, i.e. financial penalties or at its most severe level, imprisonment.

The country therefore requires mechanisms to mitigate the potential negative impacts on South Africa’s economy in tandem with efforts to reduce GHG emissions (specifically CO2 within the context of this
The development of an international carbon price provides opportunities to leverage climate finance opportunities.

### 2.2.2 Internationally transferred mitigation outcomes

The Paris Agreement introduced the concept of a new mechanism to succeed the CDM, which generates tradable emission offsets. Article 6 of the Agreement provides a foundation for international cooperation through markets, with the value of carbon pricing incentives. The concepts of internationally transferred mitigation outcomes, to be supported by a new Emissions Mitigation Mechanism, are also introduced in the Article.

The mitigation outcomes in question could be at sectoral or project levels. Given the increasing pressure on countries to reduce emissions at a national level, these internationally transferable mitigation outcomes would likely be incorporated, or rolled-up, in the respective Nationally Determined Contributions. Hence the interpretation that such a mechanism would facilitate trade between Nationally Determined Contributions.

Ideally, the proposed Emissions Mitigation Mechanism could offer a globally accepted carbon allowance, or credit, for those countries that choose to use it. This could provide an opportunity for carbon pricing in many economies that have yet to formalise such a price. Setting a price on carbon could also spur investments in offset projects.

It is anticipated that the transfer of units between international carbon pricing systems could leverage large scale financing towards the most effective mitigation activities. These internationally transferred mitigation outcomes could also leverage economies of scale with regards to management costs. Progress regarding frameworks for local and international prices of carbon should be closely monitored because developments in this regard may impact the feasibility of CCS in South Africa.

Rules for the new mechanism are to be adopted at the first meeting of Parties after the agreement takes force. The new mechanism would require the development of suitable registry facilities and is likely to be dependent on the full implementation of the Paris Agreement (IETA, 2016).

The concepts of a new international carbon market mechanism and mandatory requirements regarding national emission reduction commitments are currently in the early stages of development. South Africa is comparatively advanced in this regard, in that is currently implementing a suite of new regulatory and fiscal frameworks related to GHG emissions. These advancements may also impact the development of CCS in South Africa, and should be monitored.

### 2.3 Possible Regulatory and Fiscal Aspects of CO₂ Emissions

South Africa is considering a mix of measures with which it intends to achieve its desired emission reduction outcomes (also known as DEROs). The measures discussed in this report include company-level carbon
budgets, the upcoming carbon tax, mandatory GHG emission reporting regulations and other environmental levies and taxes.

2.3.1 Carbon budget

The *National Climate Change Response Policy* first introduced the concept of company-level carbon budgets as a measure to align national mitigation commitments with emissions targets, at sectoral and company levels.

The Department of Environmental Affairs (2015) defines a carbon budget as a GHG emissions allowance (or cap), against which direct emissions arising from the operations of a company, during a defined time period will be accounted. The term “carbon” refers to the sum of carbon dioxide and carbon dioxide equivalents (as per the GHGs accounted for in the latest South African inventory).

Companies who are awarded carbon budgets will be required to monitor and track their emissions arising from their operations, during the defined time period. There will be no enforcement of carbon budgets in their first phase (2016 – 2020). The first phase is being implemented as a voluntary pilot to allow companies and the regulator (the Department of Environmental Affairs) adequate time to prepare for the second phase, scheduled to commence in 2021. The enforcement details of carbon budgets after 2020 are still under development.

Carbon budgets were allocated to 18 companies in 2016 in the voluntary pilot. The budgets provide a cumulative target level of GHG emissions that allocated companies are permitted to emit during the first phase (five-year period) of the carbon budget. Participating companies were selected from a set of target sectors on the basis that they emit more than 100 000 tonnes of GHG emissions per annum. Special compensation was made regarding the inclusion of companies that do not meet this 100 000 tonne threshold but do produce the ‘same primary product’ as one of the companies that meets the threshold.

A summary of the design features of the first phase of South Africa’s carbon budgets is presented in Table 1.

**Table 1: Carbon budgets phase 1 design features relevant to CCS**

<table>
<thead>
<tr>
<th>Long-term reduction goal</th>
<th>Carbon budgets set absolute emission caps for liable companies. The budgets were allocated to companies to support both current operations and existing expansion plans.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cap</td>
<td>South Africa’s GHG emission approach is the peak, plateau and decline trajectory. Carbon budgets set company level caps.</td>
</tr>
</tbody>
</table>
| Time period             | Phase 1: 2016 – 2020  
Phase 2: 2021 – 2025 |
| GHGs covered            | Carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), perfluorocarbons (PFCs), hydrofluorocarbons (HFC), and sulphur hexafluoride (SF₆). |
### Emissions scope
Carbon budgets are allocated for direct (scope 1) emissions only in phase one. The possibility of creating a mechanism for dealing with Scope 2 emissions during subsequent carbon budget phases will be considered.

### Threshold and sectors covered
Reporting threshold: 100 000 tonnes of CO₂ equivalent emissions.
The 2006 IPCC Guidelines provides a list categories and activities for which GHG data needs to be reported under.

### Price of carbon
The carbon budgets are not compliance instruments and participation is voluntary in the first phase. It is expected that they will become mandatory in the second phase.

### Linkages
There was no consideration of any national or sectoral mitigation targets when carbon budgets were set. Carbon budgets are however linked to allowances in the proposed carbon tax. Businesses that have been allocated carbon budgets will be entitled to an additional 5% tax free allowance from the second phase of the carbon budget. This over and above the basic tax free allowance of 60% and other allowances that will be provided for companies if, for example, they are considered to be exposed to the risk of carbon leakage or if they have significant process emissions.

### Consequences
There no legal consequences if companies exceed their carbon budgets in phase one.

The subsequent phases of the carbon budgets and alignment with the upcoming carbon tax will be determined by the lessons learnt during the implementation of the first phase.

Increasing international pressures to reduce emissions and the use of coal more specifically, may result in lower demand for South African coal. This reduced demand may lower coal prices, decreasing the total costs of electricity generation from coal and increasing the viability of CCS within the generation sector.

The introduction of the carbon budgets and tax supports the development of CCS in South Africa because CCS presents the opportunity for large industries to mitigate CO₂ emissions as required by these mitigation measures. CCS activities may also present compliance opportunities, where the resulting carbon credits could be used to offset liabilities under the carbon tax.

#### 2.3.2 Carbon tax
Following the release of the *Draft Carbon Tax Bill* in November 2015, the South African government has indicated that the tax will come into effect during 2017.

The carbon tax is an economy wide instrument that covers various sectors. Its aim is to tax emissions producing activities above set thresholds, specified in Annexure 1 of the *Draft National GHG Reporting Regulations* (Department of Environmental Affairs, 2016). The *Draft Carbon Tax Bill* makes allowances for sensitive industries (companies exporting to competitive markets) and presents opportunities for entities to reduce their tax liability with carbon offsets (Republic of South Africa, 2015). While a local trading scheme
is yet to be implemented, the inclusion of carbon offsets as a method to reduce tax liability presents the necessity for establishing a market where carbon offsets can be traded.

These markets present opportunities to register CCS project activities under the respective standards (CDM or Voluntary Carbon Standard). Registered facilities would be able to generate and trade in certified carbon credits within the local carbon offset market, envisaged under the carbon tax.

The key features of the carbon tax are described in Table 2 (IETA, 2017).

Table 2: Summary of the key features of the South African Carbon Tax relevant to CCS

<table>
<thead>
<tr>
<th>Long-term reduction goal</th>
<th>The tax policy will be implemented in conjunction with South Africa’s DEROs and carbon budgets. The DEROs will set long term emission reduction objectives for specific industries while the carbon budgets will set absolute emission caps for liable companies. Options to align these measures are still under development.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compliance periods</td>
<td>The carbon tax is expected to come into effect in 2017, with the first implementation phase lasting until 2020, where after aspects of the policy may be revised. The carbon tax and carbon budgets will be aligned from 2020.</td>
</tr>
<tr>
<td>GHGs covered</td>
<td>Carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), perfluorocarbons (PFCs), hydrofluorocarbons (HFC), and sulphur hexafluoride (SF₆).</td>
</tr>
<tr>
<td>Sectors covered</td>
<td>The tax will be applicable to all stationary and mobile direct and process emission sources including electricity generation; gasification; glass; cement; crude oil refining; mining; paper and pulp; iron and steel; aluminium; chemicals and transport.</td>
</tr>
<tr>
<td>Point of regulation</td>
<td>The carbon tax will apply to activities where GHG emissions are emitted directly from fuel combustion, non-energy industrial processes and fugitive emissions.</td>
</tr>
<tr>
<td>Threshold</td>
<td>The threshold to determine whether an activity is taxable or not varies depending on the sector and type of activity. However, in many case activities with equivalent capacities greater than 10 MW thermal are taxable. This threshold is based on the draft regulations and may still change.</td>
</tr>
<tr>
<td>Average carbon price</td>
<td>The tax rate will initially be set at ZAR 120 per tonne CO₂e, which the Draft Carbon Tax Bill roughly equates to US$ 9 or € 8 per tonne CO₂e in 2016. This tax rate will be subject to annual revision as with other national taxes. The tax design makes provision for relief mechanisms to reduce the tax burden on the economy during the first phase. Companies conducting taxable activities will not be required to pay for a fixed percentage of their emissions. These tax free thresholds can reduce the effective tax rate to between ZAR 6 – ZAR 48 per tonne CO₂e. Some of the basic relief mechanisms, such as the tax free threshold, will be phased out after 2020.</td>
</tr>
</tbody>
</table>

South Africa’s developing carbon pricing system is unique in the respect that it combines a carbon tax with carbon offsets. In line with international examples, such as the EU Emissions Trading System, the South African government has opted to reduce the impact of carbon pricing on the economy during the first phase of implementation. This reduction is achieved through a series of relief measures, which includes the right to offset between 5% and 10% of taxable emissions through the purchase of qualifying carbon offset credits.
CCS project activities could qualify as eligible offset activities under the carbon tax. If priced correctly, offset credits represent a least-cost mitigation option. The need for carbon offset credits by tax-eligible entities could therefore motivate the development and commercialisation of CCS in South Africa.

Such opportunities should be considered within the context of the Mandatory GHG Emission Reporting Regulations and the Energy Management Plans, which support the implementation of the carbon tax.

2.3.3 Mandatory Reporting Regulations

In 2016, the Department of Environmental Affairs released two draft climate change related regulations which are focused on assisting government meet its reporting obligations and ultimately, reducing the country’s emissions.

The Draft National GHG Emission Reporting Regulations were gazetted in June 2016 by the Department of Environmental Affairs. The purpose of the draft regulations is to introduce a comprehensive, single, national system for the transparent reporting of GHG emissions.

At a country level, understanding the country’s national GHG profile will assist South Africa develop effective and appropriate measures to mitigate climate change. Such information will also assist identify suitable sources of CO₂ for CCS applications. A comprehensive national inventory will also assist government, and the private sector, to allocate resources to where they are needed most and where they may have the highest impacts. The proposed carbon tax will be based on the GHG emissions reported to the Department of Environmental Affairs, as per these regulations. At a company level, understanding the business’ direct GHG emissions will therefore assist in determining carbon tax and carbon budget obligations.

The draft regulations apply to companies that are responsible for direct GHG emissions that arise from facilities within South Africa. Such companies are only required to report their GHG emissions if they meet the threshold criteria outlined in Annexure 1 of the draft regulations. These companies must register all their facilities with the National Atmospheric Emissions Inventory System (also known as the NAEIS).

The second draft set of regulations under discussion is the Pollution Prevention Plan Regulations, issued in January 2016 under the National Environmental Management: Air Quality Act (Act 39 of 2004). Businesses which are eligible for carbon budgets are required to develop pollution prevention plans as per the regulations, which must be submitted to the Minister of Environmental Affairs. Such plans must describe company led interventions that will be implemented to reduce GHG emissions over the course of the next five years, and the expected mitigation impact that these actions will have. These companies will also be required to submit annual progress reports, which must include any variances from the approved plan and the proposed remedial actions to address deviations.

It is expected that carbon budgets will become mandatory post 2020. While the specifics to enforce the budgets are yet to be determined and the two draft regulations discussed above have not been finalised, these measures signal increasing regulatory pressures on South African entities to mitigate GHG emissions. The motivation to pursue CCS increases in light of this increasing market demand for clean technologies. Environmental levies and taxes also contribute to South Africa’s GHG mitigation goals.
2.3.4 Environmental levies and taxes

The environmental levy on electricity generation in South Africa was implemented in 2009 and includes a tax on the production of electricity from non-renewables such as coal, petroleum-based fuels, natural gas, and nuclear. The cost of the levy is passed on to consumers by the state-owned enterprise, where a portion of the funds generated are used by government for various environmental measures to mitigate GHG emissions. The implementation of this levy was intended to initiate a preliminary framework for the development of a carbon tax, which is subsequently expected to result in a reduction in the same electricity levy.

The successful rollout of CCS in the country could well see a reduction in the environmental levy, considering that CCS will mitigate the emission of CO₂ from the production of electricity. If the levels of CO₂ mitigation are of a significant quantity, further reductions in the country’s other fiscal instruments (such as the CO₂ vehicle emissions tax) could also feasibly be conceived.

Understanding the progression of South Africa’s various measures to reduce national emissions is important because these measures set the context for assessing the rationale behind the development of CCS in the country. Overall, the South African regulatory environment is supportive of CCS deployment, particularly if it is developed in the context of the latest GHG regulations and opportunities related to carbon pricing and markets.

The following section of this report outlines the cost-benefit analyses of the technology. This provides the next, critical level of information relating to recommendations on the advancement of the CCS programme in South Africa.
3  POTENTIAL FOR CCS IN SOUTH AFRICA

The potential for CCS is explored based on its expected time for commercialisation and the period of operation as a transitional technology in the path to a low carbon world. An assessment of the capturable sources of CO₂ for this period is undertaken by examining information sources including the current National Greenhouse Gas Inventory, the International Energy Agency’s (IEA) energy balances for South Africa, Integrated Resource Plan (IRP Update Report 2013), Integrated Resource Plan Update Assumptions, Base Case Results and Observations 2016, Integrated Energy Planning (IEP) Report 2013 and Integrated Energy Plan 2016. Sources of unavoidable emissions from industrial process are highlighted. The storage potential and transport potential for CO₂ is assessed from existing SACCCS research. All this information is used in subsequent sections to evaluate and identify the basket of feasible emissions sources and storage locations for CCS implementation.

3.1  EXPECTED OPERATIONAL PERIOD FOR CCS

CCS is expected to be commercially viable in South Africa by 2030. This is based on consultation with SACCCS and their current work on the development of CCS technology. For South Africa and elsewhere CCS is envisaged as an important technology that could facilitate the transition to a low carbon world. As such it is expected that CCS is likely to be most active in South Africa within the period of 2030-2050. This business case will focus on this period although the currently planned and constructed coal fired power plants will operate beyond this period and thus CCS may continue beyond 2050 if the capacity for storage allows.

3.2  CONTEXT FOR CAPTURABLE EMISSIONS

Emissions data provided in the National GHG Inventory (2010), National Energy Balances and reported in voluntary company level disclosures, such as the Carbon Disclosure Project (CDP), provide context of the country’s historical and current emissions. The investigations undertaken for the purposes of this report largely focus on data from the National GHG Inventory (2010) as this represent the country’s latest emissions count as approved by government³.

The data sets assist in conceptualising and projecting future emissions. Assumptions of price trends, market growth rates and infrastructural plans can also be applied to the current and historical emissions information to develop scenarios of future emissions profiles. The Integrated Energy Plan (IEP) and the IRP (updated in 2013) are the main sources of data used for this exercise within the scope of this report.

³  An updated inventory (up to 2012) is expected to be released by government in early 2018.
3.2.1 Current sources of GHGs

According to the most recent National GHG Inventory (2010) South Africa emitted an estimated 544 Mt of CO$_2$e (total GHGs converted to CO$_2$ equivalent values) across all sectors (sequestration from forestry and other land use excluded). A high level breakdown of the emissions per major contributing gas is provided in Figure 12.

![Figure 12: GHG emissions by gas for South Africa (Department of Environmental Affairs, 2014a)](image)

The vast majority (85%) of the national GHG emissions are from CO$_2$. The two Intergovernmental Panel on Climate Change (IPCC) categories contributing to CO$_2$ emissions are, Energy, and Industrial Processes & Product Use (IPPU). In 2010, the energy category accounted for approximately 423 Mt of CO$_2$ emission in 2010 (78% of the national inventory) while the IPPU category accounted for approximately 43Mt of CO$_2$ (8% of the national inventory). It is these sectors that present opportunities for carbon capture and will be considered in further detail.

The sources of CO$_2$ emissions within the energy category are summarised in Figure 13.
Energy transformation accounts for 63% of the CO₂ emissions from energy related activities. Transport contributes as much as 11% to the total CO₂ emissions in the sector and manufacturing and construction account for 10%. Fugitive emissions from fuels accounts for 5% with the remaining emissions are attributed to other sectors and non-specified activities.

Power stations, the liquid fuels industry (refineries and synthetic fuel plants specifically) and certain industrial facilities (particularly those related to cement and iron and steel industries) provide large concentrated point sources of emissions suitable for capturing CO₂. As such these concentrated sources may be a focus area for carbon capture. Transport, manufacturing and construction, and fugitive emissions do not present opportunities for capturing carbon due to their mobile and dispersed natures.

Eskom fossil fuel power stations and their emissions calculated for 2014 are presented in Table 3. Of these plants only the 7 shaded plants in the table will have 10 or more years remaining operational life by 2030 when CCS is believed to be commercially operational in South Africa. These plant would then produce approximately 192 Mt CO₂ per year post 2030.
Table 3: Eskom fossil fuelled power stations\(^4\) (highlighted plants have greater than 10 years lifetime post 2030) (Eskom, 2016)

<table>
<thead>
<tr>
<th>Plant name</th>
<th>Installed capacity (MW)</th>
<th>Commissioning date</th>
<th>Fuel type</th>
<th>CO(_2) emissions 2014 (Mt/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arnot</td>
<td>1 980</td>
<td>1971/09/21</td>
<td>Coal</td>
<td>16</td>
</tr>
<tr>
<td>Duvha</td>
<td>3 450</td>
<td>1980/01/18</td>
<td>Coal</td>
<td>22</td>
</tr>
<tr>
<td>Hendrina</td>
<td>1 895</td>
<td>1970/05/12</td>
<td>Coal</td>
<td>14</td>
</tr>
<tr>
<td>Kendal</td>
<td>3 840</td>
<td>1988/10/01</td>
<td>Coal</td>
<td>38</td>
</tr>
<tr>
<td>Kriel</td>
<td>2 850</td>
<td>1976/05/06</td>
<td>Coal</td>
<td>22</td>
</tr>
<tr>
<td>Lethabo</td>
<td>3 558</td>
<td>1985/12/22</td>
<td>Coal</td>
<td>39</td>
</tr>
<tr>
<td>Matimba</td>
<td>3 690</td>
<td>1987/12/04</td>
<td>Coal</td>
<td>35</td>
</tr>
<tr>
<td>Majuba</td>
<td>3 843</td>
<td>1996/04/01</td>
<td>Coal</td>
<td>32</td>
</tr>
<tr>
<td>Matla</td>
<td>3 450</td>
<td>1979/09/29</td>
<td>Coal</td>
<td>29</td>
</tr>
<tr>
<td>Tutuka</td>
<td>3 510</td>
<td>1985/06/01</td>
<td>Coal</td>
<td>27</td>
</tr>
<tr>
<td>Acacia</td>
<td>171</td>
<td>1976/05/13</td>
<td>Kerosene</td>
<td>0</td>
</tr>
<tr>
<td>Ankerlig</td>
<td>1 327</td>
<td>2007/10/01</td>
<td>Diesel</td>
<td>1</td>
</tr>
<tr>
<td>Gourikwa</td>
<td>740</td>
<td>2007/10/01</td>
<td>Diesel</td>
<td>1</td>
</tr>
<tr>
<td>Port Rex</td>
<td>171</td>
<td>1976/09/30</td>
<td>Kerosene</td>
<td>0</td>
</tr>
<tr>
<td>Camden</td>
<td>1 600</td>
<td>1966/12/21</td>
<td>Coal</td>
<td>20</td>
</tr>
<tr>
<td>Grootvlei</td>
<td>1 200</td>
<td>1969/06/30</td>
<td>Coal</td>
<td>13</td>
</tr>
<tr>
<td>Komati</td>
<td>1 000</td>
<td>1961/11/06</td>
<td>Coal</td>
<td>10</td>
</tr>
<tr>
<td>Medupi</td>
<td>4 764</td>
<td>In progress</td>
<td>Coal</td>
<td></td>
</tr>
<tr>
<td>Kusile</td>
<td>4 800</td>
<td>In progress</td>
<td>Coal</td>
<td></td>
</tr>
<tr>
<td>Khanyisa and Thabametsi</td>
<td>863</td>
<td>Awarded in Coal</td>
<td>Coal</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>48 702</strong></td>
<td></td>
<td><strong>320</strong></td>
<td></td>
</tr>
</tbody>
</table>

While no power plants in the fleet are currently fuelled by biomass the capture of CO\(_2\) emissions from combusted biomass or refined biofuel presents an opportunity to effectively extract CO\(_2\) from the atmosphere.

The liquid fuels industry in South Africa represents a further feasible source for the application of CCS. The refineries located in South Africa are presented in Table 2.

\(^4\) Calculations based on IPCC emission factors, calorific values and densities.
Table 4: Refineries in South Africa (SAPIA, 2014; Parsons & Brinckerhoff, 2013)

<table>
<thead>
<tr>
<th>Refinery</th>
<th>Type</th>
<th>Owners</th>
<th>Location</th>
<th>Capacity bbl/day</th>
<th>CO₂ emissions Mt/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapref</td>
<td>Crude</td>
<td>BP &amp; Shell</td>
<td>Durban</td>
<td>180 000</td>
<td>0.9</td>
</tr>
<tr>
<td>Enref</td>
<td>Crude</td>
<td>Engen</td>
<td>Durban</td>
<td>125 000</td>
<td>1.0</td>
</tr>
<tr>
<td>Calref</td>
<td>Crude</td>
<td>Caltex</td>
<td>Cape Town</td>
<td>100 000</td>
<td>0.6</td>
</tr>
<tr>
<td>Natref</td>
<td>Crude</td>
<td>Sasol &amp; Total</td>
<td>Sasolburg</td>
<td>92 000</td>
<td>0.7</td>
</tr>
<tr>
<td>Sasol</td>
<td>Synfuels (CTL)</td>
<td>Sasol</td>
<td>Secunda</td>
<td>150 000</td>
<td>44.0</td>
</tr>
<tr>
<td>Sasol</td>
<td>Synfuels (GTL)</td>
<td>Sasol</td>
<td>Sasolburg</td>
<td></td>
<td>4.7</td>
</tr>
<tr>
<td>PetroSA</td>
<td>Synfuels (GTL)</td>
<td>State owned</td>
<td>Mossel Bay</td>
<td>45 000</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>692 000</strong></td>
<td><strong>53.3</strong></td>
</tr>
</tbody>
</table>

CCS may also be feasibly applied to sources of unavoidable emissions that arise from various industrial processes. The origin of GHG emissions from IPPU (industrial processes and product use) sectors are summarised in Figure 14.

Iron and steel production and ferroalloys production processes are concentrated in a number of large operations which have limited scope to avoid the emission of CO₂ through alternatives. Emissions from cement and limestone production are also difficult to avoid. These activities provide a niche opportunity for CCS as there are no other economically viable means to reduce their emissions.

Cement production and limestone production contribute almost all of the emissions of the mineral industry (11% of the IPPU sector’s emissions). A list of the cement plants in South Africa is provided in Table 5.
Table 5: Cement plants in South Africa (Cemnet, 2016; Parsons and Brinckerhoff, 2013)

<table>
<thead>
<tr>
<th>Cement Plants</th>
<th>Clinker capacity (Mt/a)</th>
<th>Cement capacity (Mt/a)</th>
<th>CO₂ Emissions (Mt/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afrisam (Pty) Ltd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dudfield</td>
<td>1.83</td>
<td>1.94</td>
<td>1.5</td>
</tr>
<tr>
<td>Ulco</td>
<td>1.00</td>
<td>~1.06</td>
<td>~0.8</td>
</tr>
<tr>
<td>Lafarge South Africa (Pty) Ltd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lichtenburg</td>
<td>2.00</td>
<td>2.40</td>
<td>1.6</td>
</tr>
<tr>
<td>Pretoria Portland Cement (PPC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De Hoek</td>
<td>0.88</td>
<td>0.95</td>
<td>0.6</td>
</tr>
<tr>
<td>Dwaalboom</td>
<td>0.72</td>
<td>0.78</td>
<td>1.2</td>
</tr>
<tr>
<td>Port Elizabeth</td>
<td>0.25</td>
<td>0.27</td>
<td>0.2</td>
</tr>
<tr>
<td>Hercules</td>
<td>0.58</td>
<td>0.64</td>
<td>0.4</td>
</tr>
<tr>
<td>Jupiter</td>
<td>0.44</td>
<td>0.49</td>
<td>0.1</td>
</tr>
<tr>
<td>Riebeeck</td>
<td>0.53</td>
<td>0.75</td>
<td>0.5</td>
</tr>
<tr>
<td>Slurry</td>
<td>1.52</td>
<td>1.68</td>
<td>1.2</td>
</tr>
<tr>
<td>Natal Portland Cement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simuma</td>
<td>0.57</td>
<td>1.00</td>
<td>0.4</td>
</tr>
<tr>
<td>Durban</td>
<td>0.56</td>
<td>1.10</td>
<td>0.7</td>
</tr>
<tr>
<td>Sephaku Cement (SepCem)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aganang</td>
<td>1.80</td>
<td>1.10</td>
<td>~1.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12.68</strong></td>
<td><strong>13.09</strong></td>
<td><strong>~10.7</strong></td>
</tr>
</tbody>
</table>

Within the IPPU sectors the vast majority of the CO₂ emissions are accounted for by the metal industries with 87% of the emissions. The largest contributors within the metal industry are iron and steel production followed by ferroalloys production. A list of metal plant in South Africa is provided in Table 6.

---

Table 6: Metal plants in South Africa (Parsons and Brinckerhoff, 2013)

<table>
<thead>
<tr>
<th>IPPU Sector</th>
<th>Company</th>
<th>Plant name</th>
<th>Location</th>
<th>CO$_2$ emissions (Mt/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>BHP Billiton</td>
<td>Bayside/Hillside</td>
<td>Richard's Bay</td>
<td>3.4</td>
</tr>
<tr>
<td>Ferro Chrome</td>
<td>Assmang Chrome</td>
<td>Machadodorp Works</td>
<td>Machadodorp</td>
<td>0.4</td>
</tr>
<tr>
<td>Ferro Chrome</td>
<td>Hernic Ferrochrome</td>
<td>Hernic Ferrochrome</td>
<td>Brits</td>
<td>0.4</td>
</tr>
<tr>
<td>Ferro Chrome</td>
<td>Samancor</td>
<td>Ferrometals</td>
<td>Witbank/eMalahleni</td>
<td>0.7</td>
</tr>
<tr>
<td>Ferro Chrome</td>
<td>Samancor</td>
<td>Middelburg Ferrochrome (MFC)</td>
<td>Middelburg</td>
<td>0.4</td>
</tr>
<tr>
<td>Ferro Chrome</td>
<td>Samancor</td>
<td>Tubatse Ferrochrome (TFC)</td>
<td>Steelpoort</td>
<td>0.6</td>
</tr>
<tr>
<td>Ferro Chrome</td>
<td>Xstrata Alloys</td>
<td>Boshoeck</td>
<td>Steelpoort</td>
<td>0.4</td>
</tr>
<tr>
<td>Ferro Chrome</td>
<td>Xstrata Alloys</td>
<td>Lydenburg</td>
<td>Lydenburg</td>
<td>0.5</td>
</tr>
<tr>
<td>Ferro Chrome</td>
<td>Xstrata Alloys</td>
<td>Wonderkop</td>
<td>Rustenburg</td>
<td>0.6</td>
</tr>
<tr>
<td>Ferro Manganese</td>
<td>Assmang</td>
<td>Cato Ridge Alloys</td>
<td>Durban</td>
<td>0.1</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>Arcelor Mittal</td>
<td>Newcastle</td>
<td>Newcastle</td>
<td>6.6</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>Arcelor Mittal</td>
<td>Vanderbijlpark</td>
<td>Vanderbijlpark</td>
<td>23.0</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>Arcelor Mittal</td>
<td>Vereenigening</td>
<td>Vereenigening</td>
<td>0.2</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>Cape Gate</td>
<td>Vanderbijlpark</td>
<td>Vanderbijlpark</td>
<td>0.2</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>Columbus Steel</td>
<td>Middelburg</td>
<td>Middelburg</td>
<td>0.4</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>Evraz - Highveld Steel and Vanadium</td>
<td>Witbank</td>
<td>Witbank/eMalahleni</td>
<td>2.8</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>Scaw Metals</td>
<td>Germiston</td>
<td>Germiston</td>
<td>2.5</td>
</tr>
<tr>
<td>Manganese Alloys</td>
<td>BHP Billiton - Samancor</td>
<td>Metalloys</td>
<td>Meyerton</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>44.1</strong></td>
</tr>
</tbody>
</table>

**Note:** The highlighted plants are no longer in operation.

These activities, where no other economically viable means to reduce CO$_2$ emissions exist, present opportunity for CCS. As such these activities provide a starting point from which to identify sources that may have the strongest case for the capture of CO$_2$. The emissions sources within the national emissions inventory with some possibility of CO$_2$ capture are presented in Figure 15.
It is evident from this analysis that 66% of the national CO₂ emissions (308Mt) presents some possibilities for capture and storage. Of these emissions the largest potentials for the application of CCS are expected in the energy related industries (57%) and industrial processes that account for unavoidable emissions including iron and steel production (5%), ferroalloy production (3%) and cement production (1%).

Power plants, while the largest source of emissions, are typically locked into an emission-intensity by the technology option that is deployed for the life of the plant. While it is possible to retrofit fossil fuel fired power plants it is likely that the cost of retrofitting carbon capture technologies relative to the remaining life of older plants will be economically prohibitive. It is anticipated that the application of CCS will therefore be confined to new projects in this sector. Arguably the same could be said for other industrial processes and therefore it is important to understand the profile of the ‘new’ emissions activities that are committed and forecast for the period of 2030-2050.

### 3.2.2 Future sources of GHGs

There is no straightforward methodology to determine what the future of South Africa’s GHG emissions will look like in the period of 2030-2050. The location and size of many emissions sources in the future are, to a large degree, uncertain. However, there are some sources that are certain to be operational in this period due to their long operational life. Heavy industry technologies such as power stations, refineries, steel plants and cement factories have lifespans that can be several decades long. Power stations such as Medupi and Kusile (each with a capacity of 4 800 MW); the power plants bid under the base load IPP programme, Khanyisa and Thabametsi (with a combined capacity of 863.3 MW) as well as the proposed 3 000 MW open cycle gas turbine facility will be in operation for 30-60 years. As large individual point sources of CO₂ emissions, these particular plants present opportunities for carbon capture.

![Figure 15: Share of Emissions Inventory with some possibility of storage (Department of Environmental Affairs, 2014a)](image-url)
However, the remainder of the sources of carbon emissions from electricity generation will need to be extracted from modelled forecasts of economic activity. The Integrated Energy Plan (IEP) is developed to determine the best way to meet current and future energy service needs in the most efficient and socially beneficial manner, while maintaining control over economic costs, serving national imperatives and minimising the environmental impacts. In doing so the IEP forecasts how the energy demand may be met under various scenarios. A summary of the forecasted IEP scenarios in terms of the total annual energy activity per technology is presented in Figure 16.

![Figure 16: Summary of the forecasted IEP scenarios in terms of the total annual energy activity per technology in PJ (Department of Energy, 2013b)](image)

Under the IEP scenarios the energy activity range for coal fired electricity generation ranges from approximately 700 to 1,640 PJ across the scenarios. The case of 700PJ would present a significant decline from the 2010 and 2030 estimates although the 1,640PJ cases present a substantial increase from the 2010 and 2030 estimates. The changes to the carbon emissions would be proportional to the changes in the demand in energy from coal fired power plants.

The IRP produced in 2010 (updated in 2013) gives projections of scenarios of the energy technology shares up to 2050. These projections can offer an insight into how emission profiles from electricity production may develop in the period when CCS could be implemented. These profiles quantify the emissions from electricity generation that can potentially be captured.

Similarly the IRP, which informs aspects of the IEP, also models projections of electricity producing technologies. The IRP provides data on the existing and committed capacities as well as scenarios around
possible new capacities. A summary of the existing and committed capacities from the IRP 2010 (2013 update) is presented in Figure 17.

![Figure 17: Existing and committed technology shares up to 2050 (Department of Energy, 2013a)](image)

The expected decline in existing and committed capacity for electricity generating plants is shown in Table 8. The figure does not include any new capacity that may be planned for after 2013. This curve presents a base of technology shares that will not change with the scenarios of energy generation futures. These future scenarios include Medupi, Kusile, Khanyisa and Thabametsi, which will account for a significant proportion of the existing and committed coal capacity in the future.

The IRP (2013 update) has developed a number of scenarios for the shares of technology for the total expected electricity generation over and above the base case in Figure 17. The emissions trajectories of these scenarios are plotted in Figure 18 below. It is evident that the emissions trajectories of the scenarios span a wide range, between 120 – 400 Mt per year in 2050. A number of these scenarios also converge in a plateau at approximately 275 Mt per year in 2050.
Some of the emissions scenarios align with the concept of a peak, plateau and decline in emissions trajectory as committed to by South Africa. However, there are a number of scenarios where the decline does not occur and these may present possible futures where CCS will be required in order to meet emissions obligations.

The IRP update report (2013) detailed the emissions trajectory limits for each sector in order to meet the quantified peak plateau and decline that has been committed to, presented in Figure 19. In this breakdown emissions from energy generation need to fall from approximately 230Mt per year in 2030 to approximately 180Mt per year in 2050. Petroleum refining and synfuel production as well as industrial process emissions are required to decrease at a similar rate. CCS may be relevant in these sectors under scenarios that are unable to meet these prescribed limits.
Figure 19: Emission limit trajectory of emitting sectors to align with the national peak, plateau and decline trajectory (Department of Energy, 2013b)

The 2012 Integrated Energy Planning report: Annexure A: Technical Report Part 1: Demand Modelling Report provides energy projections for various demand sectors. The projected energy demand by energy carrier is provided for the iron and steel sector in Figure 20.

Figure 20: Energy demand projections for the iron and steel sector (IEP Report 2012) (Department of Energy, 2013b)
Considering the IEP’s projected increased energy demands, the resulting emissions from the iron and steel sector are expected to continue growing with a 31% increase from emissions of coal and 42% increase in emissions from gas by the year 2050.

The context for capturable emissions in South Africa has been established by considering the country’s latest emissions inventory and considering future sources of GHGs. CO₂ emissions from energy transformation and use and IPPU tend to be from concentrated sources, providing practicable opportunities for capture. The analyses above indicate that the material sectors in which CCS may feasibly implemented include planned new build electricity generation (as per the IRP); the liquid fuels industry (from refineries to synthetic fuel plants); the cement industry as well as the iron and steel industry. These sectors are therefore the focus areas for investigations into the viability of the CCS business case, which is explored further in Section 6, which considers the impact of CCS in the context of South Africa’s efforts to reduce GHG emissions.

An assessment of South Africa’s CO₂ storage and transport potentials follow, in order to better understand the practical feasibility of implementing CCS in South Africa.

### 3.3 Transport Potential

The ability to transport CO₂ from the source of emission to the point of storage is critical to any CCS chain. This is particularly relevant for a national CCS strategy. Due to the quantities of CO₂ that are captured for storage the preferred option for CO₂ transportation is pipeline in most CCS projects. The scale of CCS projects typically makes it uneconomical for systems such as ship or road.

A pipeline system known as a “trunkline system” allows a common pipeline to transport CO₂ to a common beach facility where the CO₂ can then be transported offshore to the sink. This pipeline system allows for connections from individual sources to the common trunk line. Current research indicates that a trunkline approach is the most economical and feasible way to implement a CCS network on a national scale. As such a trunk line based network may be best suited to the South African context.

The next key consideration for the transportation system is the state in which CO₂ will be transported. CO₂ can be transported in dense phase or gaseous phase. Transportation of CO₂ in gaseous phase to some degree lessens the risks associated with a CO₂ pipeline. However a gaseous phase system would require considerably larger diameter pipelines for the same mass flow rate as dense phase CO₂.

It is possible to split a system into sections which are gaseous phase and sections which are dense phase. Connections to the trunkline that may never transmit large quantities of CO₂ may benefit form gaseous phase transportation with booster compression where this joins the trunk line.

The requirements for ancillary equipment vary with the operation of either an end to end dense phase system or a partial dense phase system. A dense phase end to end system would require compression of up to 200 bar at the emission source. To maintain this pressure, booster stations would be required at regularly spaced points along the branch pipeline with a specific booster station at point of entry to the trunkline. A dense phase system must also consider and account for the additional risk in its design. Extra equipment for drying, venting and filtering is necessary for dense phase CO₂ transport.
In addition to the technical constraints in the design of the pipeline, there are physical constraints on the areas through which the pipeline could be routed. These constraints include:

- Natural Geography (mountains);
- Population (large populated zones);
- Geophysical (rivers and lakes);
- Built Environment (mines);
- Environmental (parks and reserves); and
- Emitter Locations.

South Africa’s sources of carbon emissions are predominantly in the north east and east of the country, or in the south west and west of the country. There is a great geographical separation between the sources and the large offshore storage basins in the Western Cape and Kwa-Zulu Natal coast. Many of the physical barriers mentioned above would need to be overcome in order to reach either storage location.

However, there may be an opportunity to run a pipeline for the transportation of CO₂ along the same routes as the existing network of national oil and gas pipelines, owned by Transnet. Using these routes may help to overcome some of the barriers listed above and any additional planning or permissions issues related to the use of the land. These pipelines are summarised in Figure 21. Currently, the existing pipeline network only connects the Kwa-Zulu Natal coast with the north eastern parts of the country. However, this section of the country is where many of the large emissions sources, such as the refineries, are located. It is therefore conceivable that a CO₂ pipeline could be installed parallel to the fuel pipelines, to transport captured CO₂ back to the coast for storage.
The proposed gas pipelines that would connect the north eastern part of the country to the west coast are also highlighted in Figure 21. These proposed pipelines may present similar opportunities for the deployment of a parallel pipeline to transport CO$_2$ to the storage locations on the west coast. While the future of these pipelines is uncertain it is possible that provisions could be made for the inclusion of a CO$_2$ pipeline if there is a strong business case for CCS to use the storage basins off the west coast.

Beyond the physical constraints, an important consideration in comparing of the various types of CO$_2$ transportation systems is the cost of the systems. A system can be arranged to function in many ways however some arrangements may be more economical than others. The techno-economic report compiled by Parson and Brinckerhoff (2013) explored the cost associated with several potential national transport systems for CO$_2$. The costings from this study, and others, will be discussed in subsequent sections of this report.

### 3.4 STORAGE POTENTIAL

An assessment of the potential geological storage for CO$_2$ in South Africa was commissioned by the Department of Energy and conducted by the Council for Geoscience in 2010, with other studies conducted as early as 2004. The output of the 2010 assessment was a Technical Report and an Atlas on geological storage of CO$_2$ in South Africa which formed one of the first stages of the CCS Road Map.
A further techno-economic review of the potential for CCS implementation in South Africa was conducted by Parsons Brinckerhoff in 2013 and was funded by the World Bank. These assessments provide the foundation of the current knowledge on the geological storage potential for CO₂ in South Africa.

The geological storage of CO₂ involves injecting it into underground formations where it can be securely and permanently stored. CO₂ is effectively stored in the same way as hydrocarbons such as oil and gas which are trapped in reservoirs underground by impermeable layers of material. Geological storage of CO₂ is possible in deep saline formations where it becomes trapped in the pore spaces between the grains of sedimentary rock. It is also possible to use depleted oil or gas reservoirs or ‘unminable’ coal seams where the CO₂ can displace oil, gas or coal bed methane respectively.

The storage component of CCS is unique to each country as it is based on the prevailing geology. The Atlas on geological storage of CO₂ in South Africa has been developed through assessing the county’s ‘effective storage capacity’. This considers the subset of the ‘theoretical storage capacity’ which is physically accessible and meets a range of geological and engineering criteria. It is this ‘effective storage capacity’ that is discussed in this section and will provide context for the exploration of what storage potential may be practical and then matched to emissions sources.

The technical report and atlas on geological storage of CO₂ in South Africa were developed using existing geological data. This data included: seismic and historical drill-core data from the onshore and offshore sedimentary basins. Data were used to estimate the storage potential of a variety of structures such as: depleted oil and gas reservoirs, deep, ‘unmineable’ coal seams and deep saline formations. The criteria that were used to assess the sedimentary basins were modified to suite the local conditions although they were based on the methods of Bachu (2003), Gibson-Poole et al. (2006) and CO₂CRC (2008). From the geological assessments of the basins the calculations of storage capacities were done according to the standard methods as recommended by the Carbon Sequestration Leadership Forum 2007. The results of the data assessment presented in these reports are summarised here.

The ‘effective’ static (absolute volume of pore space available for CO₂ storage) geological storage capacity for CO₂ in South Africa is estimated to be approximately 155 000 Mt. This storage capacity is expectedly disaggregated and is the sum of a number of geological storage sites. A summary of the potential static storage per geological site is summarised in Table 7 for the saline aquifers and Table 8 for coal fields. The tables also provide details on the percentage of the total storage capacity that each site accounts for.

It must be noted that the Karoo Basin has been omitted as it is composed mostly of basalt and is thus considered an unconventional storage site. The IEA GHG Research and Development Programme (IEA GHG) is, however, investigating possibilities of storing CO₂ in basalt.

**Table 7: Summary of the static storage potential of the saline basins (Parsons & Brinckerhoff, 2013)**

<table>
<thead>
<tr>
<th>Basin</th>
<th>CO₂ Storage Capacity (Mt)</th>
<th>Percentage of Total Storage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange</td>
<td>56 906</td>
<td>36.58</td>
</tr>
<tr>
<td>Durban &amp; Zululand</td>
<td>42 282</td>
<td>27.18</td>
</tr>
<tr>
<td>Basin</td>
<td>CO₂ Storage Capacity (Mt)</td>
<td>Percentage of Total Storage (%)</td>
</tr>
<tr>
<td>-----------------------</td>
<td>---------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Bredasdorp</td>
<td>19 000</td>
<td>12.21</td>
</tr>
<tr>
<td>Pletmos &amp; Infanta</td>
<td>12 298</td>
<td>7.91</td>
</tr>
<tr>
<td>Molteno-Indwe</td>
<td>9 804</td>
<td>6.30</td>
</tr>
<tr>
<td>Southern Outeniqua</td>
<td>6 615</td>
<td>4.25</td>
</tr>
<tr>
<td>Algoa &amp; Gamtoos</td>
<td>4 166</td>
<td>2.68</td>
</tr>
<tr>
<td>Northern Karoo</td>
<td>2 041</td>
<td>1.31</td>
</tr>
<tr>
<td>Onshore Zululand</td>
<td>466</td>
<td>0.30</td>
</tr>
<tr>
<td>Onshore Algoa</td>
<td>404</td>
<td>0.26</td>
</tr>
<tr>
<td>Durban-Lebombo</td>
<td>289</td>
<td>0.19</td>
</tr>
<tr>
<td>Springbok Flats</td>
<td>29</td>
<td>0.02</td>
</tr>
<tr>
<td>Total</td>
<td>154 300</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Table 8: Summary of the static storage potential of the coal fields (Parsons & Brinckerhoff, 2013)

<table>
<thead>
<tr>
<th>Basin</th>
<th>CO₂ Storage Capacity (Mt)</th>
<th>Percentage of Total Storage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amersfoort/Utrecht</td>
<td>332</td>
<td>0.21</td>
</tr>
<tr>
<td>Ellisras</td>
<td>293</td>
<td>0.19</td>
</tr>
<tr>
<td>Welkom/Hennenman</td>
<td>154</td>
<td>0.10</td>
</tr>
<tr>
<td>Kroonstad</td>
<td>100</td>
<td>0.06</td>
</tr>
<tr>
<td>Springbok Flats</td>
<td>84</td>
<td>0.05</td>
</tr>
<tr>
<td>Simkele</td>
<td>83</td>
<td>0.05</td>
</tr>
<tr>
<td>Pafuri</td>
<td>57</td>
<td>0.04</td>
</tr>
<tr>
<td>Kangwane</td>
<td>53</td>
<td>0.03</td>
</tr>
<tr>
<td>Newcastle/Ladysmith</td>
<td>43</td>
<td>0.03</td>
</tr>
<tr>
<td>Edenville</td>
<td>26</td>
<td>0.02</td>
</tr>
<tr>
<td>Tuli</td>
<td>21</td>
<td>0.01</td>
</tr>
<tr>
<td>Heilbron</td>
<td>10</td>
<td>0.01</td>
</tr>
<tr>
<td>Frankfort</td>
<td>10</td>
<td>0.01</td>
</tr>
<tr>
<td>Nongoma</td>
<td>5</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>1 271</td>
<td>0.81</td>
</tr>
</tbody>
</table>
The geological storage sites for saline formations summarised in Table 7 are mapped in Figure 22. Similarly, the geological storage sites for coal fields are summarised in Figure 23.

Figure 22: Map of the locations of the saline basins which are possible geological storage sites (Parsons & Brinckerhoff, 2013)

Figure 23: Map of the locations of the coal fields which are possible geological storage sites (Council for Geoscience, 2010)
In addition to the geological storage sites discussed above, South Africa has oil and gas fields which are situated in the offshore Outeniqua Basin. The depleted areas of these oil and gas fields are relatively small and have the static potential to store only approximately 62 Mt of CO2. The known oil and gas reserves in the Outeniqua Basin and Orange Basin may present a further 15 Mt of static CO2 storage potential with the benefits of possible enhanced oil and gas recovery. Small sites could offer an early economic opportunity for the storage from local emissions sources.

In contrast the deep saline formations in the offshore Mezosoic Basins such as the, Orange Basin, Outeniqua Basin and Durban and Zululand Basin, are estimated to have very large capacities to store CO2. The sum of the storage capacities of these offshore basins accounts for over 97% of the total static geological storage potential of the country. An added benefit of the saline formations over the oil and gas reservoirs is that they typically do not require any structural traps to seal the CO2 as top and lateral seals are present in the form of impermeable mudstones.

The onshore saline basins present similar possibilities although with far smaller static storage potentials. The effectiveness of capping rocks and lateral seals must also still be determined. Furthermore, some of the low permeability and porosity measurements taken for the onshore formations in the Karoo Supergroup present some practical issues for injectivity that will need to be overcome.

The storage potential associated with coal fields is highly disaggregated amongst a number of sites with small CO2 storage potentials. The storage potential of coal fields is to some extend less certain than the saline basins as this storage will depend on the development of a coal bed methane industry in the country. Similarly uncertainties around the techno-economic future of coal mining leads to uncertainties about which coal fields will remain ‘unmineable’ and hence available for CO2 storage. Furthermore technological advances in underground coal gasification may also negate the potential for enhanced coal bed methane recovery as a means for CO2 storage.

Considering that the offshore saline basins have very large potential storage capacities and generally better data certainty, due to the availability of more seismic and drill core information, they are likely the most viable geological sites. The existing infrastructure and the availability of geological data makes the Outeniqua Basin a particularly valuable basin at present. However, the Outeniqua Basin and other offshore basins present major challenges in terms of their offshore position, lack of data in some areas, the depth of the reservoirs and the distance from the main CO2 point sources. The issues of location and costs of development will however be discussed in subsequent section of the report and considered under a set of scenarios.

At this point it would be useful to extend the understanding of potential storage from the net static storage discussed so far to the concept of dynamic storage (storage impacted by injection rates and permeability of the geology). In their techno-economic report produced in 2013, Parsons and Brinckerhoff explored the concept of dynamic storage which considers the amount of storage potential in a basin at each moment in time, given a set of technical and geological criteria.

The dynamic storage considers an injection rate for wells and the utilisation rates of the basin as a whole based on permeability assumptions (P90 high permeability - P10 low permeability). The higher permeability assumptions yield higher dynamic storage potentials. The dynamic storage potential analysis has only been
performed for the deep saline basins. The dynamic storage potentials for the basins under different injection rates per well are summarised in Figure 24 to Figure 28.

**Figure 24: Annual CO₂ utilisation of the saline basins for various well injectivity rates under high permeability assumptions P90 (Parsons & Brinckerhoff, 2013)**
Figure 25: Annual CO₂ utilisation of the saline basins for various well injectivity rates under moderate-high permeability assumptions P70 (Parsons & Brinckerhoff, 2013)

Figure 26: Annual CO₂ utilisation of the saline basins for various well injectivity rates under moderate permeability assumptions P50 (Parsons & Brinckerhoff, 2013)
The higher well injection rates for CO₂ require that less wells need to be drilled in order to store the same quantity of CO₂. This is favourable as the drilling of wells is an expensive process during the storage of CO₂. However, few basins are able to sustain high injection rates from a single well. It is only the Orange and Bredasdorp basins that can store any significant volumes of CO₂ at 5Mt per year sustainably over the 20 year period. These dynamic storage estimates do also rely on relatively higher permeability levels.

Under similarly high permeability assumptions the Durban Zululand basin presents sizable storage potential at the 2.5 Mt per year injection rates. The Durban Zululand basin, while also offshore, is significantly closer in proximity to the country’s large emissions sources than the basins located off the Western Cape coastline. As such, the Durban Zululand basin may have the greatest practical potential when considering the feasibility of the transport of CO₂. The matching of emitters with storage locations will be discussed at length in subsequent sections of this report and will integrate the costs and other constraints of capture, transport and storage.

### 3.5 SUMMARY

An assessment of the country’s latest emissions inventory and future sources of GHGs reveal that CCS may be most applicable and practicable in the energy (particularly planned new build generation and liquid fuels) and IPPU sectors (such as the cement and iron and steel industries). This is due largely to the volumes and
concentrations of CO₂ emissions that arise from activities in these sectors as well as the limited alternatives to lower CO₂ emissions from the IPPU sector. The impacts of CCS installations on these sources of CO₂ are explored further in Section 6, particularly with respect to national efforts to reduce GHG emissions.

While South Africa’s static storage potential is in excess of 155 000 Mt CO₂ the physical constraints relating to the injection and utilisation rates for the basins greatly reduces the figures for the dynamic storage potential. The dynamic storage potential varies based on permeability assumptions for the basins. Under moderate permeability assumptions (P50) large basins, such as the Orange basin, can sustain well injection rates of up to 1 Mt per year and utilise up to 300 MtCO₂/year (6 000 MtCO₂ stored over the 20 year period). However, other smaller and more appropriately located basins, such as the Durban and Zululand basin, can only sustain well injection rates of 0.1 Mt per year and under lower permeability assumptions (P30) are likely to utilise up to 139 MtCO₂/year (2 778 MtCO₂ stored over the 20 year period). In terms of the national emissions, 139 MtCO₂/year equates to approximately 45% of the potentially capturable emissions from 2010. It is likely that in assessing the economic viability of CCS, the storage potential will present a constraint on the system. Thus it is likely that only the most technically and economically suitable emitters will be identified for carbon capture and storage.
4 TECHNOLOGY COSTS AND BENEFITS OF CCS IN SOUTH AFRICA

This section discusses the benefits and costs associated with CCS as a technology. As discussed in Chapter 1 of this report, the primary benefit of CCS is its carbon sequestration potential. Technologies that sequester carbon aid in the fight against climate change and present opportunities for meeting climate change commitments and managing the impacts of carbon pricing. Further benefits of CCS, in terms of its impacts beyond climate change, are also summarised here from prior work by the SACCCS. These benefits focus on aspects of industry preservation, job creation and other indirect economic effects within South Africa. Costs of development and commercial deployment of CCS in South Africa are drawn from prior studies undertaken by the SACCCS and are augmented by other current literature where relevant. These costs are considered in terms of the value chain: capture technology; transport technology; and storage technology. The costs are used in subsequent chapters within scenarios of possible CCS implementation, to assess its economic viability.

4.1 BENEFITS

4.1.1 Climate Change and Carbon Sequestration

Climate change and specifically global average temperature is directly related to the concentration of GHGs in the atmosphere. As one of the countries that is likely to be most severely affected by climate change, South Africa has reconfirmed its commitment to working with global counterparts to limit global temperature increases below 2°C above pre-industrial levels, and ideally to 1.5°C. CCS may present opportunities to sequester carbon and reduce South Africa’s contribution to the onset of anthropogenic climate change. Beyond the benefits to the global climate, carbon sequestration through CCS also presents benefits in managing potential regulatory requirements and carbon pricing associated with international climate change efforts as well as other domestic agendas.

4.1.2 Regulatory Requirements on the National Greenhouse Gas Inventory

In light of international climate change commitments, there may be regulatory demands established in South Africa to reduce GHG emissions at a sector level. This has already been envisioned to some extent through the peak, plateau and decline trajectory and the carbon budgets process. If strict regulatory requirements materialise, CCS will present a compliance opportunity for GHG emitters that have limited mitigation options. As such, CCS will be beneficial to these emitters in aiding them comply with regulations and continuing operation if financially viable.

The compliance of emitters with regulations will in turn assist South Africa to reduce its national GHG inventory. In doing so South Africa may then be able to meet its international emissions obligations and avoid any negative repercussions as a result of defaulting on its commitments.
4.1.3 Carbon offsets

Emitters implementing CCS technology may be presented with economic opportunities in the event of adequate carbon pricing as they may be able lower comparative operating costs, depending on the carbon price and cost of CCS. South Africa is currently developing its own national carbon pricing instrument in the form of a carbon tax and offset system.

There is a significant body of research exploring the idea of a global carbon pricing system through the direct and indirect linking of carbon markets (Dellink et al., 2014). Recently, Article 6 of the Paris Agreement, plus the respective paragraphs in Decision 1/CP.21 (36-40), makes provision for the development of a mechanism for Internationally Transferred Mitigation Outcomes (ITMOs). This allows for the use of the international carbon market, even though the term ‘market’ is not explicitly mentioned.

Some studies suggest that there will likely be an international carbon market with an international carbon price in the period between 2030 and 2050 (European Climate Foundation, 2010; Department of Energy and Climate Change, 2011; Synapse Energy Economics, 2016). Carbon price projects are considered under the scenario studies in Section 5.

It is expected that by 2030 the South African carbon price will be aligned with an international price on carbon. In this case CCS technology is presented with two distinct benefits to South Africa.

- **Carbon Tax:** As mentioned above, under a carbon tax, significant emitting companies may reap financial benefits from pursuing CCS over incurring the costs of the tax.

- **Carbon Offset Credits:** It is probable that the Clean Development Mechanism (CDM) of the UNFCCC would form the basis of future international carbon pricing systems. The CDM has made provision for the generation of offset credits from CCS projects. As such there may be financial benefits for South African emitters to pursue CCS projects and sell the generated offset credits on the international market.

4.1.4 Industry sustainability

As a consequence of international climate regulations, discussed above, in the period from 2030 to 2050 South Africa is likely to face a situation where participation in the global economy will be conditional on the country’s ability to limit its GHG emissions (Paris Agreement). It is possible that the country may be in a position where targets, aligned to limiting the global temperature increase to 1.5°C, are not achievable if particular carbon intensive industries and practices persist in a business as usual fashion.

In South Africa these emissions intensive industries (iron and steel production) and supporting industries (coal mining) form a core part of the economy. Therefore if the country wishes to facilitate participation in the global economy, while still preserving its local emissions intensive industries, then CCS will form a beneficial part of the industrial infrastructure of the country.
4.1.4.1 Coal Mining

While the preservation of the coal mining industry will exact some additional environmental costs the industry has some important socio-economic benefits for the country. In 2010 South Africa’s coal industry employed over 73 000 people and paid in excess of R14 billion in wages (Fossil Fuel Foundation, 2011).

In South Africa coal is a key input for a number of other nationally important industries, such as electricity generation, coal-to-liquids synthetic fuel production and metal and ferrochrome smelting. Approximately three-quarters of the coal produced is consumed domestically in these sorts of processes. The predominantly high quality bituminous coal, which accounts for the remaining quarter, is one of South Africa’s biggest export revenue earners, generating R 50 billion in export revenue in 2011 (Fossil Fuel Foundation, 2013). Coal exports in relation to South Africa's total exports are reflected in Figure 29.

![Figure 29: Coal exports in relation to South Africa's total exports (The Atlas of Economic Complexity, 2014)](image)

The application of CCS technologies to projects such as coal-fired power stations could support the coal industry in the face of emissions regulations. This could help the demand for coal to remain robust post 2020 when coal production is expected to decrease. The benefit of this would be the prevention of losses in export revenue and jobs within the industry and other dependant industries.
4.1.4.2 Ore Mining and Beneficiation Industry

In addition to coal, South Africa is a resource rich country. However, the economy has traditionally been based on a limited level of resource beneficiation. This included the manufacture of iron, steel, metal alloys and consumer goods such as cars. The further development of the beneficiation of South African resources before export is a central component of government policy. The Industrial Policy Action Plan 2016/17 aims to “strengthen the important economic linkages between the primary agriculture, mining and manufacturing sectors in order to secure much greater downstream beneficiation and maximise upstream linkages”. The National Development Plan 2030 however recognises that “given the energy-intensive nature of mining and mineral beneficiation, South Africa will need to invest heavily in helping the industry to reduce its carbon footprint”. In recognising this, CCS presents beneficial opportunities to achieve the joint objectives of the Industrial Policy Action Plan and the National Development Plan for these sorts of industries.

4.1.5 Job Creation

Investments in CCS would generate additional employment opportunities in various sectors of the economy. These sectors include: coal mining, transport services, construction, electricity generation and water production. Both the construction of the CCS infrastructure and on-going CCS operations present opportunities for employment. Estimates of potential employment opportunities for a 20 year period are presented in Table 9. Details are presented for both the construction and operation phase for skilled, semi-skilled and low skilled workers in a lower and higher CCS implementation estimate.

Table 9: Summary of the expected numbers of skilled, semi-skilled and low-skilled jobs created under a high and low extent of CCS implementation (SLR and Prime Africa Consultants, 2013)

<table>
<thead>
<tr>
<th>Operation Jobs</th>
<th>Salary Range (Annual)</th>
<th>Number of Jobs (Low)</th>
<th>Number of Jobs (High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skilled</td>
<td>R280 000 - R850 000</td>
<td>1 - 3</td>
<td>42 - 128</td>
</tr>
<tr>
<td>Semi-Skilled</td>
<td>R180 000 - R250 000</td>
<td>42 - 59</td>
<td>1 762 – 2 447</td>
</tr>
<tr>
<td>Low-Skilled</td>
<td>R54 000 - R102 000</td>
<td>28 - 53</td>
<td>1 167 – 2 204</td>
</tr>
<tr>
<td>Construction Jobs</td>
<td>Salary Range (Annual)</td>
<td>Number of Jobs (Low)</td>
<td>Number of Jobs (High)</td>
</tr>
<tr>
<td>Skilled</td>
<td>R280 000 - R850 000</td>
<td>209 - 635</td>
<td>617 – 1 874</td>
</tr>
<tr>
<td>Semi-Skilled</td>
<td>R180 000 - R250 000</td>
<td>9 303 – 13 005</td>
<td>27 632 – 38 378</td>
</tr>
<tr>
<td>Low-Skilled</td>
<td>R54 000 - R102 000</td>
<td>3 776 – 7 013</td>
<td>11 144 – 21 051</td>
</tr>
</tbody>
</table>

Table 9 presents data for “Low” and “High” scenarios. These scenarios are defined by:

- **Low scenario**: This scenario is based on the capture of 20 MtCO₂/year. It is estimated that in this low scenario, approximately 3 776 – 7 013 low-skilled workers would be employed in the construction phase as well as a further 28-53 low-skilled workers in the operational phase.
• High scenario: This scenario is based on the capture 80 MtCO₂/year. It is estimated that construction jobs for low-skilled workers would increase to 11 144 – 38 378 and the operational job estimates for low-skilled workers increase to 1 167 – 2 204 for the 20 year period.

The employment figures presented in Table 9 were derived based on an expected percentage of employment’s total input into production (10-20%) and expected expenditure. The distribution of jobs between skilled, semi-skilled and low-skilled jobs was based on the distributions typically observed in the construction and utilities sectors. The higher estimates assume a CCS implementation of 80 MtCO₂/year and the lower is in the region of 20 MtCO₂/year.

It is also expected that many of the low-skilled jobs will also be rural jobs.

4.1.6 Indirect Economic Effect

It is expected that expenditure on CCS will stimulate entrepreneurial activity through the creation of business opportunities and generate indirect economic effects. The indirect economic benefits that result from expenditure can be measured using an economic ‘multiplier effect’. A multiplier effect can be understood as the additional value generated throughout the economy for unit of expenditure in a given industry or project.

The multiplier effects for several sectors that are relevant to CCS are summarised in Table 9. The figures can be understood as the spending of R1 in the coal mining sector will generate an additional R7.15 in the economy as the expenditure ripples through the industry value chain.

Table 10: Summary of the economic multiplier effect figures for industries associated with CCS (SLR and Prime Africa Consultants, 2013)

<table>
<thead>
<tr>
<th>Economic Sectors</th>
<th>Economic Multiplier Effect (R generated/R Spent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Mining</td>
<td>7.15</td>
</tr>
<tr>
<td>Transport Services</td>
<td>8.43</td>
</tr>
<tr>
<td>Construction</td>
<td>6.92</td>
</tr>
<tr>
<td>Electricity Generation</td>
<td>7.35</td>
</tr>
<tr>
<td>Water provision</td>
<td>8.46</td>
</tr>
</tbody>
</table>

Based on the multiplier effects for the above industries, the multiplier effect for CCS is estimated to be between 6 and 9. In this case the indirect economy activity generated through CCS will be in the region of 6 to 9 times greater than the initial expenditure. This is within range of the average multiplier for the other production sector as well as the goods and services sector. However, to some extent these indirect economic effects may be offset by the reallocation of resources from other sectors to CCS which will lead to reductions in economic activity in those sectors.
4.2 COSTS RELATED TO CCS

Establishing the costs of CCS as a first of its kind technology in South Africa is not a simple task. As a technology the cost of CCS are characterised by great uncertainty. However, to date, research commissioned by SACCCS has developed a mounting body of knowledge about the range of costs for CCS systems. The Techno-Economic Report completed by Parsons and Brinckerhoff in 2013 established the costs for a number of CCS scenarios where the quantity of CO₂ avoided nationally ranged between 92 and 302 Mt CO₂ per year. Before assessing the costs of a commercial national CCS system it is useful to consider the development costs that may be incurred prior to deployment.

4.2.1 Development Costs

Before CCS reaches the stage where it is commercially viable in South Africa, there are a number of developments that need to take place. According to the CCS Road Map developed by SACCCS a test injection of 10 000 tCO₂ and a demonstration injection of 100 000 tCO₂ are required. Before either phase can be undertaken there are regulatory issues that need to be overcome. Both these regulatory issues and costs for development steps are discussed here.

4.2.1.1 Regulatory Costs

Before captured CO₂ can be transported and stored there are a number of regulatory challenges that need to be overcome. These challenges may come at some cost in terms of revising legislation, or even creating new legislation. Currently there is no CCS specific legislation or regulations in South Africa. However, aspects of the existing environmental legislative framework would apply to the operational and closure phases of CCS projects. Although, under these regulations there is no single classification for CO₂. In fact CO₂ falls within a number of different classifications across various legislation such as the National Environmental Management: Air Quality Act (NEM:AQA), National Environmental Management: Waste Act (NEM:WA) and South African Bureau of Standards (SABS). In the various statutes, CO₂ has been classified as: a “GHG”, a “priority air pollutant”, a “Class 2 dangerous good”, a “Group II hazardous substance” and a “waste product”. These different classifications create challenges in identifying the correct legal treatment of captured, transported, injected and stored CO₂. Further legal challenges relate to the use of subsurface storage as the Mineral and Petroleum Resources Development Act (MPRDA) does not make specific provision for it.

A study on the development of a regulatory framework for carbon capture and storage in South Africa, assessed how the current regulations could be applied to CCS (ERM, Carbon Counts and Imbewu Sustainability Legal Specialists, 2013). The analysis concluded that there are several options for regulating CCS in the South Africa.

It is considered that there are four principal options for the design of the regulatory framework in South Africa. These options are based on the NEM:WA, the NEMA, and the MPRDA. The options include one or a combination of these regulations with the establishment of a free-standing “CCS Act”. Within these options, the approaches will involve either minor modifications of existing statutes, or more thorough or major modifications. These options are summarised below.
1. **NEM:WA as the basis for CCS Regulation (the status quo)**
   - Waste management legislation provides basis for regulating CCS storage
   - NEM:EIA covers various other aspects
   Requires CCS activities to be included in NEMA Listing Notices.

2. **NEMA as basis (CO\(_2\) not a waste)**
   - Rely on NEMA and EIA provisions to regulate aspects of CCS
   - Exclude captured CO\(_2\) from scope of NEM:WA
   Requires CCS activities to be included in NEMA Listing Notices.
   Requires CO\(_2\) or CO\(_2\) injection activities to be excluded from NEM:WA.

3. **MPRDA & NEMA (use mineral and petroleum acts to regulate CCS)**
   - Amend MPRDA to include CO\(_2\) storage or prepare CCS part of MPRDA
   - NEM:EIA covers various other aspects
   Requires extensive amendments to MPRDA.
   Requires CCS activities to be included in NEMA Listing Notices.

4. **New CCS Act & NEMA**
   - Use relevant approaches/language from MPRDA to draft new CCS Act
   - NEM:EIA covers various other aspects
   Could be a new act under NEMA (NEM:CCS).
   Requires CCS activities to be included in NEMA Listing Notices.

The legislative process and outcome of the four approaches may differ and it is likely that each will come at a cost to the government, which could be in the order of millions of Rand. However, it may be considered that these cost are internalised by the functioning of the government policy and legislative systems.

### 4.2.1.2 Costs of Test Injection and Demonstration Injection

The costs associated with the test injection and demonstration injects can to some extent be derived from the unit costs discussed later in this chapter. However, test injections and demonstration plants typically exhibit inflated costs due to small scales of implementation and first time experiences. There may also be additional research and monitoring requirements associated with test and demonstration injections.

It is therefore useful to consider the cost of other test and demonstration injections of a similar size to those planned for South Africa (10 000 tCO\(_2\) for the test injection and 100 000 tCO\(_2\) for the demonstration injection). A number of similar sized plants that capture and store CO\(_2\) have been summarised in Table 11. The data has been sources from the most recently updated database of the National Energy Technology Laboratory (NETL).
Table 11: Summary of the costs and CO2 injection totals for projects conducting capture and storage of less than 100 000 tCO₂. (NETL, 2016)

<table>
<thead>
<tr>
<th>Project (start year)</th>
<th>Country</th>
<th>Status</th>
<th>Cost</th>
<th>Injection Total (tCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARI Eastern Shale CO₂ Injection Test (2010)</td>
<td>United States</td>
<td>Active - Site Characterization</td>
<td>USD 1 999 041</td>
<td>300</td>
</tr>
<tr>
<td>CONSOL Energy Coalbed Methane Project (2001)</td>
<td>United States</td>
<td>Active - Post-Injection Monitoring</td>
<td>USD 13 216 903</td>
<td>4 300</td>
</tr>
<tr>
<td>MRCSP Validation Phase - Michigan Basin Test (2008)</td>
<td>United States</td>
<td>Active - Injection Complete</td>
<td>USD 28 801 838</td>
<td>60 000</td>
</tr>
<tr>
<td>Otway Basin Project - CO2CRC (2008)</td>
<td>Australia</td>
<td>Active - Injection Ongoing</td>
<td>USD 32 000 000</td>
<td>65 000</td>
</tr>
<tr>
<td>PCOR Validation Phase - Zama Field Test (2005)</td>
<td>Canada</td>
<td>Complete - Injection Complete</td>
<td>USD 29 329 948</td>
<td>84 986</td>
</tr>
<tr>
<td>OXYCFB300 Compostilla Project (2009)</td>
<td>Spain</td>
<td>Active - Capture Ongoing</td>
<td>EUR 180 000 000</td>
<td>100 000</td>
</tr>
</tbody>
</table>

Many of the existing or planned projects represent their injection levels in tonnes of CO₂ per day. Total CO₂ injections of 10 000 tonnes and 100 000 tonnes equate to CO₂ injection rates of 27.4 and 274 tonnes per day respectively. As such the projects conducting capture storage of up to 274 tCO₂ per day are listed in Table 12 with their associated costs.
Table 12: Summary of the costs and CO$_2$ injection rates for projects conducting capture and storage of less than 274 tCO$_2$ per day (100 000 tCO$_2$ per year). (NETL, 2016)

<table>
<thead>
<tr>
<th>Project (start year)</th>
<th>Country</th>
<th>Status</th>
<th>Cost</th>
<th>Injection Rate (tCO$_2$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enel Brindisi CCS Project (2010)</td>
<td>Italy</td>
<td>Active - Capture Ongoing</td>
<td>EUR 20 000 000</td>
<td>21.92</td>
</tr>
<tr>
<td>Enecogen Cryogenic CO$_2$ Capture (2013)</td>
<td>Netherlands</td>
<td>Active - Plant in Operation</td>
<td>EUR 37 000 000</td>
<td>24.66</td>
</tr>
<tr>
<td>Hazelwood Post-Combustion 2030 Project (2008)</td>
<td>Australia</td>
<td>Active - Plant in Operation</td>
<td>AUD 333 400 000</td>
<td>50.00</td>
</tr>
<tr>
<td>CS Energy Callide Oxyfuels Project (2006)</td>
<td>Australia</td>
<td>Active - Capture Ongoing</td>
<td>AUD 200 000 000</td>
<td>82.20</td>
</tr>
<tr>
<td>Schwarze Pumpe (Vattenfall CO$_2$-Free Oxyfuel Plant) (2008)</td>
<td>Germany</td>
<td>Hold - Plant in Operation</td>
<td>EUR 120 000 000</td>
<td>216.00</td>
</tr>
<tr>
<td>Karsto NGCC Capture Project (2009)</td>
<td>Norway</td>
<td>Active - Plant Design</td>
<td>NOK 1 560 000 000</td>
<td>274.00</td>
</tr>
<tr>
<td>Fairview ZeroCarbon Project (2009)</td>
<td>Australia</td>
<td>Terminated - Plant Design</td>
<td>AUD 445 000 000</td>
<td>274.00</td>
</tr>
<tr>
<td>Mongstad Cogeneration Plant with CO$_2$ Storage (2010)</td>
<td>Norway</td>
<td>Active - Plant in Operation</td>
<td>USD 635 000 000</td>
<td>274.00</td>
</tr>
<tr>
<td>SECARB Development Phase - Anthropogenic Test (2007)</td>
<td>United States</td>
<td>Active - Capture Ongoing</td>
<td>USD 111 413 431</td>
<td>274.00</td>
</tr>
<tr>
<td>American Electric Power – Mountaineer (2009)</td>
<td>United States</td>
<td>Terminated - Injection Complete</td>
<td>USD 668 000 000</td>
<td>274.00</td>
</tr>
</tbody>
</table>

It is evident that a demonstration injection of 100 000 tCO$_2$ could cost anywhere in the region of USD 111 million to USD 668 million (not considering currency, inflation or technology cost changes).
Similarly a test injection of 10 000 tCO₂ could cost in the region of EUR 37 million (not considering currency, inflation or technology cost changes).

4.2.2 Implementation Cost Components

The costs associated with implementing a CCS system can be understood in terms of the costs for each of the distinct components: capture; transport and storage. It is well-established that the costs to capture CO₂ typically account for the largest fraction of the total costs of a CCS system and the costs of storage can be the most wide ranging (Kolstad and Young, 2010; Rubin et al., 2015). The IRP 2016 includes cost estimates for CCS on various energy generation technologies and these unit costs, as well as those for transport and storage, will serve as input information for the modelling of the costs of CCS implementation under various scenarios.

4.2.2.1 Capture

The most recent capture costs to South Africa for the various technologies are summarised in the IRP 2016 and the Parsons and Brinckerhoff (2013) techno-economic study. These reports provide unit costs for capital and operational expenditures for capture technologies located at electricity generation facilities. The figures for electricity generation in Table 13 are quoted in 2015 Rand values and address the additional unit costs of carbon capture for electricity generation.

Table 13: Summary of the additional unit cost (2015 Rand) of CO₂ capture from combustion technologies relating to electricity generation (with flue gas desulphurisation already fitted) (Department of Energy, 2016a)

<table>
<thead>
<tr>
<th></th>
<th>Pulverised Coal</th>
<th>Circulating Fluidised Bed</th>
<th>Combined Cycle Gas Turbine (CCGT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed O&amp;M costs (R/kW)</td>
<td>596 - 660</td>
<td>254 - 287</td>
<td>208</td>
</tr>
<tr>
<td>Variable O&amp;M costs (R/kW)</td>
<td>61.8</td>
<td>50.2</td>
<td>11.1</td>
</tr>
<tr>
<td>Overnight capital cost (R/kW)</td>
<td>30 292 - 32 159</td>
<td>27 616 - 29 467</td>
<td>9 825</td>
</tr>
<tr>
<td>LCOE (R/MWh)</td>
<td>843.5 – 888.6</td>
<td>744.4 – 784.8</td>
<td>463.6</td>
</tr>
</tbody>
</table>

The additional costs of CCS presented in Table 13 will increase the levelised cost of electricity by approximately 77% for pulverised coal, 63% for circulating fluidised bed and 65% for CCGT technologies. Similarly the costs presented in Table 14 summarise the unit costs for the capital and operational associated with carbon capture at various other emitting process. However these costs are levelised per tonne of CO₂ captured.

Table 14: Summary of the CAPEX and OPEX unit costs for CO₂ capture from other sectors (Parsons and Brinckerhoff, 2013)
<table>
<thead>
<tr>
<th>Sector</th>
<th>Process</th>
<th>Carbon Capture Technology</th>
<th>CAPEX per tCO₂ captured/year (R)</th>
<th>Annual OPEX per tCO₂ captured (R)</th>
<th>Levelised cost R/tCO₂ captured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synfuels</td>
<td>Rectisol off-gas</td>
<td>Pre-combustion</td>
<td>825</td>
<td>33</td>
<td>133</td>
</tr>
<tr>
<td>Synfuels</td>
<td>Power island</td>
<td>Post-combustion</td>
<td>461</td>
<td>100</td>
<td>173</td>
</tr>
<tr>
<td>Cement</td>
<td>Calciner</td>
<td>Post-combustion</td>
<td>3 086</td>
<td>266</td>
<td>669</td>
</tr>
<tr>
<td>Cement</td>
<td>Calciner</td>
<td>Oxy-combustion</td>
<td>1 769</td>
<td>146</td>
<td>376</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>Blast Furnace</td>
<td>Top gas recycle</td>
<td>3 644</td>
<td>93</td>
<td>523</td>
</tr>
<tr>
<td>Refining</td>
<td>Steam methane reformer (SMR off-gas)</td>
<td>Pre-combustion</td>
<td>1 862</td>
<td>53</td>
<td>274</td>
</tr>
<tr>
<td>Refining</td>
<td>Fluid catalytic cracking (FCC)</td>
<td>Post-combustion</td>
<td>2 434</td>
<td>67</td>
<td>355</td>
</tr>
<tr>
<td>Refining</td>
<td>Fired Heaters</td>
<td>Post-combustion</td>
<td>2 141</td>
<td>60</td>
<td>314</td>
</tr>
</tbody>
</table>
4.2.2.2 Transport

As with the capture costs, transport costs can also be estimated in unit terms. The SLR report on the impacts of CCS on South Africa’s national priorities other than climate change summarises the expected unit costs for transport infrastructure in 2010 Rand values. These costs are summarised in Table 15 and are given in a range for two different cost criteria based on the terrain of the route. These is a lower cost range for flat rural terrain and a higher cost range for mountainous or congested urban terrain.

Table 15: Summary the unit costs for transport pipeline infrastructure for two cost levels based on the terrain complexity (SLR and Prime Africa Consultants, 2013)

<table>
<thead>
<tr>
<th>Cost Level per Terrain Type</th>
<th>Cost /cm diameter/km length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Cost (flat, rural, agriculture)</td>
<td>R242 300 – R323 067</td>
</tr>
<tr>
<td>High Cost (mountains, urban congested)</td>
<td>R420 462 – R504 555</td>
</tr>
</tbody>
</table>

The techno-economic study by Parsons and Brinckerhoff (2013) provides an in-depth costing of individual CO2 transport lines of various lengths, diameters and pressures. Their costing are in 2013 Rand values and range from R260 009 – R913 949/cm diameter/km length. The median price is R435 422/cm diameter/km length. Although these prices are slightly higher than those in the SLR report this may be due to inflation and the evolution of costs with newer technologies.

4.2.2.3 Storage

The costs of storage are typically the least predictable costs in the CCS process as they depend on the diverse nature of the geological formations. The geological formations determine the sustainable injection and utilisation rates for CO2 storage and as such determine the infrastructure and equipment required. The capital and operational costs of this equipment may vary greatly depending on the structural requirements and thus it is challenging to present unit cost for each storage plant setup.

It is therefore instructive to consider the cost of storage in terms of the levelised cost of CO2 avoided. This is calculated as the cost per tonne of CO2 stored and is the generally reported measure of cost for storage. The SLR report present a comprehensive range of costs for CO2 storage which are the same figures consulted in Rubin et al 2015. The cost has been converted to 2009 rand values from Euro and are summarised in Table 16.
### Table 16: Summary of the ranged levelised costs of CO$_2$ storage for different forms of geological storage onshore and offshore (SLR and Prime Africa Consultants, 2013)

<table>
<thead>
<tr>
<th>Offshore</th>
<th>Levelised cost of storage R/tonne CO$_2$ (2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>Saline aquifers with no legacy wells</td>
<td>69.0</td>
</tr>
<tr>
<td>Depleted oil and gas fields with no legacy wells</td>
<td>34.5</td>
</tr>
<tr>
<td>Depleted oil and gas fields with legacy wells</td>
<td>23.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Onshore</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Saline aquifers with no legacy wells</td>
<td>23.0</td>
</tr>
<tr>
<td>Depleted oil and gas fields with no legacy wells</td>
<td>11.5</td>
</tr>
<tr>
<td>Depleted oil and gas fields with legacy wells</td>
<td>11.5</td>
</tr>
</tbody>
</table>

It is useful to note that the levelised cost estimates for storage in offshore saline aquifers as calculated in the Parsons and Brinckerhoff 2013 report range between R47 - R234 per tonne of CO$_2$ (in 2013 Rand Value). This estimate is consistent with the levelised costs of storage presented by both the SLR Report and Rubin et al 2015.

#### 4.2.2.4 Combined Costs of Capture, Transport and Storage

Parsons and Brinckerhoff (2013) conducted a techno-economic study where they assessed the costs for a number of national CCS scenarios which avoided between 92 and 302 Mt CO$_2$ per year. The study combined the costs calculated for each of the CCS components to produce a levelised cost of avoiding each tonne of CO$_2$. The total levelised cost of avoiding one tonne of CO$_2$ ranged between R416 and R542 depending on the scenario as different sources and stores of CO$_2$ were considered. The ranges of these costs for the combined CCS system, as well as each component of it, are summarised in Figure 30.

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*6 A legacy well is a well that was drilled in the exploratory or extraction phase of oil or gas recovery and is now no longer in use.*
4.2.2.5 Other Costs

Beyond the infrastructural and operational costs of CCS there are some additional external costs to consider. These costs relate to the environmental and economic costs of the technology in terms of its impact on water use and the electricity price.

Water

Water is an extremely valuable, and in some areas scarce, resource in South Africa. In South Africa water is used extensively for cooling in power plants and other processes in coal to liquids production. It has been estimated that the inclusion of CCS to coal-to-liquids (CTL) production process increases water consumption by 5.6% (Williams et al., 2011). Similarly the implementation of CCS for fossil fuel fired power plants is expected to increase water withdrawals and consumption significantly.

The increases in water consumption and withdrawals for a range of combustion technologies are presented in Figure 31 and Figure 32 respectively. The values have been adapted from the work of Meldrum et al. (2013).
The largest net increases in water consumption and withdrawal occurs for circulating fluidised bed and subcritical pulverised coal technologies. In relative terms the implementation of CCS is expected to increase the water consumption by between 72% for Integrated Gasification Combined Cycle (IGCC) and 81% for Natural Gas Combined Cycle (NGCC). Similarly the withdrawal rates increase in the range of 64% for IGCC and 104% for NGCC. The rates of increase for the other three technologies fall within these ranges. Medupi and Kusile are both considered to be supercritical plants while the independent power producer coal plants are expected to be subcritical.

**Energy**

On the other side of the water energy nexus, the implementation of CCS will present an additional cost to electricity generation which will in turn have an impact on the receiving economy. Currently, South African households spend relatively high portions of their monthly income on energy needs, 14% in 2012 (Department of Energy, 2012).
If the additional costs associated with CCS were to be passed onto the energy consumer then the end price of electricity and liquid fuels would rise. This would exacerbate the already heavy burden of fuel expenses on the economy which may have other social repercussions. Alternatively if the costs of CCS are subsidised so as to not pass on the cost to energy consumers this money would need to be sourced from general tax revenues that may have been spent elsewhere in the economy. Depending on how funds are all allocated this may have varying impacts on the economy and society.

4.2.3 Cost Summary

As a technology that is still developing with continued research, it must be recognised that the costs associated with CCS investment are characterised by great uncertainty. The costs of investing in CCS can however be understood as increasing in orders of magnitude as the technology progresses from development to implementation stages. For instance the costs associated with developing the regulatory framework and legislation to allow for the deployment and operation of CCS infrastructure is likely to cost in the order of millions of Rand.

The research and development expense of a test injection of approximately 10 000 tCO2 could cost in the region of hundreds of millions of Rand. To scale this development up to a full demonstration injection of 100 000 tCO2, the costs could amount to billions of Rand.

The estimates for a national scale roll out of CCS would result in a total cost in the region of trillions of Rand. The cost outputs from the techno economic study conducted by Parsons and Brinckerhoff (2013) are summarised in Table 17. The figures are quoted for a 25 year implementation period from 2025 to 2050.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>CO₂ Avoided (Mt/year)</th>
<th>Levelised Cost of CO₂ Avoided (2013 R/ton)</th>
<th>Total Cost of CO₂ Avoided (2013 R Trillion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case Scenario</td>
<td>302.24</td>
<td>421.7</td>
<td>3.186</td>
</tr>
<tr>
<td>Alternative Scenario 1</td>
<td>92.08</td>
<td>542.0</td>
<td>1.248</td>
</tr>
<tr>
<td>Alternative Scenario 2</td>
<td>103.12</td>
<td>416.0</td>
<td>1.072</td>
</tr>
<tr>
<td>Alternative Scenario 3</td>
<td>205.08</td>
<td>469.8</td>
<td>2.409</td>
</tr>
</tbody>
</table>

It is expected that if smaller quantities of CO₂ were avoided each year then the total cost would decrease. However it is likely that the cost per tonne CO₂ avoided would increase as a result of reduced economies of scale. Further emissions reductions estimates and associated costs are modelled and evaluated in subsequent chapters of this report.
5 REVIEW OF SCENARIO STUDIES TO INFORM DRIVERS OF CCS

The purpose of reviewing existing scenario studies is to consider and better understand the future environments that may impact on the development and rollout of CCS in South Africa. The scenario studies analysed in this report evaluate a range of potential outcomes by considering alternative, plausible future states under a given set of assumptions and constraints. These drivers and parameter value ranges will be used together with storage potentials and technology costs to evaluate plausible impacts of CCS in South Africa to inform recommendations on the further investment into CCS.

5.1 MOTIVATION FOR SCENARIO ANALYSES

South Africa is not yet in a position to approve or implement the rollout of CCS in the country; research is ongoing in this regard. Preliminary findings indicate however that in the event that the conducive political and economic environments are in place, CCS could be implemented around 2030. To achieve this outcome, major preparations are required which will require, for example, the development of new regulations and significant capital outlays for the required infrastructure. The lengthy timeframe makes appropriate planning difficult because it is increasingly difficult to predict what the drivers of CCS will look like (e.g. the supply and demand for CO₂) the further we look into the future. Similarly, long term insights pertaining to South Africa’s political environment, economic growth and related energy profiles (drivers of the CCS drivers) are equally difficult to predict with high levels of credibility.

The markets for CCS include both energy and non-energy industries. Electricity generation holds considerable potential for CCS because South Africa is likely to remain reliant on coal-fired electricity generation well into the future. Responses to climate change are changing the way the electricity sector is developing with significant additions of renewable energy generation. Non-energy industries such as cement and steel production have fewer mitigation options due to the emissions inherent in the production processes. CCS may be the only viable options for these industries.

While it is acknowledged that the increased ambition of the Paris Agreement is accelerating shifts in the mitigation efforts, there is great uncertainty regarding what extent or timing of these shifts. Scenario analysis has therefore been utilised as an effective tool for overcoming uncertainties because the scenarios provide a range of possible outcomes which can be assessed and planned for.

The scenarios considered in this report have therefore been selected on account of their focus on transitional risks, which provide insights into the environments that impact the CCS business case. The scenarios range from formal government strategies to those developed for the purpose of considering global trends.
5.2 SELECTED SCENARIOS

The analysis undertaken in this report is a qualitative assessment of the different scenario pathways but includes quantification of essential drivers of growth and environmental constraints. Two key drivers for CCS in South Africa (illustrated in Figure 33) were identified as a starting point: the level of commitment to carbon emission mitigation and the economic environment, specific to South Africa. The risks and constraints are discussed further in chapter 6.

With reference to the first selected driver, CCS is likely to be supported in an environment that is characterised by high levels of commitment to mitigating climate change. Signals in this regard could relate to the level of implementation of policies and activities aimed at addressing climate change, as well as those concerned with socio-economic development in South Africa. There is increasing recognition that meaningful, equitable and widespread socio-economic growth in South Africa is inextricably linked to sustainable development. The Sustainable Development Goals link various crosscutting indicators of socio-economic development to climate change.

According to a United Nations Development Programme (UNDP) report released November 2016, it is clear that addressing climate change go hand-in-hand with addressing the Sustainable Development Goals (SDGs). Climate change is a multi-dimensional and cross-cutting development issue that affects every aspect of sustainable development (United Nations Development Programme, 2016). This is further illustrated in Figure 34.
This emphasises the need to scale-up climate action in order to effectively address the various Sustainable Development Goals. Therefore the drive towards South Africa’s low carbon and climate resilient economy should include initiatives which could impact the broader context of South Africa’s development objectives, specifically considering climate change.

The CCS business case is being developed precisely because it has the potential to meet a number of the country’s developmental objectives such as increasing or protecting employment opportunities (the carbon intensive industries and coal mining sector employs a substantial share of the South African working population) and energy security requirements, in tandem with reducing carbon emissions in the country’s GHG inventory.

The second driver of the CCS business case lies in the economic environment. Initial estimations for the rollout of CCS (discussed in detail further in this report) indicate that the technology has relatively high capital and operating costs. The responsibility for these costs is yet to be determined. Either the state or the private sector may bear the responsibility, or alternatively it may be shared. In any event, large capital and operating outlays only occur where there are favourable economic conditions, and where the state and private companies are more likely to have sufficient funds for activities that are outside of their ‘core’ activities. Signals for these conditions could include growth in the country’s GDP or economic sectors and increases in the price of carbon. Ideally, the most conducive environment for the CCS business case would be one with high levels of implementation of climate change policy combined with high domestic growth.
These two drivers, implementation of climate change policy and a conducive economic environment, are considered in the context of the following scenarios.

5.2.1 Integrated Resource Plan 2013 Update Report: Scenarios for Expected Demand

The IRP 2010-2030 was promulgated in 2010 and is the latest official state document even though various draft reviews of the plan have been published. The IRP focuses specifically on the electricity sector and aims to ensure that the proposed resource choices in South Africa can adequately meet the country’s electricity demand in the future, under the most foreseeable circumstances. The IRP was updated in 2013 following a number of developments in the energy sector in South Africa and the region, as well as a marked change in the electricity demand outlook. The 2013 Update Report while providing several scenarios has no official status from government. A subsequent IRP update was released in late 2016, however it only contains the base case scenario. Therefore scenarios contained in the 2013 IRP Update have been considered in this report.

The 2013 IRP Update Report considers several scenarios including the aspirational economic growth suggested by the National Development Plan. One of the material changes in the 2013 IRP Update Report is the anticipated shift in economic development away from energy intensive industries. This has and will continue to dramatically reduce the electricity intensity of the economy as shown in Figure 35.

![Figure 35: Declining electricity intensity of South African economy (Department of Energy, 2013a)](image)

5.2.1.1 Description of Scenarios

Economic growth is considered as a key determinant of electricity demand. The IRP 2013 Update Report therefore includes an assumed outlook of economic growth for the next fifty years. The two drivers of the economic scenario framework are global growth and domestic climate policy implementation.
The underlying assumptions and policy direction of the economic scenarios are described in Figure 36. While not a prediction of economic growth per se, the framework considers the impact of different scenarios on the demand in the electricity industry.

- **Traditional Sectors**: Where global growth is strong and the domestic policy environment has failed to reform industry structures and dynamics. Low domestic policy implementation infers that CCS implementation would be unlikely in this electricity sector scenario, considering the high costs associated with capital outlays for infrastructure and retrofitting, as well as high operational costs.

- **Green Shoots**: Where global growth is strong and the domestic development agenda, as espoused in the National Development Plan, succeeds in reforming the structure of the South African economy. CCS could conceivably be rolled out under such an environment.

- **Weathering the Storm**: Where successful domestic policy interventions alleviate the downward pressure from anaemic global economic growth. CCS could be feasible in such circumstances should the climate change and socio-economic policies be implemented.

- **Adrift in Troubled Waters**: Where global growth is weak and the domestic policy environment fails to provide any internal impetus to growth. These characteristics are unlikely to support the CCS business case in South Africa.

![Figure 36: IRP 2013 Update Economic Scenarios (Department of Energy, 2013a)](image)

While the economic scenarios above focus on the future of the electricity industry in South Africa, they can also be taken as a proxy for future developments in energy intensive sectors such as steel and cement. For
example, growth in the electricity industry is a good indicator of growth in energy intensive sectors. CCS may then be a technology of choice in the cement and steel industries.

The determinants above are considered in relation to various scenarios and test cases illustrated schematically in Figure 37.

![Figure 37: IRP Update Test Cases and Scenarios (Department of Energy, 2013a)](image)

The application of CCS is considered for both coal and gas technologies in the 2013 IRP Update Report. The construction of new coal-fired generation between 2020 and 2025 is expected in all the scenarios, in addition to a limited exposure to new combined cycle gas turbines (CCGT) capacity. The Weathering the Storm scenario has one of the highest expected levels of new coal-fired generation. The Update Report’s recommendations go on to include investigations into the feasibility of extending the life of various coal-fired power stations, or alternatively building new coal-fired generation which is more efficient and with lower emission rates or non-emitting alternatives. These recommendations represent positive signals for the development of the CCS business case.

5.2.1.2 Scenario Inputs and Assumptions

The 2013 IRP Update scenarios vary considerably. For the purposes of this report, the IRP scenario assumptions related to impacts to GDP growth (Figure 38) and carbon mitigation (Figure 39) have been selected for input into our analysis in later chapters.
The base case (constant emissions) is the continuation of the 275 million tonnes per annum emission target, established in the IRP 2010. The moderate decline scenario starts at the 275 million tonnes established in IRP 2010 and then starts to decline in 2037 at a moderate pace before reaching 210 MT per annum in 2050. The advanced decline scenario allows for an earlier reduction in carbon emissions from the IRP 2010 limit of 275 MT per annum in 2030, before declining at an increasing rate to reach 140 MT per annum in 2050. The upper and lower limits evident in Figure 39 refer to the range of the official Peak, Plateau and Decline commitment made by South Africa under the Paris Agreement.

The differences between the three emission trajectories only become evident beyond 2030. The differences in the 2050 capacity outlook are highlighted in the shift from coal generation to nuclear. The CCGT also increases slightly as the emission requirements reduce.

The 2013 IRP Update considers an effective carbon tax rate (in real terms) on electricity generation against the shadow price of the emission constraints, illustrated in Figure 40.
Figure 40: Effective Carbon Tax (in real terms) on Electricity Generation against the Shadow Price (Department of Energy, 2013a)

With regards to the carbon tax scenario, the IRP Update Report finds that the proposed carbon price, even at R117/tonne in 2025, is not sufficient to enable CCS as an economically viable technology choice for use in the electricity generation market segment. This implies that the emissions limits may be met at a cheaper cost with alternative technologies. The application of the emissions limit in the IRP Update Report results in a higher shadow carbon price than the carbon tax, implying that the carbon tax would have a lower impact on CO₂ emissions reductions than regulating the emissions limit. The Update Report recommends that consideration should be given to using one of the two but not both.

In summary, the electricity sector scenarios outlined in the IRP 2013 Update Report impact on the CCS business case depending on the assumptions used for the input parameters values. The signals that may lead to the realisation of these scenarios are well established in both the domestic and international environments.

5.2.2 Integrated Energy Plan Scenarios

The Integrated Energy Plan considers the country’s entire energy sector including all major energy carriers and cross-cutting issues. The plan is intended to be the guiding policy for various electricity, gas and liquid fuel infrastructure plans; for the selection of appropriate technologies to meet energy demand and the guide for the development of policies and targets. Updated in 2016, the Integrated Energy Plan utilises the latest national assumptions on GDP projections (based on the 2016 Budget Vote), as well as revised projections on commodity and coal prices.
### 5.2.2.1 Description of Scenarios

Four key scenarios were developed to analyse energy consumption trends within different sectors of the economy. The trends are subsequently used to project future energy requirements. The scenarios are provided in Figure 41:

**Integrated Energy Plan Scenarios**

1. **Base Case Scenario**: assumes that existing policies are implemented and will continue to shape the energy sector landscape going forward. It assumes moderate economic growth in the medium to long term.
2. **Resource Constrained Scenario**: global energy commodity prices (i.e. coal, crude oil and natural gas) are high due to limited supply.
3. **Environmental Awareness Scenario**: characterised by more stringent emission limits and a more environmentally aware society, where a higher cost is placed on externalities associated with carbon, with the cost placed at R270/tonne.
4. **Green Shoots Scenario**: describes an economy in which the targets for high economic growth and structural changes to the economy, as set out in the National Development Plan are met.

**Figure 41: Integrated Energy Plan Scenarios (Department of Energy, 2016b)**

CCS could be feasible in the Environmental Awareness and the Green Shoots scenarios because these are characterised by high levels of emission mitigation policies actions and higher levels of economic growth.

Drivers include the implementation of the National Development Plan, the Industrial Policy Action Plan; the Beneficiation Strategy and other guiding documents that focus on the need to grow the country’s economy in a sustainable manner. The Beneficiation Strategy in particular prioritises five value chains for advancement through beneficiation. Energy expansion is one of the values and given that coal is an abundant and affordable fuel source, the Beneficiation Strategy sees this as continuing to play a vital role in meeting local and international energy demand.

### 5.2.2.2 Scenario Inputs and Assumptions

The GDP assumptions (presented in Figure 42) in the scenarios correspond with the GDP growth projections used for the IRP 2013 update.
The factor driving the CCS business case is the need to reduce carbon emissions. The *National Climate Change Response White Paper* outlines the country’s Peak-Plateau-Decline (PPD) emissions limit trajectory, the upper limit of which was applied to the Base Case, Green Shoots and Resource Constrained scenarios illustrated in Figure 43.

The carbon dioxide input constraints for all of the energy sector scenarios are within the specified emissions limits of the PPD. The increase in emissions is driven by new or an increase in coal based electricity generation or the life extension of older coal-fired plants. Typically, retired plants are replaced with technologies which have lower emissions or no emissions, resulting in a general decrease in the emissions.
An increased demand for electricity is anticipated in all the scenarios, largely attributable to the projected GDP growth. Increases in the economy are linked to the country’s power generation capacity which is primarily produced by coal fired power stations. As such, all the scenarios demonstrate an increase in carbon dioxide emission from 2015 to around 2020.

The Environmental Awareness and the Green Shoots scenarios are likely to be most supportive of the CCS business case, where the implementation of CCS on the majority or all fossil fuelled power stations could curb carbon dioxide emissions. The latest Integrated Energy Plan therefore recommends further investment in research, development and the demonstration of new technologies such as CCS.

### 5.2.3 Coal Roadmap Scenarios

Developed in 2013, the South African Coal Roadmap aims to support the coal industry, policymakers and other stakeholders in navigating an uncertain future (up to 2040). By identifying four different futures and conducting an in-depth quantitative and qualitative analysis of the implications of following each of these futures, an understanding is gained of the contribution of the coal value chain to the South Africa economy and the well-being of its people and natural environment under different scenarios.

Coal use in South Africa was the element selected as a key focus area in this report, specifically the related coal-fired electricity build plans and coal demand assumptions, on account of the close alignment with the scope of this project. As a starting point, the Coal Roadmap findings indicate that the resource base of the Waterberg coalfield is so large that even with the considerable coal consumption of ‘More of the Same’ scenario and the ‘Lags Behind’ scenario, the resource base is depleted by less than 15%.
5.2.3.1 Description of Scenarios

The Coal Roadmap framework encompasses four scenario determinants, illustrated in Figure 44. The Coal Roadmap employs two drivers of South Africa’s coal demand and use: global response to climate change and local response to climate change. The Coal Roadmap considers the implementation of CCS as the key mitigation mechanism in the scenarios that are characterised by higher global responses to climate change.

![Coal Road Map Scenarios Framework]

- **Lags Behind (coal remains a significant energy source):**
  - Characterised by ultra-supercritical power stations, CCS, underground coal gasification
  - One new coal-to-liquids plant is built in 2027 to meet local liquid fuels demand

- **Low Carbon World (nuclear and renewables dominate):**
  - Renewable energy and nuclear; no new coal built beyond Medupi and Kusile. CCS is pursued
  - No further coal-to-liquids plants are built

- **More of the Same (continued coal use, globally and locally):**
  - Ultra-supercritical power stations; coal fired power stations but no CCS
  - Two new coal-to-liquids plants are built between 2027-2040 to meet local liquid fuels demand

- **At the Forefront (continued coal use as well as renewables and nuclear):**
  - New coal plants use ultra-supercritical technologies, with smaller power stations
  - No further coal-to-liquids plants
5.2.3.2 Scenario Inputs and Assumptions

The assumptions underpinning coal use in South Africa are based on the IRP 2010, where electricity demand for the country is assumed to be identical between scenarios and driven by GDP growth of 4.5%, corrected for a projected decline in energy intensity of the economy and adoption of demand side management opportunities. As the IRP 2010 only considers resource options up to 2030, the Coal Roadmap makes assumptions about the build plan for the period 2030 to 2040.

The inputs of the ‘Lags Behind’ and ‘Low Carbon World’ scenarios are considered further as they make specific provision for CCS rollout.

Table 18: Key Inputs of the Coal Roadmap Scenarios (Fossil Fuel Foundation, 2013)

<table>
<thead>
<tr>
<th>Key input</th>
<th>Coal Roadmap scenarios that consider CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lags Behind</strong></td>
<td><strong>Low Carbon World</strong></td>
</tr>
<tr>
<td><strong>Main determinants</strong></td>
<td>- The world decarbonises, but coal remains a significant energy source in South Africa and other developing countries.</td>
</tr>
<tr>
<td></td>
<td>- Coal-based power generation still dominates local electricity supply, but with clean coal technologies such as ultra-supercritical power stations, carbon capture and storage and underground coal gasification as they become available.</td>
</tr>
<tr>
<td></td>
<td>- A new coal-to-liquids plant is built in 2027 to meet local liquid fuels demand.</td>
</tr>
<tr>
<td></td>
<td>- The world decarbonises and moves towards use of nuclear and renewables for electricity supply. Funding is available for South Africa to follow suit, with no new coal-fired power stations built beyond Medupi and Kusile.</td>
</tr>
<tr>
<td></td>
<td>- Carbon capture and storage is pursued and no more coal-to-liquids plants are built in South Africa.</td>
</tr>
<tr>
<td><strong>Electricity build plans</strong></td>
<td>- Follows IRP 2010 Base Case scenario to 2030, under which new power stations are mostly coal-fired.</td>
</tr>
<tr>
<td></td>
<td>- From 2030-2040 new build is a mix of ultra-supercritical pulverised fuel with flue-gas desulphurisation, fluidised bed combustion and underground coal gasification combined cycle gas turbine and a smaller proportion of combined cycle gas turbine.</td>
</tr>
<tr>
<td></td>
<td>- New pulverised fuel is built in the Waterberg and fluidised bed combustion utilises discards in the Mpumalanga coalfields. Underground coal gasification utilises coal resources in the Free State coalfields.</td>
</tr>
<tr>
<td></td>
<td>- CCS installed on new large coal build (ultra-supercritical pulverised fuel) from 2034.</td>
</tr>
<tr>
<td></td>
<td>- Mid-range decommissioning of coal-fired power stations.</td>
</tr>
<tr>
<td></td>
<td>- Follows IRP 2010 Emissions 3 scenario to 2030, under which no new coal-fired power stations are built after Medupi and Kusile.</td>
</tr>
<tr>
<td></td>
<td>- From 2020 new build is made up of nuclear and combined cycle gas turbine for base load and renewables/other supply (hydro imports, co-gen).</td>
</tr>
<tr>
<td></td>
<td>- CCS is retrofitted to Medupi and Kusile from 2029.</td>
</tr>
<tr>
<td></td>
<td>- Early decommissioning of coal-fired power stations.</td>
</tr>
<tr>
<td>Key input</td>
<td>Coal Roadmap scenarios that consider CCS</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td><strong>Lags Behind</strong></td>
</tr>
<tr>
<td></td>
<td>- One new CTL plant with a capacity of 80,000 bbl/day begins to be brought on line in 2027.</td>
</tr>
<tr>
<td></td>
<td>- CCS is fitted in 2034 to both Secunda and the new CTL plant to capture process CO₂ stream.</td>
</tr>
<tr>
<td>Coal-to-liquids</td>
<td>- No new CTL plants are built.</td>
</tr>
<tr>
<td></td>
<td>- CCS is fitted to Secunda in 2029 to capture process CO₂ stream.</td>
</tr>
<tr>
<td>Global coal demand</td>
<td>- Global demand for coal declines as the world moves away from fossil fuels, retiring existing coal-fired power stations early.</td>
</tr>
<tr>
<td></td>
<td>- Whilst demand for the higher grades of export coal declines, demand in low-grade coal for Asian markets remain strong throughout the period.</td>
</tr>
<tr>
<td></td>
<td>Although there is some lock-in to existing infrastructure growth for the higher grade export products slows and ultimately declines. All new demand in export coal from 2020 onwards is assumed to be for low-grade coal for Asian markets.</td>
</tr>
<tr>
<td>Competitiveness</td>
<td>- South Africa’s export markets could be heavily penalised due to the continued coal intensity of the economy, given the global drive away from coal towards lower carbon energy sources.</td>
</tr>
<tr>
<td></td>
<td>- This penalty could be in the form of border tax adjustments on export products.</td>
</tr>
<tr>
<td></td>
<td>- South Africa’s efforts to reduce GHG emissions should ensure a place in the global export markets, as the world decarbonises.</td>
</tr>
</tbody>
</table>

CCS is considered in both of the two Coal Roadmap scenarios above. These scenarios demonstrate the typical tension between risks related to employment levels and the risks associated with slow or poor levels of decarbonisation. While the considered scenarios focus on coal-fired electricity generation, the state of this sector can also be viewed as a reflection of related energy-intensive sectors (such as steel and cement). Growth in the electricity sector is a good indicator of growth in the energy-intensive sectors, and *vice versa.*

### 5.2.4 The NBI’s Power Generation Scenarios

Initiated in 1995, the National Business Institute (NBI) is a voluntary coalition of South African and multinational companies, working towards sustainable growth and development in South Africa. In 2016 the NBI published the results of a study on potential power generation scenarios in South Africa. The methodology considered the drivers of change in the country, their potential connections and outcomes.

#### 5.2.4.1 Description of Scenarios

The NBI developed four scenarios illustrated in Figure 45. These scenarios represent the potential outcomes of the levels of implementation of the two model drivers: social polarisation and the balance of institutional power. While CCS is not specifically considered in the NBI scenarios, it is feasible that the CCS business case would be supported in a world where there is a relatively high degree of social development and transformation. The basis for this assertion is the direct relationship between sustainable development and climate change, where efforts to mitigate climate change are also likely to benefit the communities and societies in which those efforts are realised.
The Patronage Driven scenario encompasses the following characteristics:

- People who are accountable to elites not vice versa; socially and economically unsustainable
- CCS is unlikely to be applicable due to the high costs associated with implementation

The State Driven scenario encompasses the following characteristics:

- Elites accountable, still interventionist, but socially effective
- Greater political accountability sustains higher social spend and also institutional loans to drive state owned companies
- State / state owned company debts and ongoing patronage could compromise fiscals
- CCS could be viable on account of the construction of new coal-fired power plants

The Private Business Driven scenario encompasses the following characteristics:

- Business demands more market place reforms and also takes ownership of transformation
- Negotiations on the likes of the National Development Plan and Industrial Action Policy Plan improve national investment sentiment and reduces inequality
- Cities demand more market place reforms and businesses take ownership of transformation
- CCS could be a viable due to the construction of new gas plants

The Consumer Driven Disruption scenario encompasses the following characteristics:

- Dual society persists
- Urban middle class use innovative disruption to create growth
- Less oligopolies, state owned companies and state planning unleash innovation and disruption
- Polarisation could drive populism and social instability
- CCS is unlikely to be viable in this scenario because few new large fossil fuel plants will be built. Most new generation is expected to be financed on consumer balance sheets
5.2.4.2 Scenario Inputs and Assumptions

The NBI utilises a number of key assumptions in the development of the power generation scenarios:

<table>
<thead>
<tr>
<th>Input</th>
<th>State Driven scenario</th>
<th>Private Business Driven scenario</th>
<th>Consumer Driven Disruption scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per Capita GDP Growth post 2014 (per annum)</td>
<td>~0.5%</td>
<td>~2.5%</td>
<td>~1%</td>
</tr>
<tr>
<td>Gini Coefficient post 2008 (World Bank estimate)</td>
<td>~0.59</td>
<td>~0.55</td>
<td>~0.63</td>
</tr>
<tr>
<td>Fixed Capital Formation (% of GDP)</td>
<td>~22%</td>
<td>~25%</td>
<td>~22%</td>
</tr>
<tr>
<td>Foreign Direct Investment (World Bank estimate)</td>
<td>~$10bn</td>
<td>~$10bn</td>
<td>Not provided</td>
</tr>
</tbody>
</table>

The NBI also considers the following IRP 2015 demand forecast, illustrated in Figure 46.

In summary, the State Driven and Private Business Driven scenarios recognise that social transformation and environmental sustainability are closely connected. The impacts of climate change affect the very basis of South African society, which relate to risks associated with agricultural production, urbanisation and health sectors, to name a few. The signals for the transition to an equitable society are supported by high levels of implementation of government policies such as the National Development Plan, the New Growth Path, Industrial Action Policy Plan and others.
5.2.5 SLR and SACCCS Scenarios

In 2013 the South African Centre for Carbon Capture and Storage (SACCCS) published a report on the impacts of CCS on South African national priorities, other than climate change, drafted by; SLR Global Environmental Solutions and Prime Africa Consultants.

5.2.5.1 Description of Scenarios

The three SLR and Prime Africa scenarios are described in Figure 47. The Low and High Case scenarios specifically consider the application of CCS.

SACCCS and SLR scenarios:

1. **Base Case Scenario:** No CCS deployment; assumes successful implementation of the electricity generation sources outlined in the policy adjusted IRP 2010.

2. **Low Case Scenario:** About 20 Mt/a of CO2 is captured by 2045. Sources include new coal, closed cycle gas and the coal to liquid industry. In this scenario, South Africa does not reach its emissions reduction goals and follows a medium development pathway trajectory for GHG emissions. CCS is part of an integrated basket of measures to reduce GHG emissions.

3. **High Case Scenario:** About 80 Mt/a of CO2 is captured by 2050, which equates to about 20% of the South African output in 2013: 30 Mt/a of CO2 is captured from coal to liquid plants and the remaining 50Mt/a is captured from coal-fired power plants.

Figure 47: Scenarios of the SLR and Prime Africa Consultants Report (2013)

5.2.5.2 Scenario Inputs and Assumptions

Three CCS deployment scenarios were adopted for the purpose of modelling of CO2 capture volumes. The scenarios are based on projected carbon emissions in South Africa up to 2050, under three differing sets of developmental pathways developed by the Wuppertal Institute and illustrated in Figure 48.
The Growth without Constraints Emissions Trajectory shows the forecasted growth in carbon emission taking current trends into account. Policies to reduce carbon emissions are not implemented and electricity generation capacity is expanded primarily through the addition of coal plant capacity.

The Medium Developmental Trajectory illustrates a situation where coal based generating capacity is more or less at the same level until 2050. In this trajectory, increases in overall systems capacity are achieved through the expansion of natural gas, oil, nuclear, wind and solar photovoltaic based generation.

The Upper and Lower Limit National GHG Emissions Trajectories outline the limits of South Africa’s emission reduction goals. This trajectory assumes successful implementation of the Integrated Resource Plan for Electricity 2010 – 2030 (IRP 2010).

Various additional inputs were assumed under the three cases, described in Table 19.
Table 19: Assumptions of the SLR and Prime Africa Consultants Report (2013)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Assumptions</th>
</tr>
</thead>
</table>
| **Base Case** | - No CO₂ is captured; assumes successful implementation of the electricity generation sources outlined in the policy adjusted IRP 2010 with no CCS deployment in South Africa.  
- 30% of all energy production is renewable energy.  
- Greenhouse emissions produced by the secondary sector including iron and steel smelting, petroleum, refining, cement manufacturing and other sources are restricted according to the national GHG emissions trajectory, which decline to a lower limit of 212 Mt and upper limit of 428 Mt by 2050.  
- 75% of the electricity produced is from renewable energy sources by 2050. |
| **Low Case** | - Some CO₂ is captured (about 20 Mt/a by 2050).  
- All capture takes place in the Coal to Liquid industry. The estimated CO₂ emissions from Sasol in 2010 are about 614 Mt/a (NBI, 2011).  
- South Africa does not reach its emissions reduction goals and follows a medium development pathway trajectory for GHG emissions. The effort made to expand non-fossil energy sources lags behind.  
- CCS is part of an integrated basket of measures to reduce emissions.  
- Coal fired power plants reach 45 GW from 2030, meaning that older power plants will be replaced by new power plants. There is an increase in gas use, nuclear power plants reach 12 GW from 2030. Renewable capacity will increase from 7.5 GW in 2020 to 37 GW in 2050. |
| **High Case** | - 80 Mt/a of CO₂ assumed to be captured by 2050 (represents about 20% the 2013 SA output)  
- Projected energy mix: increase from 37GW of power to 120 GW by 2050. The assumption used to validate the application CCS is the high projected development pathway of coal fired power plants.  
- About 30 Mt/a CO₂ is captured from Coal to Liquid plants and the remaining 50Mt/a is captured from coal-fired power plants. |

The report assumes that CCS will be implemented post 2020 and will form part of the existing plan to reduce energy consumption and GHG emissions, while expanding non-fossil energy sources (including wind, solar, biomass and geothermal) in South Africa.

### 5.2.6 World Energy Council Scenarios

The World Energy Council aims to provide a wide range of insights into the current status and future of the world’s energy industry through its various flagship studies. One such study encompasses the World Energy Scenarios, which provide insights based on views of possible futures for the energy industry, developed with partners Accenture Strategy and the Paul Scherrer Institute. The scenarios were developed over a period of three years and were built by a network of more than 70 members from over 25 countries, and quantified with a global multi-regional energy system model.
The scenarios consider the latest disruptive energy trends characterised by lower population growth, radical new technologies, greater environmental challenges and a shift in economic and geopolitical power. The World Energy Council anticipates that these underlying drivers will re-shape the economics of the global energy industry looking to 2060, in a process called the Grand Transition.

5.2.6.1 Description of Scenarios

The World Energy Council report presents three exploratory world scenarios, described in Figure 48.

<table>
<thead>
<tr>
<th>World Energy Council Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Modern Jazz</strong>: a ‘digitally disrupted’, innovative and market-driven world</td>
</tr>
<tr>
<td>2. <strong>Unfinished Symphony</strong>: a world in which more ‘intelligent’ and sustainable economic growth models emerge as the world drives to a low carbon future</td>
</tr>
<tr>
<td>3. <strong>Hard Rock</strong>: explores the consequences of weaker and unsustainable economic growth with inward-looking policies</td>
</tr>
</tbody>
</table>

While the scenarios above consider future global outlooks, they can also be applied to the local South African context where CSS could be implemented in the future.

5.2.6.2 Scenario Inputs and Assumptions

A range of assumptions underpin the Grand Transition process. Key determinants are illustrated in Figure 50:

*Could include rollout of CCS*
The World Energy Council assumptions indicate that the Grand Transition takes us into a world of much lower population and global labour force growth; a range of new powerful technologies; a greater appreciation of the planet’s environmental boundaries and a shift in economic and geopolitical power towards Asia.

While CCS is not included as a specific parameter in the World Energy Council scenarios, one can infer that the business case in South Africa could be well supported by the Unfinished Symphony scenario because one of the foundations of this future is the global cooperative drive to reduce carbon emissions. As per previous scenarios considered in this report, the Unfinished Symphony scenario highlights the interconnections between sustainable socio-economic economic growth (seen in the increase in demands for primary energy and electricity) and the need to limit global warming. CCS could also be applicable in the Modern Jazz scenario, however the main driver in this scenario would be market demand. Market demand could, for instance, be directed by market-based policies such as a South Africa’s upcoming carbon tax or those pertaining to operating licences, which could at a future date include carbon budget parameters.

It is unlikely that CCS would feature in a world dominated by the Hard Rock scenario. The newly introduced future pathway is based on isolationist policies that would likely prioritise the development of least-cost energy supplies in South Africa, with reduced regard of their environmental or wider global consequences.

### 5.2.7 World Energy Outlook Scenarios

The World Energy Outlook is a bi-annual assessment that utilises a large-scale simulation model designed to replicate how energy markets function. The 2015 World Energy Model covers energy developments up to 2040, in 25 regions with 12 countries being individually modelled. While the model considers future global

<table>
<thead>
<tr>
<th>Pre-determined elements</th>
<th>Factors that shaped world energy 1970 to 2015</th>
<th>Pre-determined elements 2015 to 2060</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population / Workforce</td>
<td>• Global population grew 2x (1.7%)</td>
<td>• Global population will grow by 40% (0.7%)</td>
</tr>
<tr>
<td>New Technologies</td>
<td>• ICT revolution</td>
<td>• Pervasive digitalisation</td>
</tr>
<tr>
<td></td>
<td>• Productivity growth rate of 1.7% p.a.</td>
<td>• combinational impacts and productivity paradox</td>
</tr>
<tr>
<td>Planetary Boundaries</td>
<td>• Four planetary boundaries already crossed</td>
<td>• Water stress in high risk regions</td>
</tr>
<tr>
<td></td>
<td>• 1,000+ GtCO₂ consumed</td>
<td>• 1,000 GtCO₂ to 2,100 to avoid 2°C</td>
</tr>
<tr>
<td>Shifts in power</td>
<td>• Rapid growth of non-OECD countries</td>
<td>• 2030: India is most populous country</td>
</tr>
<tr>
<td></td>
<td>• Growing role for global institutions</td>
<td>• 2035–45: China is the world’s largest economy</td>
</tr>
</tbody>
</table>

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**Figure 50: Assumption in the Grand Transition Process.**

(*World Energy Council, 2016*)
scenarios, these may also be applied to the local South African context where CSS could be implemented in the future.

The *World Energy Outlook* is published by the International Energy Agency, an autonomous agency which aims to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 29 member countries and beyond.

### 5.2.7.1 Description of Scenarios

The *World Energy Outlook* series considers three main scenarios, described in Figure 51.

**World Energy Outlook** scenarios:

1. **Current Policies Scenario**: “Business-as-usual” future which is projected to generate warming of 6°C. This scenario only considers been formally adopted policies by governments which continue unchanged.

2. **New Policies Scenario**: Central to the World Energy Outlook model, this scenario is projected to generate warming of 4°C. Existing policies are maintained and recently announced commitments and plans, including those yet to be formally adopted, are implemented in a cautious manner.

3. **450ppm Scenario**: Considers the necessary action in the energy sector to limit the rise in long-term average global temperature to 2°C (with a likelihood of around 50%). The rapid expansion of CCS after 2025 is noted as a key action.

**Figure 51: World Energy Outlook Scenarios (World Energy Council, 2016)**

While all of the scenarios include CCS to some degree, the carbon price and fossil fuel demand are the main drivers.

The International Energy Agency (2016a) notes that achieving the Paris Agreement’s goals will require an unprecedented shift in global energy systems, both to implement the current Nationally Determined Contributions (which are considered in the New Policies Scenario) and to go beyond them as required to keep the well-below 2°C collective goal within reach. The International Energy Agency recommends scaled-up actions in this regard, where CCS is explicitly referenced as a material technology required to limit average global temperatures. Retrofitting CCS on coal-fired power plants is further considered as a measure (in addition to decommissioning regulations, dispatch rules, carbon pricing and other policies) that can be used to reverse the ‘lock-in’ of emissions from these plants. By 2050, unabated coal generation is virtually phased out worldwide under the International Energy Agency 2°C scenarios.

### 5.2.7.2 Scenario Inputs and Assumptions

The World Energy Outlook scenarios largely use the same macroeconomic and demographic assumptions:
### Population growth
- Growth rates are based on the medium-fertility variant projections contained in the United Nations Population Division 2013. In the World Energy Outlook 2015, world population is projected to grow by 0.9% per year on average, from 7.1 billion in 2013 to 9.0 billion in 2040. Population growth slows over the projection period, in line with trends of the last three decades: from 1.0% per year in 2013-2025 to 0.8% in 2025-2040.
- Estimates of the rural/urban split for each region have been taken from UNDP (2014). This database provides percentage of population residing in urban areas by country in 5 yearly intervals to 2050. In 2013, slightly more than half of the world population was estimated to be living in urban areas. This is expected to rise to 63% by 2040.

### Macroeconomic assumptions
- Economic growth assumptions for the short to medium term are based largely on those prepared by the OECD, IMF and World Bank. Over the long term, growth is assumed to converge to an annual long-term rate.
- In World Energy Outlook 2015, world GDP (expressed in year-2014 dollars at purchasing power parity terms) is expected to grow on average by 3.5% per year over the projection period. Growth is assumed to rise from 3.7% in 2013-2020 to 3.8% in 2020-2030 and then drop to 3.1% in 2030-2040. India and Africa are expected to grow faster than all other regions, followed by China and Brazil. The economies of many regions are expected to shift away from energy-intensive heavy manufacturing towards lighter industries and services, though the pace of this process, which is well advanced in the OECD and some emerging economies, varies. Industrial production growth over the next decades is going to come mainly from countries outside the OECD.

Energy demand, supply and power generation are also modelled extensively, based on various key inputs which vary per region. The 450ppm scenario puts the energy sector on course to reach a point, before the end of the 21st century, when all residual emissions from fuel combustion are either captured and stored, or offset by technologies that remove carbon from the atmosphere. While the 450ppm scenario acknowledges transformation of the energy sector as vital, it notes that this not enough to achieve a pathway below 2°C. Substantial effort must also be made to reduce GHG emissions in non-energy sectors. The 450ppm scenario is less of a projection influenced by policy actions because it deliberately selects a plausible energy pathway, which includes the deployment of CCS.

The International Energy Agency’s analyses conclude that faster and more extensive deployment of CCS could shift the energy and industrial process sectors from a 2°C pathway to well below 2°C (IEA, 2016b).

The theoretical basis for the deployment of CCS in South Africa has been well established in the various scenarios discussed above. The practical rollout is however dependent on a conducive economic environment and central to this is the cost of carbon. The following scenarios consider a number of potential carbon price trajectories in the local and international markets.
5.2.8 Scenario Forecasts on the Carbon Price

Carbon is sold as a commodity across international markets. Currently, the primary aim of carbon markets is to encourage or assist countries and companies to limit their CO₂e emissions. Trading is an effective tool in this regard because it can provide emitters with a least-cost-mechanism to reduce their GHG emissions. For example, a formal price of carbon (such as a carbon tax) sets a price ceiling where the demand for carbon credits may fall below the ceiling price, providing a cost saving to the emitter. The price ceiling needs however to be high enough for project developers to invest in activities for which they will feasibly generate a suitable financial return. A robust carbon price therefore promotes investment in clean, low-carbon technologies. CCS is one of the potential carbon mitigation technologies which would benefit from an established and robust carbon price on account of the relatively high capital and operational costs associated with its implementation.

The price of carbon may be derived from various mechanisms such as the avoided costs, the damage cost or a market driven cost. Quantification enables countries and companies to assess the costs associated with their GHG producing activities. GHG mitigation strategies and plans can subsequently be developed and quantified on a cost basis – thereby enabling cost benefit analyses with the emitting activities. In this way, insights into the price of carbon will provide insights into the costs at which technologies will become competitive. An adequate carbon price will therefore motivate high level support and subsequently drive investments in low-carbon opportunities by governments and private companies alike.

Pricing carbon also shifts the burden of GHG emissions to the sources that are responsible for it. The price of carbon is an economic signal that provides emitters with the option of continuing with their emitting activities, at a price, or reducing their emissions (ideally at a lower cost or with additional benefits). A suitable price on carbon can therefore be a flexible market mechanism to effectively address the need to reduce emissions to limit increases in global average temperatures.

The latest CDP results reveal that 44 South African companies (including: consumer staples; energy; financial; health care; materials; and industrial businesses) are voluntarily embedding a cost of carbon in their current financial plans and strategies as a precautionary principle (CDP, 2016). The internal price ranges from $3.27 to $8.17 per tonne, primarily linked to the proposed carbon tax. At a global level some of the highest values are used by Pennon Group ($75.83–$291.65/tCO₂e), National Grid PLC ($86.04/tCO₂e), Kawasaki Kisen Kaisha, Ltd ($90/tCO₂e), Novartis ($100/tCO₂e), NGK Spark Plug Co., Ltd ($384/tCO₂e) and Astellas Pharma Inc. ($893.29/tCO₂e).

The following carbon price forecasts have selected as a viable range of values when considering the CCS business case. The carbon prices considered as explicit, in that the prices refer to mechanisms such as a tax or emissions trading scheme, where carbon emissions are directly priced. The forecasts are categorised into international and domestic markets.

5.2.8.1 Domestic Carbon Price Forecasts

The South African government is piloting a carbon budget (currently on a voluntary basis with no penalties) and plans to implement a carbon tax in the near future. Companies that emit significant amounts of GHGs
will be required to participate in these schemes. It is anticipated that these two schemes will be linked, possibly post 2020.

The carbon tax policy for South Africa has been designed as an economy wide instrument to tax activities which emit priority GHGs above set thresholds. In the interest of reducing the initial impact of the tax on the economy, the policy includes relief mechanisms in the initial stages. These relief mechanisms aim to reduce the tax liability of entities required to pay carbon tax. It is expected however that most of the mechanisms will be phased out after the first five years (or so) of the implementation of the tax, which will increase the effective tax rate. The implementation of CCS will provide financial benefits for such companies and would also be further supported by a reduction in the relief mechanisms.

Furthermore, the carbon tax legislation allows entities to reduce their tax liability through carbon offsets. Carbon offsets can be used to reduce an entity’s tax liability by between 5-10%, depending on the sector in which the entity falls. Offsets must be issued under one of three international crediting systems, namely the Clean Development Mechanism (CDM), Verified Carbon Standard (VCS) and Gold Standard. The CDM has approved, in principle, the registration of CCS projects under the standard, however no methodologies have yet been approved in this regard. Should these barriers be overcome, CCS projects could feasibly be registered under the CDM (and possibly the VCS which allows the use of CDM methodologies) and could be eligible to trade credits under the South African carbon offsets scheme (assuming the relevant eligibility criteria are met).

A carbon price of R120 has been stipulated in the latest draft bill and related publications pertaining to the upcoming carbon tax. The final price is expected to be published during the course of 2017. Early government documents suggest that initial annual increases on the carbon price will be in the region of 10% however this is still to be confirmed.

5.2.8.2 International Carbon Forecasts

Various market signals indicate that there will be an international carbon market with an international carbon price by 2030. The ratification of the Paris Agreement is particularly pertinent, as it motivates and allows for the creation of such a market. Notably the agreement includes recognition of voluntary cooperation to implement nationally determined contributions to achieve lower emissions using ‘internationally transferred mitigation outcomes’ or ITMOs – a new class of carbon assets. In this regard, the agreement calls for a UNFCCC-governed mechanism that will support mitigation and sustainable development post-2020, which enables international transfers of emission reductions while delivering overall mitigation in global emissions. The widening of the scope to include international trade will differentiate such a mechanism from the CDM, however it is anticipated that the latter will inform the new mechanism.

The following three scenario forecasts on the international carbon price provide insights into the direction in which the market is headed.

The Future of Coal Consumptions in a Carbon Constrained World (US)

McFarland et al undertook a study published in 2006 that investigates the impacts that US policies to mitigate carbon dioxide have on coal dominance in the country’s electric power sector. Of relevant to this report is
the effect of the carbon price projections on the consumption of CO₂, the influence of CCS technologies on the carbon price projections and effects on consumption up to 2050.

McFarland et al. (2015) consider three carbon price scenarios for the period 2000 to 2100 (US and Europe market), illustrated in Figure 52:

- **Low Case Scenario**: carbon price starts at $10 per tonne in 2010 and initially rises by 9% per year before stabilising at $300 per tonne by 2100

- **Mid Case Scenario**: carbon price starts at $20 per tonne and rises by 10.4% per year to rise to $340 per tonne in 2050 and peaking around $450 per tonne in 2100

- **High Case Scenario**: carbon price starts at $20 per tonne and reaches $500 per tonne by 2050

![Figure 52: Carbon Pricing Scenarios (McFarland et al., 2015)](image)

The study further concludes that the carbon prices have strong negative impact on coal consumption in 2050. In the context of South Africa’s economy, the coal sector and its related value chains provide significant employment and also contribute to the country’s GDP. Considering a predicted rise in carbon prices, the risks to both the international and local coal sectors could be offset by technologies such as CCS.

**Synapse Energy Economics’ 2016 US Carbon Dioxide Price Forecast**

Synapse Energy Economics is a research and consulting firm specialising in energy, economic and environmental topics. In the 2016 study, Synapse developed Low, Mid and High case forecasts for CO₂ prices in the USA from 2022 to 2050. In these forecasts, the Clean Power Plan together with other existing and proposed federal regulatory measures place economic pressure on CO₂-emitting resources.

- **Low Case scenario**: this forecast assumes that Clean Power Plan compliance is relatively easy, and stringent policy is only applied beyond 2030. Low case carbon prices are due to incremental costs to produce electricity with natural gas instead of coal
- **Mid Case scenario**: federal prices are implemented with some difficulty but are reasonable and achievable goals. Clean Power Plan is achieved with an 80% decrease in emissions from the electric power generation in the period 2005 to 2050.

- **High Case scenario**: implementation of standards is more aggressive than the Clean Power Plan. New regulations may mandate electricity generated emissions reduction of 90% from 2005 values by 2050. Characterised by restricted availability or high cost of technologies such as nuclear, biomass, CCS and more aggressive international actions.

The price of CO₂ begins at $15 per tonne in 2022 in the Low Case scenario. The price increases to $21 per tonne in 2030 and $36 per tonne in 2050, representing an increase of $42 per tonne levelised price over the full period. The Mid Case forecast price begins in 2020 at $20 per tonne, increasing to $26 per tonne in 2030 and $81 per tonne in 2050, representing a $38 per tonne levelised price over the full period. The High Case forecast price begins in 2020 at $25 per tonne, increasing to $43 in 2030 and $110 in 2050, representing a $55 per tonne levelised price over the period. The scenarios are illustrated in Figure 53.

![Figure 53: 2016 Carbon Price Forecast](Synapse Energy Economics, 2016)

The forecasts project an increase in carbon price, hence it is in the best interest for any carbon intensive industry to incorporate the price of carbon with their policies or plans. Technologies such CCS could be a useful bridge to offset carbon emission liabilities for such companies.

**a. European Carbon Price Forecasts**

The European Union has been particularly active in the recent climate change negotiations. The respective high level commitments are reflected in domestic policies and movements in regulations and mandates regarding national carbon pricing are particularly useful signals.
The European Commission’s draft EU Reference Scenario 2016 demonstrates that while there were surplus allowances in the early phases of the EU’s Emission Trading Scheme (ETS), equilibrium levels are expected shortly before 2025. The ETS price is expected to increase slowly until 2025 with stronger increases thereafter. The increasing ETS price induces a switch in power generation towards the use of low and zero carbon fuels or technologies (such as CCS). In the longer term, and in particular from 2040 onwards, the level of the ETS price is expected to increases significantly. Price increases are the consequence of a decreasing supply of allowances in line with the yearly linear reduction factor that reduces the cap substantially over time, as well as a combination of energy supply factors. Supply factors include the delayed technology developments of CCS, public acceptance of nuclear energy and others. The forecast is illustrated in Figure 54.

![Figure 54: Draft EU Reference Scenario 2016 (Energy Transitions Commission, 2016)](image)

In addition to the carbon price determined in the EU ETS, sovereign states in the EU also have the mandate to set their own domestic prices. For example, in 2016 France set a more ambitious carbon price and has confirmed that it will introduce a floor price for carbon emissions from coal power stations, which will increase from around €20 in 2020 to €50 in 2030 (Euractive, 2016).

The UK’s short-term traded carbon values were recently updated in 2015. These values are used for valuing the impact of government policies on emissions in the traded sector, i.e. those sectors covered by the EU ETS. Three scenarios (central, high and low) have been developed which consider short-term traded carbon values (up to 2020) as well as long-term values (beyond 2020). The long-term carbon values reflect the costs required to achieve the internationally agreed UNFCCC long term goal of limiting global temperature increases to 2 °C above pre-industrial levels. The 2015 short-term traded carbon values are compared with the 2014 values in Figure 55.
All the UK scenarios show a flat market up to 2020 (due in part to an oversupply of allowances), following which the price is anticipated to increase in line with policy adjustments and measures that are required to meet the UNFCCC targets.

Considering the heightened climate change focus in the global political environments and movements in the various carbon markets (outside of South Africa), it is feasible to assume that by 2030 cohesive international market will emerge and the South African carbon price will be aligned with the international price on carbon.

Forecasting carbon pricing is a complex process and considering the limited scenarios considered above, the ranges differ considerably. The We Mean Business *Carbon Pricing Pathways* report (2015) provides an indication of carbon pricing bands, illustrated in Figure 56, which the association uses to provide a common language to talk about pricing levels, focusing on how price affects economic behaviour and vice versa.
The scenario forecasts considered in this report reflect the current global carbon markets that are comprised of varying global, sovereign, regional and non-state actions. In order for a meaningful response to climate change and the related global socio-economic impacts, it is essential that these policies and actions interact positively.

The We Mean Business *Carbon Pricing Pathways* report further asserts that the potential of carbon pricing to help to keep global temperature rises below 2°C is dependent on three levers, illustrated in Figure 57.
These three levers are echoed in varying degrees in the scenarios discussed above. There is increasing pressure on governments to scale-up national policies and measures that support climate change initiatives. In South Africa, there is a particular focus on policies that seek to change behaviours related to the continued use of fossil fuels in the energy sector (which is the largest source of CO₂ emissions in the country). National policies, such as emissions caps or taxes (which place a value on emissions), will drive the private sector to switch technologies or undertake appropriate measures to ensure that they comply with the country’s laws and are not penalised. Stringent policy reforms could however result in the closure of businesses and sectors should the costs of compliance outweigh the respective costs of doing business.

An adequate carbon price is therefore required to support such policy measures. A ‘high-enough’ carbon price must be lower than the cost of non-compliance but high enough to see returns on emission mitigation projects. As climate change is a global concern, the development of an international carbon market and carbon price is considered a crucial element required to achieve the collective goal of keeping average global temperature increases well below the 2°C mark.

5.3 KEY THEMES FROM THE CONSIDERED SCENARIOS

Scenarios are hypothetical constructs. Their aim is to highlight central elements of a possible future, not to provide a forecast or full description of that future. Scenarios are principally concerned with the key factors that may drive future developments. The scenarios considered in this report were selected for their ability to explore alternatives to the business-as-usual scenarios and unpack the factors that may impact the CCS business case in South Africa. The scenarios provide insights into potential strategies that can be employed to transition South Africa’s business models to ones that remain valuable once ambitious climate policies are in place.

The selected scenarios are therefore largely “transition risk scenarios”. Scenarios typically draw conclusions, often based on modelling, about how policy and interventions (such as energy sources and related GHG emissions) interact with economic activity (such as structural changes in the economy), energy consumption and GDP among other key factors. The rate of transition of the scenarios often depends on different rates
of change of key parameters used as inputs or assumptions. They may include for example high global growth rates compared to the level of implementation of key policies (as per the 2013 IRP Update Report); global and local responses to climate change (as per the Coal Roadmap); and social polarisation and the balance of institutional power (as per the NBI’s power generation scenarios). The other scenarios provided other indicators for the transition to environments that are conducive to the CCS business case.

Many of the scenarios and models considered in this analysis the direct economic consequences of the various proposed methods to transition to a lower-carbon, clean energy economy. Some also consider the cost of business as usual, where GHG emissions continue to be emitted at current rates. These costs may be related to physical risks associated health impacts, shortened lives due to lifestyle, and a host of other economic and social factors. While the models and inputs vary, what is clear is that overall, undiscounted costs in the future are very large, meaning that the benefits of emissions reductions are equally large.

Internationally, positive signals in this regard are increasing. The recently ratified Paris Agreement recognises that the current nationally determined contributions submitted by countries prior to the negotiations in late 2015 are not sufficient to deliver the objective reducing to average global warming to below 2°C above pre-industrial levels. As such, the Paris Agreement has introduced a “ratcheting” requirement for countries to communicate enhanced nationally determined contributions, every five years. This will require countries to develop even more ambitious climate change plans in order to achieve the Agreement’s objectives.

In a world that is committed to capping average global warming to 2°C or less, activities that mitigate emissions, such as CCS, should therefore be prioritised for development.

5.3.1 Summary of GDP Growth Inputs used in Studied Scenarios

A common trend among the considered studies is the utilisation of GDP growth as a driver of the climate change scenarios, on account of the typically carbon intensive nature of economic and industrial growth. A summary of the economic growth assumptions underlying the assessed scenarios is presented in the table below.

Table 20: Consolidation of Key Scenario Inputs

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>GDP GROWTH INPUT</th>
<th>ANNUAL EMISSION LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013 IRP Update: Economic Scenarios</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Traditional Sectors</td>
<td>5.4% (av. annual, real growth up to 2050)</td>
<td>275 MT/a carbon emissions limit throughout the period (based on Constant Emissions trajectory)</td>
</tr>
<tr>
<td>• Green Shoots (Base Case)</td>
<td>5.4% (av. annual, real growth up to 2050)</td>
<td>201 MT/a in 2050 (based on Moderate Decline trajectory)</td>
</tr>
<tr>
<td>• Weathering the Storm</td>
<td>2.9% (av. annual, real growth up to 2050)</td>
<td>275 MT/a carbon emissions limit throughout the period (based on Constant Emissions trajectory)</td>
</tr>
<tr>
<td>• Adrift in Troubled Waters</td>
<td>2.4% (av. annual, real growth up to 2050)</td>
<td>275 MT/a carbon emissions limit throughout the period (based on Constant Emissions trajectory)</td>
</tr>
<tr>
<td>Integrated Energy Plan 2016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Base Case</td>
<td></td>
<td>Within PPD range</td>
</tr>
</tbody>
</table>
In addition to economic growth trajectories, the practical development and rollout of the technology in South Africa will be informed by various economic parameters. The carbon price is central to the feasibility of the CCS business plan on account of its ability to stimulate market innovation which may fuel new, low-carbon economic growth.

5.3.2 Summary of Carbon Price Inputs used in Studied Scenarios

Understanding carbon price trends will provide both the public and private sectors with valuable insights for the development of policies and strategies that drive the decarbonisation of our environment. The latest CDP statistics reveal that an increasing number of companies use an internal price for carbon in order to prepare for a carbon-constrained future by building prudent buffers into their business models today. This is a strong signal that points to the development of an international carbon market in the near future.
<table>
<thead>
<tr>
<th>CARBON PRICING SCENARIO</th>
<th>CARBON PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domestic</strong></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>Proposed Carbon Tax</td>
</tr>
<tr>
<td></td>
<td>Base Case Scenario</td>
</tr>
<tr>
<td></td>
<td>Resource Constrained Scenario</td>
</tr>
<tr>
<td></td>
<td>Green Shoots Scenario</td>
</tr>
<tr>
<td></td>
<td>Environmental Awareness Scenario</td>
</tr>
<tr>
<td><strong>International</strong></td>
<td></td>
</tr>
<tr>
<td>McFarland <em>et al</em> (USA)</td>
<td>Low Case Scenario</td>
</tr>
<tr>
<td></td>
<td>Mid Case Scenario</td>
</tr>
<tr>
<td></td>
<td>High Case Scenario</td>
</tr>
<tr>
<td>Synapse Energy Economics (USA)</td>
<td>Low Case Scenario</td>
</tr>
<tr>
<td></td>
<td>Mid Case Scenario</td>
</tr>
<tr>
<td></td>
<td>High Case Scenario</td>
</tr>
<tr>
<td>European Commission</td>
<td>Draft EU Reference Scenario 2016 for EU ETS</td>
</tr>
</tbody>
</table>
CARBON PRICING SCENARIO | CARBON PRICE
--- | ---
France | Floor price for carbon emissions from coal power stations: € 20 in 2020; € 50 in 2030
UK’s short-term traded carbon values | High Scenario: £ 40 in 2020; just below £ 118 in 2030
Central Scenario: Around £ 5 in 2020; just below £ 80 in 2030
Low Scenario: Around £ 0 in 2020; £ 40 in 2030
World Energy Outlook | 450ppm Scenario: $ 140/t in 2040, in most OECD countries

While the carbon pricing scenarios considered above vary, the dominant trend that emerges is the increase in price, particularly from 2020. It is widely assumed that activities and initiatives to meet the UNFCCC’s goals of limiting global temperatures will be ramped up or implemented around this time. The scenarios indicate that CCS deployment is likely to increase (worldwide) at this time or slightly later. The development of a unified, international carbon market could also feasibility occur at this point. Should this happen, it is further conceivable that South Africa’s carbon price will be aligned with the price in an international market.

The scenarios considered in this analysis are only a sample of the studies and information available. The exercise has brought to light a number of key variables that are utilised in the following model of emission reductions and associated costs.

5.3.3 Assumptions for Techno-Economic Analysis

The selected scenarios above concur with the general consensus that economic growth is a driver of emissions. This is relevant for South Africa’s economy which is particularly emissions intensive on account of the country’s abundant mineral resources and its developing nature. The economic feasibility of the CCS business case is therefore related to the emissions intensity of the South African economy: if national carbon emissions levels are high then there is a respectively high demand for CCS. Furthermore, if national carbon emissions levels are high and demand is high, it stands to reason that the costs to implement CCS will reduce based on economies of scale.

The feasibility of the CCS business case is further supported by a strong carbon price, which has the potential to stimulate the development of CCS as a carbon mitigation measure. A high carbon price may make the business decision (related to capital and operational costs, as well as other risks) more attractive to potential investors.

While GDP growth and carbon prices are not the only drivers of the CCS business, the analyses of the scenario studies above indicate that their relationship material, illustrated in Figure 58.
Figure 58: Scenario Assumptions underlying the CCS Business Case

The GDP growth and carbon price drivers are dependent on various assumptions. A series of scenarios are proposed in the following section to assess the combinations of these two drivers which are drawn from on the ranges identified in the reviewed studies:
6 SCENARIO ANALYSIS AND CONTRIBUTION OF CCS TO NATIONAL CO2 EMISSION REDUCTION

The extent to which CCS can contribute to national emissions reductions and the related costs are assessed in this chapter using the outputs from the analyses of the potential for CCS; estimated technology costs and various scenarios (discussed in sections 3, 4 and 5 respectively). The potential CO\textsubscript{2} emission reductions that may be achieved by CCS under the scenarios are compared against the projected national emissions reduction commitments. Finally, scenarios are highlighted where CCS can either contribute positively or is necessary to meet emissions reduction commitments.

6.1 SCENARIO ANALYSES

Various scenario studies are considered in Section 5 of this report. While the scenarios do not all specifically refer to CCS they all provide context for evaluating the technology and explore futures in which CCS could be evaluated for mitigating CO2 emissions. The international carbon price and South Africa’s GDP growth are identified as the two main drivers for the potential uptake of CCS.

The scenario study analysis identified six scenario options, summarised in Table 22. The underpinning assumptions of the scenarios are drawn from on the ranges identified in the reviewed studies. Each scenario is firstly denoted with an H (high), M (medium) or L (low) to indicate the assumed average GDP growth rate projection for the period (2017-2050) and then an H or L, to indicate the assumed carbon price projections.

Table 22: Scenarios for techno-economic analysis of CCS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>GDP Growth Rate in South Africa</th>
<th>Carbon Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. H:H</td>
<td>High (5.4%)</td>
<td>High (2010-2050: $10-$500)</td>
</tr>
<tr>
<td>2. M:H</td>
<td>Moderate (2.9%)</td>
<td>High (2010-2050: $10-$500)</td>
</tr>
<tr>
<td>3. L:H</td>
<td>Low (0.5%)</td>
<td>High (2010-2050: $10-$500)</td>
</tr>
<tr>
<td>4. H:L</td>
<td>High (5.4%)</td>
<td>Low (2020-2050: $20-$40)</td>
</tr>
<tr>
<td>5. M:L</td>
<td>Moderate (2.9%)</td>
<td>Low (2020-2050: $20-$40)</td>
</tr>
<tr>
<td>6. L:L</td>
<td>Low (0.5%)</td>
<td>Low (2020-2050: $20-$40)</td>
</tr>
</tbody>
</table>

6.1.1 Selected South African GDP Growth Rates

Extensive modelling studies have been completed which aim to explore or predict the future of South Africa’s economy. This study utilises three out of the four average annual growth rates published in the IRP Update Report (2013) in the interests of building on the extensive research undertaken by the Department.
of Energy with a view to mapping the country’s future resource pathways. For this study the growth rates for the secondary sector were adapted from the Green shoots (high growth), Weathering the storm (moderate growth) and Adrift in Troubled waters (low growth) scenarios of the IRP. The selected growth trajectories present a range of different pathways to model against different carbon pricing trajectories in order to establish the most economically feasible point for the implementation of CCS in particular sectors in South Africa.

6.1.2 Selected Carbon Price Trajectories

There is a wide range of scenario studies forecasting international carbon prices. The high carbon price forecasts were derived from McFarland et al (2006) (scenarios H:H; M:H; and L:H) and the low forecast was derived from Synapse Energy Economics (2016) (scenarios H:L; M:L and L:L).

This section focuses on international price projections as opposed to local carbon price forecasts because (as discussed in Section 5) it is widely anticipated that an international carbon market and price will emerge around 2030, to which South Africa will be aligned (European Climate Foundation, 2010; Department of Energy and Climate Change, 2011; Synapse Energy Economics, 2016). A summary of the full range of carbon price forecasts assessed in this report is presented in Figure 59. The prices are presented in 2015 US$/tCO₂ and are in real terms.

![Carbon Price Projections from Scenarios Studies](image-url)
While the range of projected carbon prices varies considerably, there is a consistent increasing trend across the selected scenarios, providing a high degree of confidence that prices are expected to rise dramatically from about 2025.

The figure above indicates that the ‘high-road’ carbon price could reach around US$ 170/\text{tCO}_2 by 2030. Conversely, the ‘low-road’ carbon price could sit around the US$ 20/\text{tCO}_2 by 2030, peaking around US$ 40/\text{tCO}_2 by 2050. The future carbon price trajectory may feasibly occur within this range although its progression may not necessarily be linear.

Depending on the carbon price trajectory, different CCS applications with difference costs may become economically viable at different points in time. For example, the timing and price at which CCS may be feasible for application on synthetic fuel applications will vary from the timing and price at which implementation may occur on blast furnaces. The following techno-economic analysis highlights the high level timing and price parameters, per selected technologies, in more detail.

### 6.1.3 Cost of CCS and the Carbon Price

The costs of various CCS applications have been summarised in Section 4.2 of this report. These costs have been converted to 2015 USD terms to make the comparison with the carbon prices. The technology options outlined in Figure 60 highlight those applications which may accommodate CCS installations (i.e. sites of suitable quantities of \text{CO}_2 emissions). The costs of CCS applications are fixed in real terms and are drawn from the IRP and other technical assessments (discussed previously in Section 4.2.2). An upper limit, lower limit and median slope of the international carbon price projections is also illustrated in Figure 60.

![Figure 60: Carbon prices and CCS costs for technology](imageURL)
It can be assumed that if the cost of applying CCS to an emitting technology is lower than the carbon price then the emitting entity will pursue CCS as an emissions mitigation and cost reduction option. From this assumption, Figure 60 illustrates that under different carbon prices trajectories different CCS applications become economically viable at different points in time. For example, the figure indicates that if the ‘upper limit’ international carbon price future were to transpire, then CCS application on the combined cycle gas turbine technology would become economically viable at a point where the carbon price reaches approximately US$ 130/tCO₂. The timeframe for the CCS application would be just prior to 2030. In fact the high carbon price trajectory would make the implementation of CCS economically viable for all technologies in South Africa prior to 2030 (the earliest expected implementation date). However, when considering the low carbon price trajectory, only synfuels technologies would take up CCS before 2050. Different carbon price trajectories between the high and low cases would similarly result in the uptake of CCS for different technologies, at different points in time, as the price exceeds the implementation costs.

6.1.4 Selected Scenarios

Scenarios 1 to 3 (H:H; M:H and L:H) have been selected for the analysis because an environment characterised by a high carbon price will likely support the deployment of CCS in South Africa. Based on this assertion, it is possible that even at low to moderate GDP growth rates the country’s economy may be suitable for CCS. In order to test the hypothesis, Scenarios 4 to 6 (H:L; M:L; and L:L) have been included. These scenarios consider the three growth trajectories with a low carbon price trajectory. The assumption is that high economic growth will result in high carbon emission volumes and therefore a greater necessity for mitigation activities like CCS.

6.2 Quantification of CCS Benefits under Scenarios

The above carbon pricing and cost analyses were subsequently extended in a more comprehensive cost benefit model. The aim of the extended model was to establish the contribution of CCS to monetary savings for South Africa’s emitters as well as the contribution of CCS to the national CO₂ emission reductions. The fundamental questions underpinning the modelling exercise are drawn from the risks analysed in Section 5 and 6.1 of this report, which consider the central questions of this study: how do the costs and benefits compare for investing in the development of CCS technology (to give the option for future implementation) vs. not investing in CCS development?

The risks are compounded due to the long term planning requirement of a CCS rollout, considering the rapid pace of technological innovations and the dynamic local and international environments which could be major, unforeseen disrupters in the future. The methodological approach to the cost benefit modelling is provided below, as are the results of the modelling exercise.

6.2.1 Methodological Approach

The largest emitting industries with potential to implement CCS technology were identified as electricity generation; iron and steel production; cement production and liquid fuels production (see Section 3). Different assumption were made about the potential of emitting sources within these industries to implement CCS. It was assumed that all facilities from the iron and steel, cement and liquid fuels industries...
were able to implement CCS technologies at the average cost of the specific technology application. For electricity generation, only the proposed new build facilities and those under construction were considered to feasibly take up CCS technologies.

The annual emissions from these electricity generation plants have been calculated utilising the emission factors per unit electricity generated, as stipulated in the IRP. The annual emissions from the cement, iron and steel and refining industries are similarly calculated from an emission factor multiplied by output. These emissions factors have similarly been derived from other techno-economic studies and annual reports of companies such as Sasol. While the electricity output of the selected plants is considered constant for the operational life, the output of the other industries is based on the projected sectoral growth rates defined in each scenario identified in this report.

For each scenario an emissions value and cost is calculated for each industry and year for two cases – the implementation and non-implementation of CCS. The difference between the total discounted cost for the two cases are then calculated for each scenario. Similarly for each scenario and case the emissions are summed over all industries and years. The differences in the total discounted cost between the two cases in each scenario illustrate the monetary and emissions saving (benefit) or loss (cost) of either implementing or not implementing CCS under the growth rate and carbon price defined by the scenarios.

6.2.2 Additional Assumptions

The real carbon price in 2015 Rand value is used in a high carbon price and low carbon price scenario projection up until 2050. The 2015 real Rand value cost of CCS per unit CO₂ abated is considered constant for the period for 2017-2050 (insufficient data are available to include cost reductions due the learning curve of CCS technology).

In addition, the model anticipates that the option to implement CCS can only be taken from 2030 onwards. It is assumed that if the cost to implement CCS post 2030 is less than the projected carbon price then an industry will take up CCS to its maximum capacity.

It is also assumed that there is no lead time before uptake, as it is expected that the development has taken place up until the point of implementation. The techno-economic analysis further assumes that the required infrastructure and regulatory environment will be ready for the rollout of CCS at the time at which the carbon price is high enough to substantiate the implementation (which will depend on the respective technology options).

Other technical assumptions include the values used in the modelling process for; discount rates, exchange rates, availability factors and percentages of capturable emissions. These are summarised below in Table 23.

Table 23: Summary of parameter assumptions in modelling process

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>USD exchange rate for 2015.</td>
<td>ZAR 13</td>
</tr>
<tr>
<td>Discount rate (Department of Energy, 2016a; Department of Energy, 2016b)</td>
<td>8.3%</td>
</tr>
</tbody>
</table>
Availability factor for pulverised coal and circulating fluidised bed combustion (Department of Energy, 2016a). 90%

Availability factor for combined cycle gas turbine (Department of Energy, 2016a). 48%

Capturable emissions from iron and steel, cement and liquid fuels production. 80%

6.2.3 Results of Cost Benefit Modelling

The modelling resulted in two outcomes:

1. The monetary difference (in Rand) between being able to implement CCS and not being able to implement CCS; and
2. The emissions difference (in tCO₂) between being able to implement CCS and not being able to implement CCS.

The results are modelled per scenario considered in this report and summarised in Table 24. As expected, it is shown that in the event that CCS is an option there are emissions savings. Similarly, it is shown that where CCS is an option (when its cost is below that of the carbon price) then there is a monetary saving to the emitters.

Table 24: Cumulative monetary and emissions savings with the option to implement CCS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cumulative discounted monetary savings for the period 2030 to 2050 (Billion 2017 Rands)</th>
<th>Cumulative emissions savings for the period 2030 to 2050 (Million tCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1 H:H</td>
<td>2 400</td>
<td>4 300</td>
</tr>
<tr>
<td>Scenario 2 M:H</td>
<td>1 800</td>
<td>3 400</td>
</tr>
<tr>
<td>Scenario 3 L:H</td>
<td>1 700</td>
<td>3 100</td>
</tr>
<tr>
<td>Scenario 4 H:L</td>
<td>8</td>
<td>1 400</td>
</tr>
<tr>
<td>Scenario 5 M:L</td>
<td>6</td>
<td>1 000</td>
</tr>
<tr>
<td>Scenario 6 L:L</td>
<td>5</td>
<td>800</td>
</tr>
</tbody>
</table>

In the high carbon price scenarios it is economically viable for all industries to implement CCS at the earliest possible point (2030) and therefore significantly reduce emissions and save costs below the carbon price. In the low carbon price scenarios it is only the liquid fuels industry that can take advantage of CCS as an economically viable abatement technology. While this does occur in 2030, the relatively small difference in the carbon price results in a much smaller monetary saving. Similarly the emissions savings are proportionally reduced based on the size of the industry in relation to the unabated emissions sources.

It is important to consider these potential emissions and monetary savings against the costs of developing CCS technology to a stage where it can be implemented, if economically viable. It is these comparisons of
investment and ‘return’ that underpin the risks associated with developing or not developing CCS technologies in South Africa. The decisions pathways and outcomes are represented in Figure 61.

From the cost analyses Section 4.2 it was determined that the investment in the development of CCS technology would be in the region of 10s of billions of Rand. The low carbon price scenarios, where the accumulated monetary saving up to 2050 is between R 4.76 – R 8.27 billion, therefore appear to present no material monetary benefit above the investment in the development of CCS technology. However, as the monetary saving in the low carbon price scenario is not greatly lower than the investment in development, there is thus little risk associated with investing. Conversely, under the high carbon price scenario the potential monetary saving is orders of magnitude larger than the investment in CCS development (trillions of Rand). Thus, there is a large opportunity to benefit from developing CCS technologies in South Africa and also a large risk of missed opportunities if not developed.

Figure 61: Decision pathways and outcomes for the investment in the development of CCS

It is important to emphasise that the emissions and monetary saving achieved are not solely a result of the investment in the development of CCS. Significant costs are incurred in the implementation of CCS. The discounted CCS implementation expenses are in the region of R 91 to R 128 billion in the high carbon price scenarios and R41 to R63 billion in the low carbon price scenarios. The implementation cost ranges are a product of the different growth trajectories. The higher growth scenarios result in greater product output.
and therefore larger volumes of emissions to capture and store. Hence the larger accumulated discounted costs.

6.2.4 Contribution to National CO₂ Reductions

CCS may make a significant contribution to national GHG emissions reductions. South Africa has committed to a peak plateau and decline trajectory. The commitment is to peak emissions below 614 MtCO₂e per annum by 2025 then plateau at this level until 2035, where after emissions must decrease to between 212 and 428 MtCO₂e per annum. This ranged trajectory is illustrated in Figure 62 and Figure 63 which respectively reflect the economic growth scenarios (high, medium and low) wherein CCS is not implemented and alternatively where CCS is implemented.

Figure 62 illustrates scenarios where CCS is not applied to the projected emission sources in the national GHG inventory, which are considered (in this study) to be mitigatable through CCS. Conversely, Figure 63 considers the projected contribution of the same emissions sources to the national GHG inventory, if all these emissions are abated from 2030 through the application of CCS (which could feasibly occur in the high carbon price scenarios). The emissions projections for the high, medium and low growth rates without CCS are shown in Figure 62 and the emissions with CCS are shown in Figure 63.

![Figure 62: South Africa’s PPD emissions trajectory and projections of emissions from sources with CCS potential but where no CCS is implemented](image-url)
Figure 63: South Africa’s PPD emissions trajectory and projections of emissions from sources where CCS has been implemented.

It can be seen in Figure 62, if the considered emissions sources grow at their modelled rates of output they will account for a significant proportion of the projected national inventory. In the modelled scenario where CCS is not implemented (Figure 62), the sources of emissions in the high and moderate growth) and close to (low growth) the lower bound of the peak plateau trajectory in 2050. In addition, the emissions under the low growth trajectory are expected to come close to the lower bound of the peak, plateau and decline trajectory by 2050 as well.

The unmitigated emissions in Figure 62 would also account for between 42% - 63% of the upper bound of the inventory trajectory in 2050. This is a significant proportion of the inventory considering that a number of other large emissions sources are not included in this analysis. These include transport sector emissions; other process emissions sources that are not suitable for carbon capture; and agriculture, forestry and other land use. It is unlikely that these emissions sources will fit into the remaining budget of the PPD. Therefore, if the economy grows and production increases in industries with unavoidable process emissions (cement, liquid fuels and iron and steel) then mitigation in the form of CCS will be necessary to budget for other emissions sources and meet the requirements of the PDD.

The emissions trajectories for the considered sources with CCS implemented in 2030 is illustrated in Figure 63 (as in the case of the high carbon price). In this case the emissions in 2050 would account for between 8%-12% of upper bound and 15% - 24% lower bound of the PDD. This leaves a significant proportion of budget to be made up by sources that are not relevant to CCS.

It is also important to note that even under the scenarios of a high carbon price and large amounts of CO₂ being captured there is sufficient storage potential in the county’s basins. As discussed in Section 3.4, the large Orange Basin and Durban & Zululand Basin can accommodate more than 6 000 MtCO₂ storage over the 20 year period, depending on the permeability assumptions and well injection rates.
6.3 CONCLUSIONS

It has been demonstrated that the carbon price plays a significant role in the uptake of CCS technologies in South Africa. High carbon price scenarios may see many industries implement CCS as the carbon price exceeds the cost of implementation. Low carbon price scenarios may only offer this opportunity to selected industries where the cost of CCS implementation is relatively low, such as liquid fuels production.

Scenarios have been analysed for a range of growth rate and carbon price trajectories. It is possible that these two parameters could emerge anywhere within the spectrum of their domains as shown by the diverse perceptions of the scenario studies considered. As such the results presented in this report represent the extreme cases of benefit and loss of investing in the development of CCS technology in South Africa.

South Africa stands to gain a large amount in terms of emissions and monetary savings. South Africa would risk forfeiting these large potential gains in the event that the country does not invest in the development of CCS technologies. Under low carbon price trajectories, only the liquid fuels industry stands to gain from the investment in CCS technologies and its gains would be relatively small compared to the investment in the development and implementation of CCS. Similarly the emissions reductions would be substantially smaller than those achieved under a high carbon price.

CCS is the only option for a number of industries with unavoidable process emissions, such as the cement and iron and steel sectors, to reduce their emissions in order to meet the requirements of the peak, plateau and decline trajectory (other than reducing production, which would negatively affect GDP growth). Substantial CCS uptake and significant emissions reductions are expected under the high carbon price scenarios substantial CCS uptake is expected and emissions are reduced significantly, providing room in the peak, plateau and decline budget for other sources of GHG emissions.

Industries may be significantly less inclined to take up CCS under the low carbon price scenarios. In such a future, the country will not meet its commitments to the PPD will not be met. This may have other repercussions for international commitments, which could affect the country's international bargaining powers and competitiveness.

If CCS is deemed essential to meeting the PPD because of growth scenarios, the technology will need to be supported through policies and measures in addition to the carbon. The measures will need to be cognisant of the costs of CCS development and implementation within the different industries. Regulation of CCS for each industry will need to be timed appropriately with the emerging carbon price to be economically efficient.

As such the decision to continue investment in the development of CCS needs to consider both the trajectory of the carbon price and the growth of industries with unavoidable process emissions. It is recommended that the decision to continue investment in CCS development be a phased approach as each phase of development incurs costs that are orders of magnitude larger than the previous phase. As each phase is completed more information will be available on the trends and possible trajectories of the carbon price and growth in the country. This will inform whether the investment in CCS development should continue.
At this stage there is sufficient evidence to suggest that CCS development should continue to the next phase of piloting a test injection of CO₂. The business case for CCS technologies in South Africa should be reassessed to determine whether further investment in a demonstration injection should be conducted.
7 RISK ANALYSIS AND MANAGEMENT

This section explores the risks associated with implementing or not implementing CCS. The risks are discussed in terms of the technical, economic, social and political challenges that may arise. Risk management options are subsequently discussed with regards to the methods to deal with the identified risks.

7.1 CONTEXT FOR OR AGAINST CCS IMPLEMENTATION

The requirement for CCS in South Africa is particularly relevant within the context of the Paris Agreement, which seeks to keep average global temperatures well below the 2°C mark. Considering the raised levels of ambition, CCS is a key measure that has potential to substantially reduce carbon emissions without disrupting the production outputs of various key sectors in South Africa such as coal-fired electricity generation and activities in the cement, iron and steel and liquid fuels sectors (assessed in section 3 of this report) in the period 2030 to 2050. These sectors are labour intensive, providing employment opportunities for a considerable portion of South Africa’s workforce, making protection of these sectors a priority for the country during the transition to carbon neutral alternatives. The double benefit of CCS in this regard makes it a particularly attractive mitigation technology.

The costs associated with developing and operating CCS facilities are however significant barriers to the roll out of CCS and provide a strong counter-argument against plans for implementation. While the costs of developing and rolling out CCS technologies have been quantified, the costs associated with not developing or implementing CCS are much more subjective and difficult to determine. Furthermore, it is possible that by 2030 (the envisaged, approximate date for the implementation of CCS), the need for the emission mitigation technologies will have been reduced due to, for example, radical technological innovations or a change in policy direction.

It is equally possible that by 2030 the pressures to mitigate emissions will be stronger than ever. In such circumstances, South Africa will need to be prepared to meet its mitigation commitments and goals, considering the environmental and geopolitical risks which would result from lethargic action.

The context for the implementation of CCS in South Africa is therefore considered from two perspectives: “with CCS” or “without CCS”. The risks associated with these two pathways are identified in the following subsection.
### 7.2 RISK IDENTIFICATION: “WITH CCS” AND “WITHOUT CCS”

The levels of risks and opportunities vary depending on whether the risk event falls under the “with CCS” context or the “without CCS” context. The PESTEL (Political, Economic, Social, Technological, Environmental and Legal) risk analysis in Table 25 considers these potential pathways.

#### Table 25: Identified Risks under the “With CCS” and “Without CCS” Contexts

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Risks Associated “With CCS”</th>
<th>Risks Associated “Without CCS”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Political International: climate commitment risks</td>
<td>Not likely</td>
<td>• Unabated emission levels could harm South Africa’s competitiveness and affect international and regional negotiations</td>
</tr>
</tbody>
</table>
| 2. Political Domestic | • Competing needs for limited finances  
• Negative impacts on economy | • Energy security  
• High penalties for non-compliance with emission regulation  
• Stranded assets  
• Negative impacts on economy |
| 3. Economic | • High capital and operational costs  
• Limited financial resources  
• Low carbon prices  
• Structural changes in the economy (decline in energy intensity could reduce demand for CCS) | • High penalties for non-compliance with emission regulation  
• Stranded assets  
• Negative impacts on economy |
| 4. Social | • Societal acceptance of CCS  
• Civil protests and unrest | • Relocation of communities to adapt to climate change  
• Civil protests and unrest |
| 5. Technological | • Retrofitting requirements  
• Long lead times for equipment  
• Competition with other emission mitigation technologies | Not likely |
### Risk Category  Risks Associated “With CCS”  Risks Associated “Without CCS”

<table>
<thead>
<tr>
<th>6. Environmental: climate change</th>
<th>• While emission risks are reduced due to mitigation activities, there is a possibility of impacts on water use</th>
<th>• Physical climate change impacts (droughts, floods, spread of pests and diseases) create health and safety risks • Economic consequences e.g. damage to infrastructure, property and goods and the disruption of commercial activities • Physical and economic risks lead to social and development risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Legal and Regulatory</td>
<td>• Onerous requirements cause higher reporting and operating costs; some industries may close • Delays in finalisation of the regulations</td>
<td>Not likely</td>
</tr>
</tbody>
</table>

### 7.3 PESTEL Analysis

The risks identified above are interrogated using the perspective of the various scenario analyses undertaken in Chapter 5 of this report as well as other literature sources. Risk analysis provides for the final evaluation and prioritisation of said risks.

#### 7.3.1 Political International: Climate Commitments

South Africa, a party to the Kyoto Protocol and the recent landmark Paris Agreement, has communicated its climate change commitments in its Intended Nationally Determined Contribution (INDC), which is required to increase in ambition by the next submission date in 2020. Unabated emission levels could harm South Africa’s competitiveness should international markets prioritise the purchase of lower-carbon goods and services over those that have comparatively high associated levels of GHG emissions.

The Paris Agreement provides a framework for stronger climate action which will increase the need for CCS. The 450 ppm scenario in the International Energy Agency’s latest *World Outlook Report: 2016* notes that the transformation required for a reasonable chance of remaining within the temperature goal of 1.5 °C is stark. It would require net-zero emissions at some point between 2040 and 2060 (even if negative emissions technologies can be deployed at scale), requiring radical near-term reductions in energy sector CO₂ emissions, employing every known technological, societal and regulatory decarbonisation option.

The International Energy Agency further considers CCS as a central component to a 2°C pathway and refers to the technology as the potential “sleeping giant” that needs to be awakened to respond to the increased ambition of the agreement (IEA, 2016b). CCS is recognised for its contribution, internationally, to the least-cost portfolio for power and is an essential mitigation solution in industry (at a Carbon price of $140/t in 2040). These benefits could be replicated at a local level in South Africa.
The rollout of CCS could therefore support South Africa in meeting the country’s climate change commitments, which will increase in ambition in 2020. This could assist to position South Africa favourably in terms of international and geopolitical relations.

7.3.2 Political Domestic

Energy security is a major domestic and political risk. The majority of electricity in South Africa is generated from coal-fired power stations which are recognised as heavy emitters of GHGs and other emissions contributing to atmospheric pollution. Considering that South Africa’s energy trajectory is likely to be dominated by continued coal use, the rollout of CCS could mitigate risks associated with emissions and pollution, while supporting electricity generation efforts required to meet the nation’s commercial and development needs.

Sustainable economic activities underpin the country’s development and growth. Various national policies and regulations, such as the proposed carbon tax and other climate/ environmental regulations, therefore motivate for increasing levels of GHG emission abatement, which are supported by punitive measures related to non-compliance. These measures may pose risks to energy and electricity generators who use hydrocarbon feedstocks, and who may consider closing or moving their operations if the costs of fuel switching or mitigating emissions outweigh their operating margins. These generators are typically in the electricity and manufacturing sectors, which underpin the country’s economy. The export or closure of these types of economic activities could have negative impacts on society as a whole.

Economic and social development are national priorities. As a new technology, the rollout of CCS may be objected to by members of society especially with regards to the outlaying of state finances, which action groups may wish to prioritise for deployment in other areas of society. If traction in this regard is significant, it could delay or prevent the implementation of CCS. The risks associated with real or perceived non-delivery of development needs include civil protests and unrest which can disrupt levels of economic productivity, cause damage to private/public property and at worst, result in loss of life.

The rollout of CCS may assist in South Africa’s economic and social development by mitigating risks associated with sustaining employment opportunities in the coal mining and manufacturing sector over the next thirty to forty years.

7.3.3 Economic

Poor growth in the economy could be a barrier to the successful development and implementation of CCS because estimated capital and infrastructure costs associated with the technology are high and implementation of new capacity would be low. Furthermore, the need for CCS is related to the country’s energy intensity. Changes in the structure of the economy (which continue the trending decline in energy intensity) could therefore reduce the requirement for CCS.

The economic risks associated with the development and deployment of CCS are related to the technology costs. These are more certain than the market risks associated with price for carbon in the case where CCS is not implemented. New research is however beginning to consider the economic risks of delaying or not implementing CCS at all. One such study is the Risky Business Project, which examines the economic risks
presented by climate change and opportunities to reduce them in the American economy. In the 2016 report titled *From Risk to Return: Investing in a Clean Energy Economy*, four pathways were developed using a sophisticated energy, economic and infrastructure planning model that compares scenarios, illustrated in Figure 64. Each pathway would achieve an 80% reduction in carbon emissions by 2050:

![Figure 64: Risky Business Clean Energy Scenarios (Risky Business, 2016)](image)

A transition to low- and zero-carbon electricity generation sources and away from fossil fuels is considered to be one of the three key pillars in the model. The Risky Business findings may conceivably be applied to South Africa, as the country is committed to moving to a lower-carbon economy. Government has prioritised a number of mitigations policies and measures, many of which are aligned with the three pillars identified in the Risky Business report. These include the development of electric vehicles through the Department of Trade and Industry’s *Electric Vehicle Industry Road Map*; the Renewable Energy Independent Power Producers Procurement Programme and the *National Energy Efficiency Strategy*.

The Risky Business model is not a macro-economic model that explicitly forecasts GDP and employment. However, additional economic studies that utilise data from the Mixed Resources pathway (which makes provision for CCS) indicate slight improvements in US GDP (between 0.4% - 0.6%) in both 2030 and 2050, compared to the current baseline (high carbon pathway). The key message is that a major substitution of the fossil fuels used to generate electricity (and hence the diversion of capital and investment to these new lower carbon activities) would have a small but positive effect on American GDP and employment.

While not definitive or perfectly applicable to our local context, these findings lend their support to the business case for CCS in South Africa as they are aligned with the aim of mitigating emissions while
simultaneously improving employment opportunities and the country’s economic outlook. Specifically, the Risky Business scenarios highlight the link between economic growth and social transformation – both of which may be feasibly achieved in South Africa through the promotion of clean energy economies.

The focus on South Africa’s green economy is particularly relevant in the context of a future without the implementation CCS, where high penalties relating to emissions may result in the closure of emissions intensive activities. The World Energy Council (2016) asserts that more stringent regulatory requirements for a low-carbon future will force companies everywhere to make significant changes in their business models or face collapse. In the case of the local coal sector, this could result in stranded assets. The World Energy Council further cautions that stranded private assets could quickly become stranded public resources, i.e. the responsibility of states, which could cause significant stresses in current geopolitical and economic power balances.

The South African Coal Roadmap highlights the overwhelming dominance of mining jobs in determining the overall employment profile for the coal value chain (Fossil Fuel Foundation, 2011). Almost 35 000 more jobs are created by 2040 in the coal dominant Lags Behind scenario in the Roadmap, compared to those created by the Low Carbon World scenario. In addition, a vast array of material and service inputs supporting the coal value chain would no longer be required in the case where coal production reduces, posing further risks to the country’s economic capacity. One of the major benefits of CCS is that it has the ability to mitigate emissions while also conserving the value chain required to generate energy from coal sources. In particular, CCS could present a compliance opportunity for GHG emitters that have limited mitigation options, by aiding compliance with regulations and continuing operations if financially viable.

The price of carbon will play a definitive role in the economic feasibility assessment of CCS in South Africa. The price levels are important because adequate prices will motivate technology shifts away from the status quo (typically fossil fuel intensive technologies) to cleaner measures or activities. This type of information, in conjunction with insights into the timeframe in which price changes are expected to occur, is crucial for policymakers as well as businesses that wish to be prepared for changing landscapes, so that the appropriate resources and capital may be allocated accordingly. There is growing recognition of the importance of an adequate carbon price to drive technology shifts in order to meet the objectives of the Paris Agreement (specifically limiting global temperature increases to well below 2°C). The World Energy Council in particular notes that very high carbon prices are required to achieve the goals.

Clarity is required regarding which South African sector/s of society should bear the responsibility for the cost of developing and implementing CCS. The state in particular has many competing demands for finite resources such as finances, where the short term development needs of the country (such as economic stimulus and improvements to the health care and education sectors) could delay investments in CCS which could be considered as a longer-term development requirement.

### 7.3.4 Social

There is increasing recognition of the pivotal role played by that societal support (or lack thereof) in the success of both state and private business activities. The King IV Report (2016) is a notable example which recognises that companies operate in the triple context of economy, society and the environment. The
manner in which organisations make revenues impacts these three elements, and in turn they impact organisations.

Societal acceptance of CCS is therefore a key component underlying the successful rollout of the technology. The social risks that CCS implementation may face include public perceptions that while effective in mitigating emissions, CCS does not address ‘dirty’ energy sources – the root cause of emissions in South Africa. There are also concerns that the storage component of the CCS may be fallible, and that leaks could arise which could jeopardise the entire value chain.

The main risks pertaining to non- or delayed implementation of CCS are climate related – floods, droughts, crop failures and more. The impacts of these risks could be physical, for example health and safety issues; damage to infrastructure; crops and more. These risks have further economic implications, which could extend to the relocation of whole communities as adaptation responses or in reaction to those impacts that have occurred. It is well recognised that pre-emptive (adaptive) climate measures are more economical and result in higher levels of co-benefits that reactive measures, undertaken after the fact.

7.3.5 Technological

As a new technology in South Africa, the implementation of CCS will require significant planning and investment in the required infrastructure. The various components of the CCS value chain (capture, transportation and storage) will have diverse needs. In particular, retrofitting requirements required at the capture stage may be complex considering the different sources of CO₂ in the country. Furthermore there may be long lead times for the required equipment, considering that the demand for these pieces may be low and they may originate in other territories.

Another technology risk is competition with other emission mitigation technologies, particularly in the electricity generation industry where renewable energy technologies have had steep learning curves. South Africa is currently considering a range of measures in this regard including a nuclear new-build plan and increased energy generation from renewable sources which use gas as a baseload. CCS may need to compete on a cost-benefit basis in order to be selected as a preferred or complementary technology.

7.3.6 Environmental: Climate Change

CCS has fresh water requirements, particularly at the capture stage, which could result in water supply risks considering that South Africa is a water scarce country. The different locations of potential CCS sources and storage areas are illustrated in Figure 65.
The potential storage areas are located in typically water scarce provinces i.e. Mpumalanga (electricity generation); Free State and Western Cape (steels and synthetic fuels) as well as the North West Province (cement). The risks of related to CCS impacts on water supply and quality will need to be considered further.

The local environmental risks associated “without CCS” relate to unabated carbon emissions (the major GHG emitted by South Africa) which result in climate change. The range of climate change impacts extends to physical, economic and social risks. In South Africa specifically, physical climate change events include droughts, floods, as well as the spread of pests and diseases. These physical impacts have economic consequences which range from health and safety risks to damage to infrastructure, property and goods and the disruption of commercial activities, among others. These in turn affect people’s livelihoods, which hampers efforts aimed at economic and social development. In South Africa and other developing countries around the world, poorer communities are typically worst affected by climate change because these communities often lack the resources to protect themselves from climate events or to adapt to these occurrences. Within these communities it is the more vulnerable members (such as women, children, the elderly or disabled) who suffer disproportionately compared to other members.

While it is unlikely that all of the carbon emissions from CCS-eligible sources will be mitigated by the rollout of CCS, the application of the technology has significant emission mitigation potential which supports efforts to limit average global temperatures to below 2°C (using levels prior to the industrial revolution as benchmarks). In particular, while there are some emissions in industrial processes which can be reduced through energy efficiency and switching to low-carbon heat and electricity generation, CCS is one of the only options available to address the bulk of emissions generated from chemical reactions inherent in the process of iron, steel and cement production. The mitigation of these emissions through their long term storage could make a material contribution to South Africa’s efforts to respond to climate change. Improving South Africa’s economy and general resilience to climate change is imperative for the country’s
economic and social development because the impacts of climate change often widen inequality gaps by unduly affecting the more vulnerable members of society who may need to be supported by government.

Adequate responses to climate change are further critical for South Africa because the cost of adaptation activities is typically proportionate to the climate change risk. The mitigation of carbon emissions (the main GHG emitted in the country) will reduce climate change impacts which will in turn reduce adaptation costs. While this principle applies on a global scale, it is the collective and scalable mitigation actions (such as CCS), implemented in the short term, that will facilitate reductions in adaptation risks and costs in the long term.

### 7.3.7 Legal and Regulatory

The regulation of CO₂ capture projects will likely be embedded in the permitting processes for the relevant emitting activities. Regulations may extend to environmental impacts, occupational health and safety, and, possibly, emissions controls and reporting. Pipelines for transporting CO₂ could also be subject to land permits and environmental controls similar to other pipeline projects. Many aspects of CO₂ storage are similar to other subsurface operations in the oil and gas industry and therefore regulation often builds on existing oil and gas legislation.

These regulations may need to be revised where they currently exist to accommodate aspects of the CCS value chain, or they may need to be developed as new pieces of legislation or regulations specifically related to the CCS activity. The long lead times in finalising regulations could pose a risk to the implementation of CCS in the country, and would also require the support of interested and affected parties.

These risks and the others discussed above are evaluated in the following section.

### 7.4 High Level Evaluation of Risks

The risks considered in the previous subsection are evaluated in Table 26 based on the probability of the risk occurring and the impact if it occurs, as per the “With CCS” and the “Without CCS” contexts.

#### Table 26: Evaluation of Risks

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Likelihood</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Remote</td>
<td>Highly Unlikely</td>
<td>Unlikely</td>
<td>Possible</td>
<td>Likely</td>
<td>Highly Likely</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Catastrophic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Massive</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

“Without”: Climate Change Risk

“With”: Political Domestic Risk

“Without”: Political Risk

“With”: Economic Risk
Nearly half (six out of fourteen) of the risks assessed fall into the critical areas, where just under a quarter of all the risks are categorised as high risks. These risks must be considered further and managed accordingly.

### 7.5 Risk Management

Following on from the identification and evaluation of the risks pertaining to the two contexts under investigation (“with CCS” and “Without CCS”), the final step in this process is an assessment of the best ways in which to effectively manage the risks in question. The typical options are illustrated in Figure 66.
The risk management options for both contexts ("With CCS" and "Without CCS") are considered in Table 27, within the context of their respective high level evaluation ratings established in the section above.

Table 27: Risk Management Options for “With CCS” and “Without CCS” Contexts

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1. Political International:</td>
<td>The risks of competing needs for limited finances may be shared with various parties, as well</td>
<td>The risks to South Africa’s competitiveness and standing in international negotiations may be</td>
</tr>
<tr>
<td>Climate Commitment</td>
<td>as lending institutions</td>
<td>avoided if the country takes the required steps to meet its climate commitments.</td>
</tr>
<tr>
<td></td>
<td>• The risks of low carbon prices and structural changes in the economy can only be accepted</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and planned for</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The risks of societal acceptance of CCS, negative impacts on the economy and civil protests</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and unrest can be shared with different CCS stakeholders, or may be avoided through</td>
<td></td>
</tr>
<tr>
<td></td>
<td>engagement and consultation</td>
<td></td>
</tr>
<tr>
<td>2. Political Domestic</td>
<td>The risks of limited financial resources and high costs may be shared between the state and</td>
<td>• Risks of energy security and non-compliance with emission regulations can be avoided by</td>
</tr>
<tr>
<td></td>
<td>private entities, as well as equity and debut funders</td>
<td>developing clean and or renewable energy measures, and providing input into the development of</td>
</tr>
<tr>
<td></td>
<td>• The risks of low carbon prices and structural changes in the economy can only be accepted</td>
<td>regulations</td>
</tr>
<tr>
<td></td>
<td>and planned for</td>
<td>• Risks of stranded assets and negative impacts on economy can be avoided through influencing</td>
</tr>
<tr>
<td></td>
<td>• The risks of societal acceptance of CCS, negative impacts on the economy and civil protests</td>
<td>policy and mobilising support for the affected sector. Alternatively the risk must be accepted</td>
</tr>
<tr>
<td></td>
<td>and unrest can be shared with different CCS stakeholders, or may be avoided through</td>
<td>and planned for</td>
</tr>
<tr>
<td></td>
<td>engagement and consultation</td>
<td></td>
</tr>
<tr>
<td>3. Economic</td>
<td>The risks of regulatory non-compliance can be avoided through adequate input in the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>development of the regulations and through controls and measures during operations.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Similarly, risks of stranded assets and negative impacts on economy can be avoided through</td>
<td></td>
</tr>
<tr>
<td></td>
<td>policy and mobilising support for the affected sector. Alternatively the risk must be</td>
<td></td>
</tr>
<tr>
<td></td>
<td>accepted and planned for</td>
<td></td>
</tr>
<tr>
<td>4. Social</td>
<td>The risks of societal acceptance of CCS, negative impacts on the economy and civil protests</td>
<td>The risks of societal acceptance of CCS, negative impacts on the economy and civil protests and</td>
</tr>
<tr>
<td></td>
<td>and unrest can be shared with different CCS stakeholders, or may be avoided through</td>
<td>unrest can be shared with different CCS stakeholders, or may be avoided through engagement and</td>
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<tr>
<td></td>
<td>engagement and consultation</td>
<td>consultation</td>
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<tr>
<td>5. Technological</td>
<td>• Retrofitting and long equipment lead time risks can be avoided through adequate planning</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>• Own CCS technologies could be developed locally</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Risks of competing emission mitigation technologies may be accepted and planned for</td>
<td></td>
</tr>
<tr>
<td>6. Environmental:</td>
<td>The physical, economic and social risks associated with climate change may be avoided and/or accepted. With regards to the former, scaled-up emission mitigation measures may be undertaken. With regards to the latter, scaled up adaptation measures may be undertaken following in depth impact analyses and the development of appropriate contingency plans. The risks associated with the use of fresh water during the capture stage will also need to be accepted and planned for.</td>
<td>The physical, economic and social risks associated with climate change may be avoided and/or accepted. With regards to the former, scaled-up emission mitigation measures may be undertaken. With regards to the latter, scaled up adaptation measures may be undertaken following in depth impact analyses and the development of appropriate contingency plans.</td>
</tr>
<tr>
<td>Climate Change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Legal and Regulatory</td>
<td>• The risks of delays in finalisation of the legislation and regulations and onerous requirements that threaten continued operations can be avoided through actively participating in the development of the regulations. These risks may also need to be accepted and planned for.</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Legend:
- Low risk
- Medium risk
- High risk
- Critical risk

The risk management options discussed above are intended to prompt discussions and initiate further interrogations.

### 7.6 KEY THEMES FROM THE RISKS ASSESSMENT

The development of CCS in South Africa is nearing a juncture point. Far reaching decisions will need to be made in the near future to determine whether further resources should be invested in the rollout of the technology or whether development activities should be halted in favour of other emission mitigation alternatives or national priorities.

There are different levels of risks, impacts and probabilities associated with each option (“with CCS” or “without CCS”), making evaluation a complex endeavour. Furthermore, the timeframe for CCS
implementation is another challenge, where decisions that are made in the present context may not hold true at the time that CCS is expected to be ready for rollout (around 2030), such as an international carbon price that is high enough to incentivise CCS.

What we can deduct from the evaluation above however, is that the economic and domestic risks are categorised as critical for both the “with CCS” or “without CCS” contexts. In the “without CCS” context non-compliance with emission regulations is a reoccurring risk both at a local and international level. At their most extreme levels, non-compliance risks could result in the closure of affected industries such as coal, cement, iron and steel and liquid fuels. This could lead to energy insecurity, stranded assets and significant job losses. These risks may either be avoided or accepted.

In the “with CCS” context the risks of limited financial resources and high capital and operational costs dominate. Given South Africa’s development needs, CCS may not be considered a priority investment by members of the state and public. Carbon pricing is one of the major drivers of these risks. An adequate carbon price will facilitate the shift in technology where CCS could be a preferred option on account of its ability to sustain coal and other industries during a transition period. The knowledge regarding what carbon price is adequate and when this price will occur is at the heart of this conundrum.
8 CONCLUSION

This report analysed the business case for continued investment in carbon capture and storage in South Africa. The timeframes considered cover an investment and development period between 2017 and 2030, followed by an operational period from 2030 to 2050. The study found that economic structure, growth rate and carbon price are the key drivers of the viability of CCS.

The study identified priority areas and industries where CCS would be most viable. These include the liquid fuels industry (refineries and gas to liquids) and industries which have little other options than to use CCS due to their inherent process emissions.

The investment in the development of CCS technology would be in the region of 10s of billions of Rand. The low carbon price scenarios, where the discounted monetary saving up to 2050 is between R 4.76 – R 8.27 billion, therefore appear to present no material monetary benefit above the investment in the development of CCS technology. However, the monetary saving in the low carbon price scenario is not greatly lower than the investment in development. There is thus little risk associated with investing. Conversely, under the high carbon price scenario the potential monetary saving is orders of magnitude larger than the investment in CCS development (trillions of Rand). Thus, there is a large opportunity to benefit from developing CCS technologies in South Africa and also a large risk of missed opportunities if not developed.

Costs are uncertain but research and demonstration projects provide information which is used for analysis. The uncertainty of the future price of carbon represents a much larger risk and needs to be monitored regularly and from a variety of different perspectives.

The risk of missed opportunities due to high carbon prices in the future, as a result of not investing into research and development of CCS up to 2030, are orders of magnitude larger than the cost of investing now.

The analyses presented demonstrate that the carbon price can play a significant role in the uptake of CCS technologies in South Africa. High carbon price scenarios may see many industries implement CCS where the carbon price exceeds the cost of implementing CCS. Low carbon price scenarios may only offer this opportunity to selected industries where the cost of CCS implementation is relatively low, such as liquid fuels production.

South Africa stands to gain a large benefits amount in terms of emissions and monetary savings in a future characterised by high carbon prices. South Africa could however risk forfeiting these large potential gains should the country not invest in the development of CCS technologies. The timing of such investments is key, considering the long lead times associated with the development of the regulatory environment and subsequent infrastructure expansion programmes. Under low carbon price trajectories economic gains would be relatively small compared to the investment in the development and implementation of CCS. Similarly, the emissions reductions would be substantially smaller than those achieved under a high carbon price.
CCS is the only option for a number of industries with unavoidable process emissions, such as the cement and iron and steel sectors, to reduce their emissions in order to meet the requirements of the Peak, Plateau and Decline trajectory (other than reducing production, which would negatively affect GDP growth). Substantial CCS uptake and significant emissions reductions are expected under the high carbon price scenarios, providing room in the Peak, Plateau and Decline budget for other sources of GHG emissions.

Industries may be significantly less inclined to take up CCS under the low carbon price scenarios. In such a future, the country will not meet its commitments to the current Peak, Plateau and Decline trajectory. This failure may have subsequent repercussions related to other international commitments, which could affect the country’s international bargaining powers and competitiveness.

If, as this report concludes, CCS is deemed essential to meeting the Peak, Plateau and Decline trajectory under high growth scenarios, the technology will need to be supported through policies and measures in addition to being driven by a high price on carbon. The measures will need to be cognisant of the costs of CCS development and implementation within the different industries. Regulation of CCS for each industry will need to be timed appropriately with the emerging carbon price to be economically efficient.

In conclusion, the decision to continue investment in the development of CCS needs to consider both the trajectory of the carbon price and the growth of industries with unavoidable process emissions. It is recommended that the decision to continue investment in CCS development be a phased approach as each phase of development inures costs that are orders of magnitude larger than the previous phase. As each phase is completed more information will be available on the trends and possible trajectories of the carbon price and growth in the country. This will inform whether the investment in CCS development should continue.

At this stage there is sufficient evidence to suggest that CCS development should continue to the next phase of piloting a test injection of CO2. The business case for CCS technologies in South Africa should be reassessed on the culmination of the test injection to determine whether further investment in a demonstration injection should be conducted.
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