sanedi

South African National Energy Development Institute

ROADMAP TOWARDS **CLEANER FOSSIL FUELS** IN SOUTH AFRICA PHASE 1

Coal Oil and Gas Decarbonisation Technology and Strategies

eTP

DISCLAIMER

Phase 1 of the study serves to describe all fossil fuel technologies that could play a role is the transition pathways to a lower GHG emissions environment. Technical performance and relative costs for each are considered at a high level, together with advantages and disadvantages for SA and highlighting key supporting factors and/or constraints for a successful execution of the technology.

Although the study proposes preferred technologies for specific fossil fuel value chains, power capacity planning is not part of the scope of this study. Rather, it serves as input for further analysis in subsequent study phases and to aid in the decision making process.

The report will be distributed to government departments and other stakeholders for review and based on their analysis and feedback, the scope of Phase 2 work will be finalised and executed.

EXECUTIVE SUMMARY

It is often said that energy is the lifeblood of an economy, that it is a key enabler that supports the economic activities of the country; however, although very important, it remains a means to an end.

The major contributors providing energy to the economy are the power (electricity), oil and gas industries. These industry sectors each utilise particular technologies generating electricity or producing products for the market. The development of new technologies and the needs of the market are constantly changing and accelerating. Technology lifecycles become shorter and what is effective and efficient today may be obsolete by tomorrow.

The world is in transition on many levels and energy is part thereof. The focus on climate change is driving key energy decisions internationally and, as always, there are trade-offs to be made in our choice of energy. This therefore creates an opportunity to reflect on the future that we envisage and finding the road to get there.

We are thus faced with trade-offs regarding to what we prepared to forgo now for a better outcome in the future.

To facilitate these choices, this study was initiated to provide valuable insight, mainly into the available technologies for the more effective and efficient generation of power and addressing the Green House Gas (GHG) emissions produced from these activities. The available technologies for the liquid fuels industry to address cleaner fuels are well established and are not discussed in the report. The use of liquid fuels in the transport sector and impact of changes in drive train technology on fuels is highlighted. The report remains focused on the fossil fuels value chains and although the nexus with other areas e.g. petrochemicals, the hydrogen economy and water are important, we only reference them.

This phase of the work by Sanedi provides three high level Technology roadmaps, i.e. for Power Generation, Liquid Fuels Manufacturing and Transport. These roadmaps do not dictate technology choice but provide options indicating which technologies are relatively more efficient and their contribution towards GHG emissions reduction.

At a high level the key areas in the fossil fuel value chain that contribute towards GHG emissions are (1) the supply of raw material (coal, gas or oil), (2) the conversion of the raw material by combustion and conversion processes and (3) the management of the emissions of these activities.

The report provides an overview of the current energy landscape in SA, an overview of the fossil fuel value chains and provides a high level qualitative approach to ranking various technologies. This is followed by a discussion on the various value chain options and issues emanating from technology assessments. Following this is a section that provides more reference information on various technologies.

A short summary of a limited engagement with stakeholders in this initial phase of the work by Sanedi, which is to be expanded in future phases of the work, is shown in the annexures. Reference information on the current policy and regulatory support for the development and deployment of technology, both locally and internationally is also provided in the Annexure.

This report will be distributed to government principals and key stakeholders and based on their feedback, the scope of work and stakeholder engagement for phase 2 of the Cleaner Fossil Fuels Roadmap will be developed.

A number of key messages can be distilled from the study and they are summarised below followed by the high level roadmaps.

Key Messages

Energy Supply

The South African power **generation capacity** is currently constrained due to low energy availability factors for coal power stations and infrastructure constraints delaying new power projects which are having a significant detrimental impact on the SA economy.

New generation capacity is **urgently required** to eliminate this shortfall, as well as supporting the economic growth required by SA for meeting its socio-economic goals of alleviating poverty and unemployment and providing a better life for all its citizens.

SA energy supply is heavily dependent on fossil fuel (coal, oil and gas) and is thus relatively **carbon intensive compared to its peers** globally. SA needs to continue to **diversify its energy mix** in order to improve security of energy supply and to meet its commitments for its contribution to the reduction of greenhouse gases in the fight against global climate change.

Energy security in a changing energy supply mix need to be carefully considered.

Technology Choices

While carbon free renewable power capacity has increased over the past few years through the implementation of the IRP2019 programme, there are a number of **reliable fossil fuel technologies currently available** that achieves GHG emissions reduction relative to current technologies used in SA, either through **improved thermal efficiencies** (High Efficiency Lower Emissions, or HELE technology), **alternative fuel feedstocks**, or **removing the carbon emissions** from the industrial plants through carbon capture processes and underground storage (CCS).

Although **carbon capture and sequestration** is currently the only real technology option to make an immediate **step change** in reducing carbon emissions to the atmosphere it remains, without any existing infrastructure and potential enhanced oil recovery (EOR) option, a **major cost to the energy system** with significant efficiency sacrifices for any existing or new fossil fuel power plants. This investment needs to be considered against non-fossil fuel generation and process technologies which have a smaller life cycle carbon footprint.

However, the energy supply risk associated with the intermittent supplies of Renewable Energy in a changing climate also needs to be factored into planning decisions and although the country has significant upside for Renewable Energy, Carbon Capture Utilisation and Storage (CCUS) remains an imperative to mitigate GHG produced by existing newer fossil fuel power stations (e.g. Kusile and Medupi, i.e. those that are expected to be in operation well beyond 2030), including other industries with concentrated GHG streams.

Thus, consideration should be given to policy, regulatory and financial support to drive the development and implementation of Carbon Capture Utilisation and Storage (CCUS).

The utilisation of carbon from captured CO_2 is a longer term option as most technologies are still in research phase of the development lifecycle and currently not economically viable.

Similarly GHG emissions emanating from the use of **fossil fuels in transport** can be reduced by **replacing** fossil fuel with renewable biofuels, using **less carbon intensive engine technology** such as LNG/CNG vehicles, hybrid electric vehicles, full electric vehicles (on green electricity) and electric fuel cell driven vehicles. Over the **longer term**, **carbon free fuels are possible** from combining green hydrogen and captured carbon to make E-Fuels and other sustainable transportation fuels.

Leveraging the most efficient mature available fossil fuel technology enables a **<u>balanced mix</u> of fossil and non-fossil fuel** energy during the transition to a lower carbon environment.

As a **carbon free technology, nuclear power is a reliable baseload power** and together with **renewable solar PV** and **wind power**, provides a **valuable option** for non-fossil fuel energy.

Infrastructure

The implementation of many of the technology options are **subject to having enabling infrastructure** in place.

- Implementing gas to power technology and increasing natural gas utilisation in SA requires additional gas imports into SA. This requires **LNG import infrastructure in ports and associated gas transmission pipelines**.
- Similarly, **SA's electricity transmission and distribution grid capacity needs upgrading and expansion** to meet the additional generation capacity, especially for connecting the renewable power projects in Northern and Western Cape.
- Furthermore, **green hydrogen** and other **sustainable fuels** production processes require **large renewable power inputs**, which in turn requires appropriate **power transmission infrastructure to support** it.

Project Execution

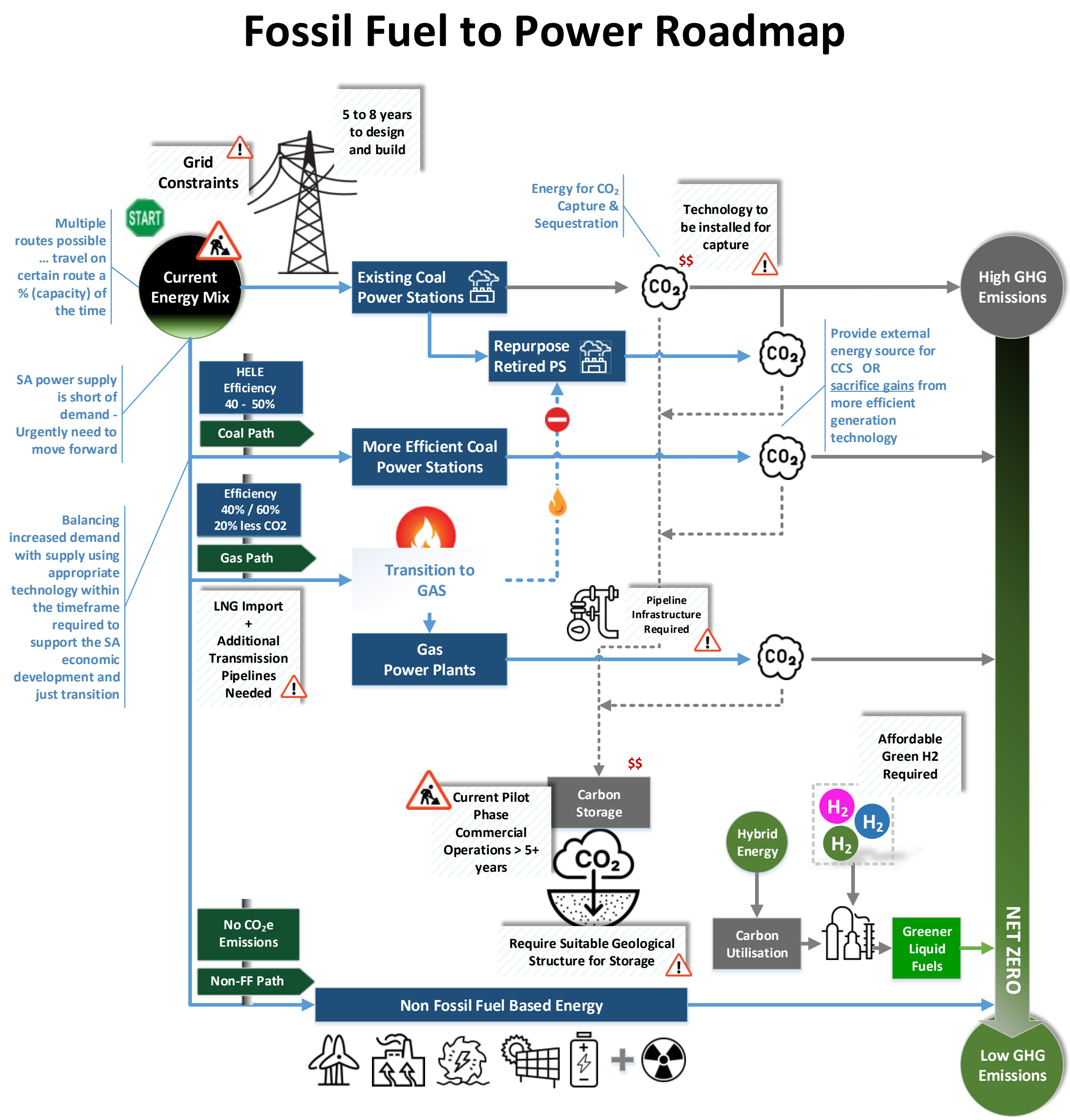
The lead time for these major **infrastructure projects** becomes, in effect, the **critical path** for any large energy projects, be it fossil fuels or non-fossil fuel based.

Technology Roadmaps

Evaluation of the technology metrics and considering the relationships between them, including dependencies and prerequisites for successful project execution, has enabled the development of Fossil Fuels Technology Pathways for Reduced Greenhouse Gas Emissions. Pathways have been developed for Power Generation, Cleaner Liquid Fuels and Carbon Capture, Storage and Utilisation. These pathways form the basis of a feasible Cleaner Fossil Fuels Roadmap and provide options for consideration during future energy planning processes.

Fossil Fuel to Power Roadmap

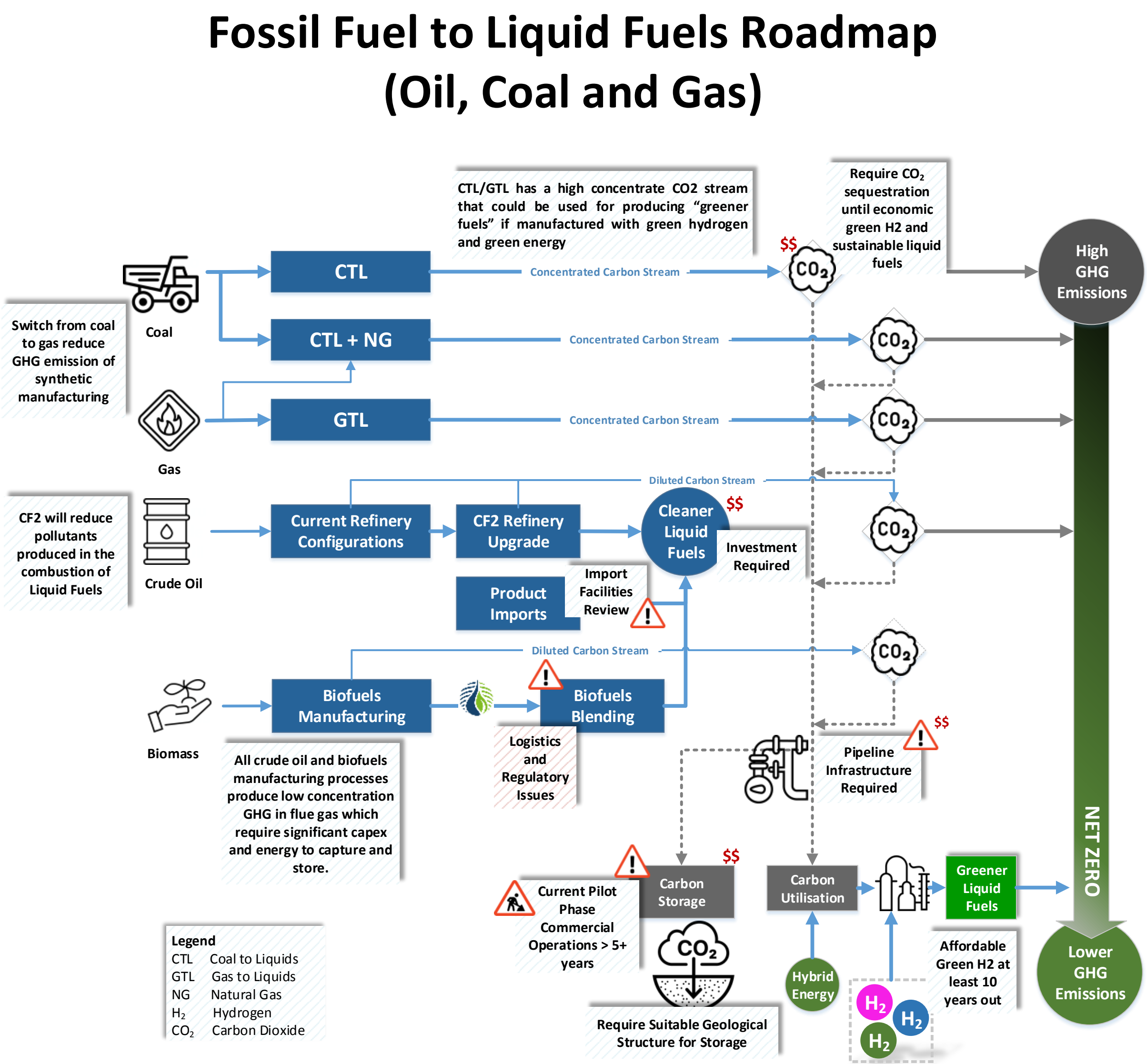
The following roadmap depicts the various technology pathways. The options are coal to power, gas to power and non-fossil fuel power. Each is shown relative to each other in terms of their GHG emissions and contribution to achieving the Net Zero objectives. Their infrastructure requirements are also articulated. For CCUS the options of storage and future utilisation options to greener liquid fuels are depicted.



Fossil Fuel to Liquid Fuel Production Roadmap

The roadmap shows the production options for liquid fuels and their relative emissions contribution. Switching from coal to natural gas at the CTL plant provides significant GHG emissions reduction over the equivalent coal use. The CTL/GTL plants are major sources of concentrated carbon, whilst crude oil refineries and biofuel manufacturing has a significantly smaller carbon footprint. The infrastructure requirements are also articulated. For CCUS the options of storage and future utilisation to greener liquid fuels are depicted.

The liquid fuels Clean Fuels 2 Programme (CF2) will only contribute to the reduction in pollutants from tail pipe emissions.



Fossil Fuel Utilisation (Transport) Roadmap

The following roadmap depicts the progression to zero carbon tailpipe emissions and changing engine technology to achieve this objective. It highlights the need for green electricity to move the EV's and the infrastructure both at transmission and distribution levels to be upgraded and expanded to support a future EV car parc. The option of Direct Air Carbon Capture is in its infancy and not currently an economically viable option for carbon sequestration. The trade-offs are between providing green energy for EV's (with associated grid investments) vs continued use of fossil fuels and high cost of capturing the carbon emissions.

The development of greener liquid fuels e.g. SAF to abate carbon emissions in the airline industry is part of the Hydrogen Roadmap including the production of green ammonia for shipping and as a "hydrogen" energy carrier.

Fossil Fuel Utilisation Technology Roadmap (Transport)

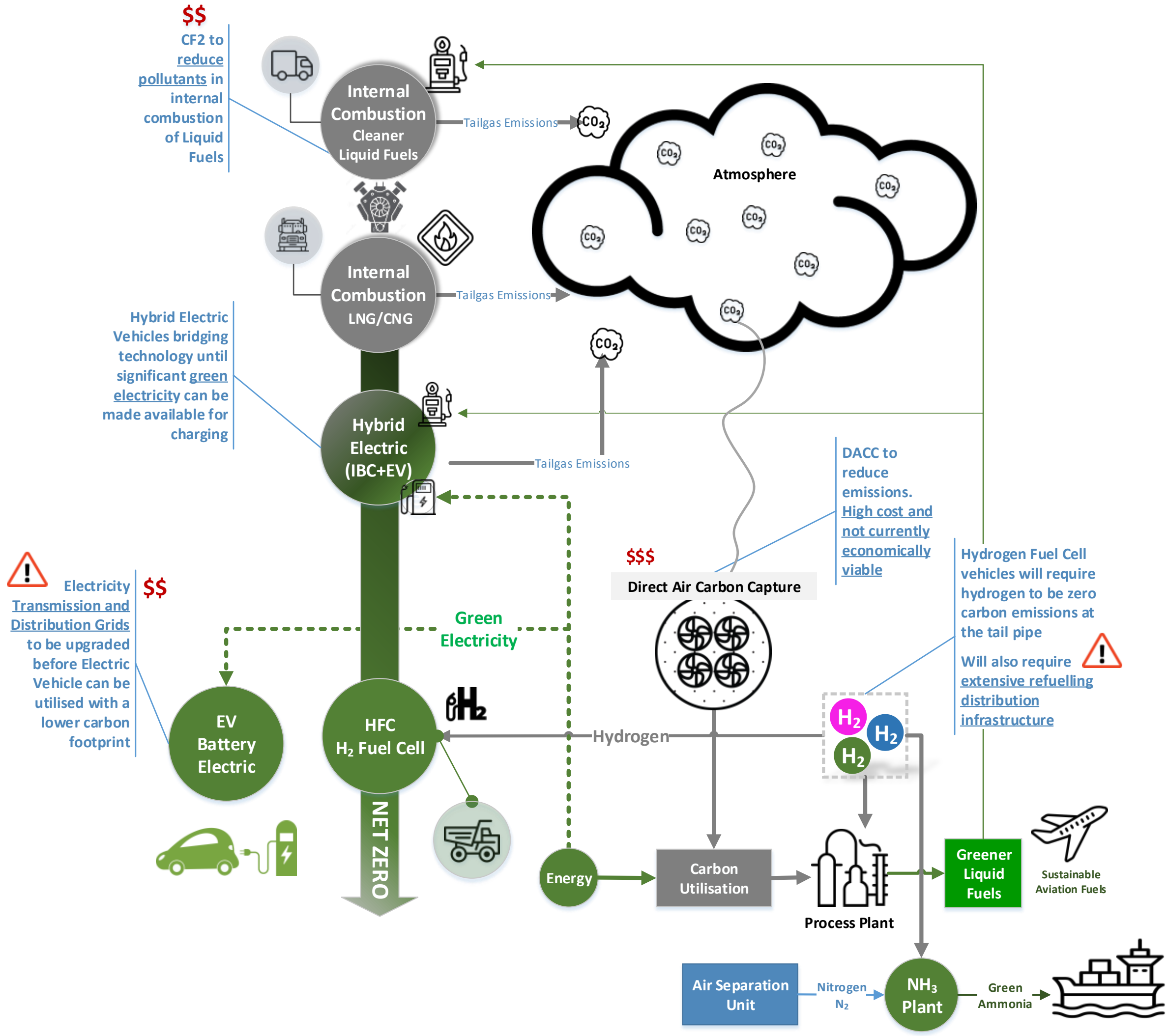


TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF TERMS

AUSC	Advanced Ultra-Supercritical Coal Plants
BATTERY	Battery Energy
BCF	Billion Cubic Feet
BESS	Battery Energy Storage Systems
BFP	Basic Fuel Price
BIOMASS	Biomass Fired Plants
BPD	Barrels per Day
CAPEX	Capital Expenditure
CBM	Coal Bed Methane
CC CONC	Carbon Capture from Concentrated CO_2 Gas Streams
CC DILUTE	Carbon Capture from Dilute CO_2 Gas Streams
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CEF	Central Energy Fund
CF2	Cleaner Fuels 2 Programme of SA
CFB	Circulating Fluidised Beds for Coal Plants
CFCs	Chlorofluorocarbons
CGS	Council for Geosciences
CH3OH	Methanol
CH4	Methane
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2 TRANSP	Transport of CO_2, normally by Pipeline
CO_2-eq	Carbon Dioxide Equivalent
COP	Durban Sasolburg Crude Oil Pipeline
CSIR	Council for Scientific and Industrial Research
CTL	Coal to liquids - Sasol Secunda
DACC	Direct Air Carbon Capture
DFFE	Department Forestry, Fisheries and Environment
DME	Dimethyl ether
DMRE	Department of Mineral Resources and Energy
E&P	Exploration and Production
E-FUELs	Electro Fuels
EJ	Exajoule = 10^{18} joules = 1000 PJ
FBC	Fluidised Bed Combustion
FCV	Fuel Cell Vehicle
FEV	Full Electric Vehicle
FFF	Fossil Fuel Foundation
FGD	Flue Gas Desulphurisation
FSRU	Floating Storage and Regasification Unit for LNG Imports
FT	Fischer Tropsch Process
GHG	Greenhouse gases
GJ	Gigajoule = 10^9 Joules
G-NH_3	Green Ammonia
GTL	Gas to liquids refinery - PetroSA
GW	Gigawatt = 1000 MW
GWP	Global Warming Potential
H_2	Hydrogen
H_2O	Water
HELE	High Efficiency Low Emission Technology
HEV	Hybrid Electric Vehicle
HFC	Hydrofluoro-carbons
HFO	Heavy fuel oil
ICE	Internal Combustion Engine
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle Plants
IGUA-SA	Industrial Gas Users Association of Southern Africa
IPAP	Industrial Policy Action Plan
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
IPPO	Independent Power Producers Office (IPP Procurement for DMRE)
IRENA	International Renewable Energy Agency
IRP	Integrated Resources Plan
KT	Kilotons
kWh	kilowatt-hour
LI-ION	Lithium Ion Battery
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LTPF	Transnet Long Term Planning Framework
MEA	Mono-ethanolamine solvent
MMBTU	Million BTU (British thermal units)
MOFs	Modified Metal Organic Framework Materials
MRG	Sasol Methane Rich Gas
MSW	Municipal Solid Waste
MT	Million tons
MTPA	Million tons per annum
Mt/y	Million Tons per Year
MW	Megawatt
NAS	Sodium Sulphide Battery
NBI	National Business Initiative
NDC	Nationally Determined Contribution - SA GHG Reduction Targets
NDP	National Development Plan
NETL	National Energy Technology Laboratory

GDP	Gross domestic product
G-H_2	Green Hydrogen
NG	Natural Gas
NH_3	Ammonia
NMPP	New Multi-Product Pipeline of Transnet
NOx	Nitrous Oxides
NUC	Nuclear Power Plants
O_2	Oxygen
OCGT	Open Cycle Gas Turbine
OPEX	Operational Expenditure
PEM	Proton Exchange Membrane
PFCs	Perfluoro-carbons
PGM	Platinum group metals
PJ	Petajoules - 10^{15} Joules
PJ p.a.	Petajoules per annum
PM	Particulate Matter
PPN	Porous Polymer Networks
PSA	Production Supply Agreement
PTX	Power to X fuels
PV BFW	Boiler Feed Water Heating by Solar Power
PWR	Power
R&M	Refining and Manufacturing
REIPPP	Renewable Energy Independent Power Procurement Programme
RFA	Road Freight Association
SAF	Sustainable Aviation Fuel
SANEDI	South African National Energy Development Institute
SAPIA	South African Petroleum Industry Association
SAPVIA	South African Photovoltaic Industry Association
SAWEA	South African Wind Energy Association
SC	Supercritical Coal Plants
SDS	Sustainable Development Scenario
SF6	Sulphur hexafluoride
SMR	Steam Methane Reforming process
SOLAR PV	Photovoltaic Power
SO_X	Sulphur Oxides
TCF	Trillion Cubic Feet
UCG	Underground Coal Gasification
ULSD	Ultra-Low Sulphur Diesel 10ppm Sulphur
USC	Ultra-Supercritical Coal Plants
WB	World Bank
WIND	Wind Turbine Power

BACKGROUND TO THE STUDY

The South African government believes that a low carbon economy can bring benefits and particularly support climate change mitigation measures. The South African Government has committed to reducing carbon emissions in line with specified targets for South Africa. As of 22 September 2021, the country's Nationally Determined Contribution (NDC) target range for 2025, has been updated from its original value of 398-614 Mt CO_2-eq, to a range of 398-510 Mt for 2025.

Of greater significance is the 2030 mitigation target range which has been updated from 398-614 Mt CO_2-eq to a range of 350-420 Mt CO_2-eq. In order to meet these emissions reduction targets, several strategies will need to be used towards meeting this goal. A strategy that should be considered is the potential for the implementation of cleaner fossil fuel technologies.

Reporting to the Department of Mineral Resources and Energy, the mandate of the South African National Energy Development Institute (SANEDI) is to serve as a catalyst for sustainable energy innovation, transformation and technology diffusion in support of South Africa's sustainable development. The Cleaner Fossil Fuels Programme at SANEDI housed the South African Centre of Carbon Capture and Storage (SACCCS), a national flagship programme of the National Climate Change Response Strategy White Paper. This Centre has since moved to the Council for Geoscience but remaining SANEDI tasks include this techno-economic study to address the Cleaner Fossil Fuels roadmap for South Africa managed under the Renewables Programme.

South Africa's energy and climate change challenges are exacerbated by a reliance on Fossil Fuels for most of its primary energy supply. Approximately 90% of primary energy is derived from Fossil Fuels of which ~72% is coal. Moreover, coal provides ~85% of electricity generation capacity and ~92% of electricity production. Coal and gas are also used for the production of liquid fuels amounting to approximately 30% of the liquid fuels used in South Africa. This reliance on fossil fuels has led to ~440 Mt CO_2 emissions per year.

South Africa's coal industry contributes significantly to employment opportunities, income generation as well as accounting for 6% of the country's total merchandised exports. South Africa also has a significant requirement for additional energy supply of electricity generation capacity as well as liquid fuel production. Furthermore, there are a multitude of other industries that contribute to national CO_2 emissions.

The reality is that fossil fuel will be used for many years to come as the capacity to switch completely to carbon free energy is currently infeasible in most developing countries. Use of fossil fuels does not have to result in the same GHG emissions. Technology improvements has enabled its use while achieving reduced GHG emissions per energy output.

Cleaner fossil fuels is a concept that implies using fossil fuels as an energy source, but with reduced GHG emissions. Due to its high dependency on fossil fuel for its energy supply, SA wishes to leverage this concept in its journey to meeting its NDC targets.

This study, as an initial high level phase 1 initiative, evaluates and identifies suitable fossil fuel technologies that could be incorporated into feasible energy and technology pathways in the achievement of GHG emission reduction and eventual net zero carbon. Technologies that are mature and available commercially with worldwide operations are preferred candidates.

The study output can be used for further detailed analysis of the technologies and potential incorporation in future energy planning processes.

STUDY APPROACH – PHASE 1

What is a Fossil Fuel Roadmap?

A fossil fuel roadmap is the feasible energy and technology pathways for South Africa in meeting the agreed GHG emission reduction targets (NDC) while ensuring power generation capacity is balanced with demand and is supportive of SA economic growth and Just Transition principles.

Phase 1 Approach

The objective of phase 1 of the project involves a high level review and evaluation to identify a range of feasible technologies that achieve the GHG reduction objectives. They are then considered for inclusion in potential pathways to cleaner fossil fuels. Phase 2 of the project envisages more detailed analysis of technology solutions for the country.

A limited number of key industry stakeholders were consulted to obtain their input and views on a range of topics. Stakeholders in the Coal, Oil and Gas value chains were identified. Meetings were held with Eskom, Sasol, Council for Geosciences, SAPIA, CEF, Road Freight Association, Transnet, South African Wind Energy Association (SAWEA), Fossil Fuel Foundation and subsequent engagements with Exxaro, CSIR and the IPP Office.

The key objectives were to establish each stakeholder's current thinking and plans with regard to cleaner fossil fuels technology and their implementation thereof, if any, and the clarification of stated objectives and timelines within company plans already in the public domain.

A review of the current energy supply and demand for the coal, oil and gas value chains was done to provide context within the South Africa's overall energy sector.

Various technologies that could potentially contribute to the development of a Cleaner Fossil Fuel Roadmap were identified and researched. These ranged from alternative feedstock options, changes in conversion technology (chemical/heat) and technology to manage GHG emissions from processes.

Each technology is summarised and represented in a compact format for easy reference in TECHNOLOGY OVERVIEW.

Criteria were developed for a high level ranking of the technologies which was then used to inform the high level roadmap.

The assessment and ranking approach is described in more detail in section on TECHNOLOGY RANKING CRITERIA.

The following diagram illustrates the major tasks.

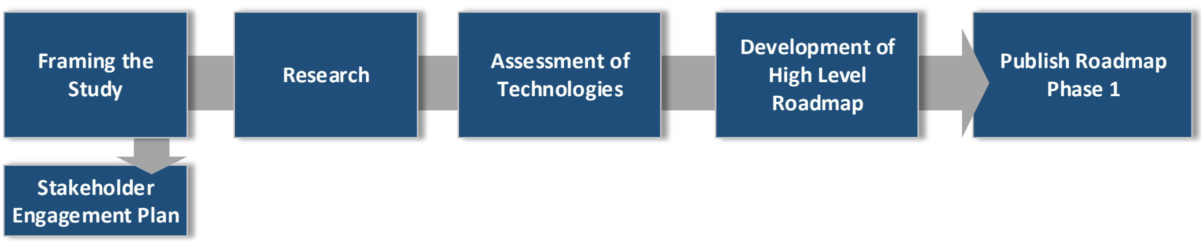


Figure 1 - Study Approach

OVERVIEW OF SOUTH AFRICA ENERGY SUPPLY AND DEMAND

South Africa's economy has relied heavily on fossil fuels and will continue to depend on fossil fuels for the foreseeable future, even as the country transitions to a diversified energy mix. It is thus critical to ensure security of supply and provide energy ahead of demand to enable certainty in economic planning and promote the much needed investment in all sectors of the economy, notably to re-industrialise the country.

The following Sankey diagram (IEA) provides a high level overview of South Africa's energy balance (2019). The diagram describes the flow and transformations of energy carriers, from production and import (left-hand side) to final consumption (right-hand side). The width of the lines indicates the relative quantum of the various energy sources. The diagram indicates that coal and oil are the major sources of energy with refined product mainly used in the transport industry. Coal is mainly used for power generation, production of liquid fuels and petrochemicals, exported or used in industry e.g. in the production of iron, steel and cement.

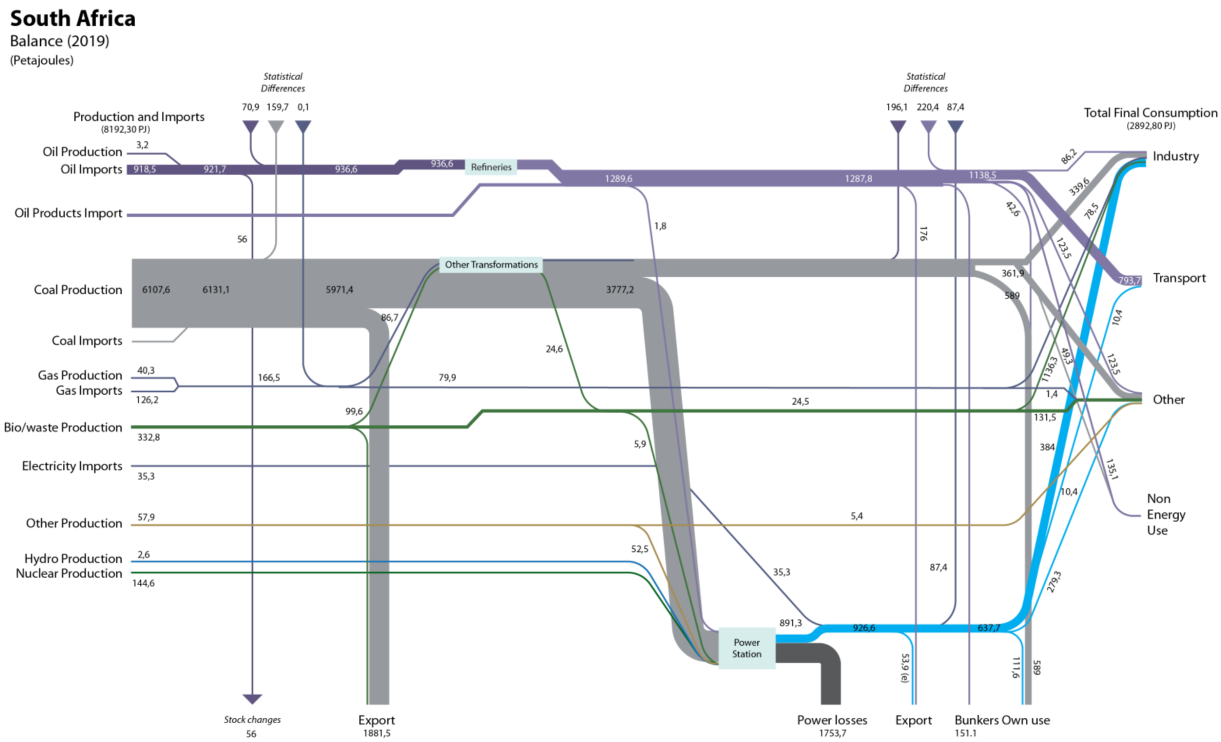


Figure 2 – SA Energy Balance 2019

Source: IEA

Opportunities for "cleaner fossil fuels" exist at various points in this diagram starting at the point of extraction or production, at every point of conversion, in its transportation and at its final point of use.

The available technologies are explored in the subsequent sections of the report.

The following section provides and overview of the SA energy landscape.

Primary Energy Consumption

Fossil fuels currently contribute approximately 95% of South Africa's energy mix. This is among the highest in the G20 countries.

The SA Climate Transparency Report 2020 reported that the share of fossil fuels in the energy mix globally needs to fall to approximately 67% by 2030 and to 33% by 2050 for the global temperature increase to be within a 1.5°C limit. If Carbon Capture and Storage (CCS) is not implemented at scale the fossil fuel contribution to the energy mix has to reduce to levels lower than 67% and 33% indicated above.

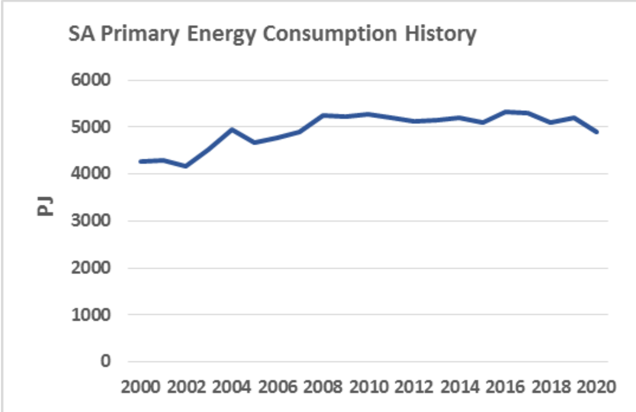


Figure 3 - SA Primary Energy Consumption

Source: BP Statistical Review of World Energy 2021

SA historic primary energy consumption in SA for the period 2000 to 2020 (Petajoules) indicates that there was a steady growth until the 2008 financial crises, which saw a contraction in consumption until 2014, with minor growth until 2016 and thereafter declining exacerbated by the COVID-19 pandemic.

In terms of the energy mix, coal was the dominant contributor, followed by oil. Share of renewables was 2.3% (2019) and 2.5% (2020). Gas contribution was 3%, similar to nuclear.

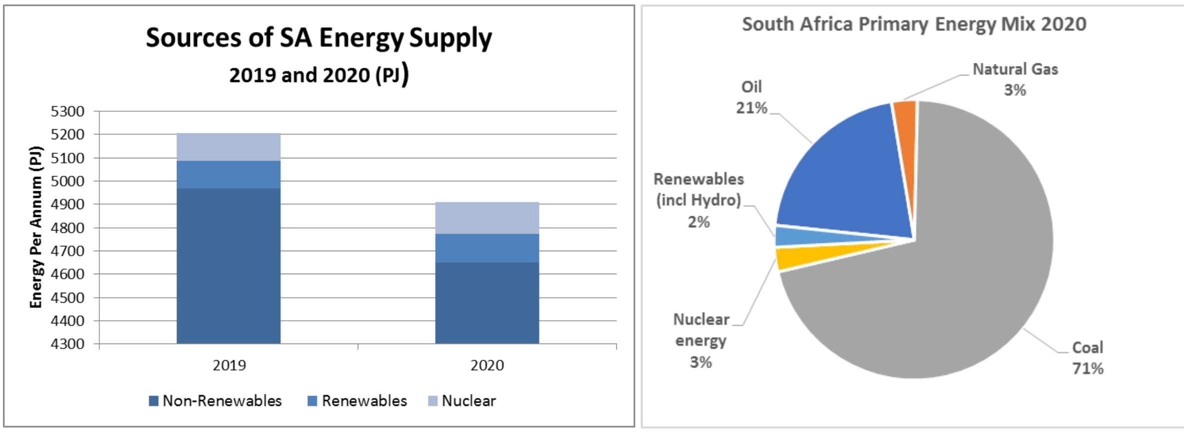


Figure 4 - Sources of Energy Supply and Energy Mix

Source: BP Statistics Review 2021

SA Coal Supply and Demand

Coal supplied by local mining in 2019 was 260 million tons plus minor imports of 1.3 million tons as shown in the figure below. The demand for coal can be broken down in three major sectors, i.e. Export, Transformation (Power and CTL) and other industrial sectors. The bulk of the coal is utilised by Eskom for power generation. Sasol is the second largest single user of coal for the production of synthetic liquid fuels and petrochemicals at Secunda.

Coal exports and coal for power and has declined in 2020 and 2021.

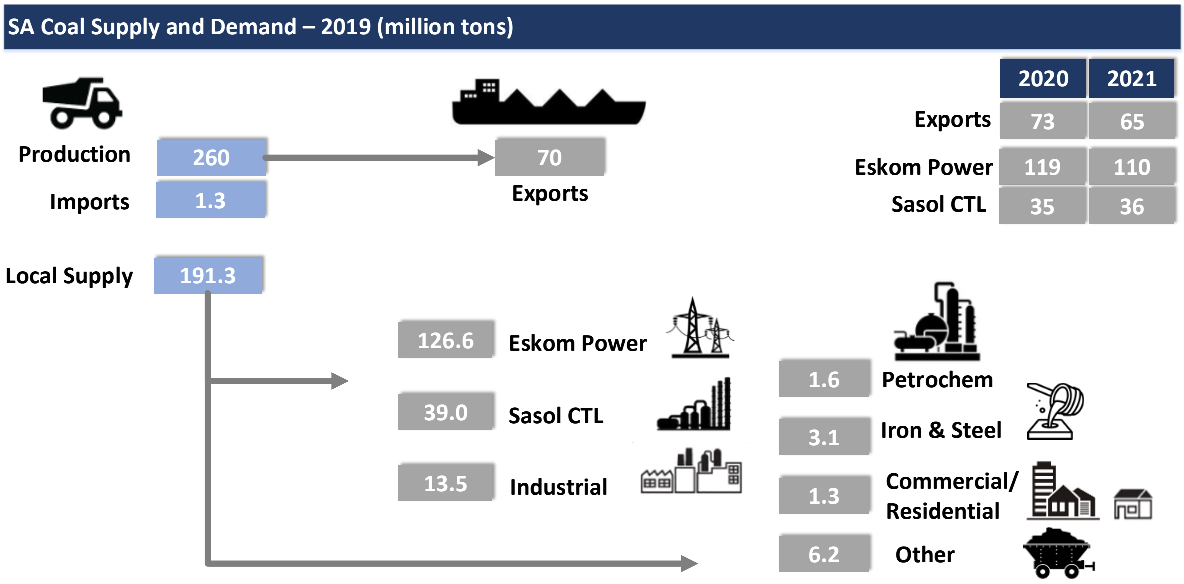


Figure 5 - SA Coal Supply and Demand 2019 – million tons per year

Source: DMRE

SA Electricity Supply and Demand

IRP2019 Energy Mix

Overall generation capacity in 2019 was 51,605 MW and it grows to 78,284 MW in 2030. Coal's contribution reduces by 29%, with a concomitant increase in renewable power, which includes hydro, storage, solar PV, concentrated solar and wind power.

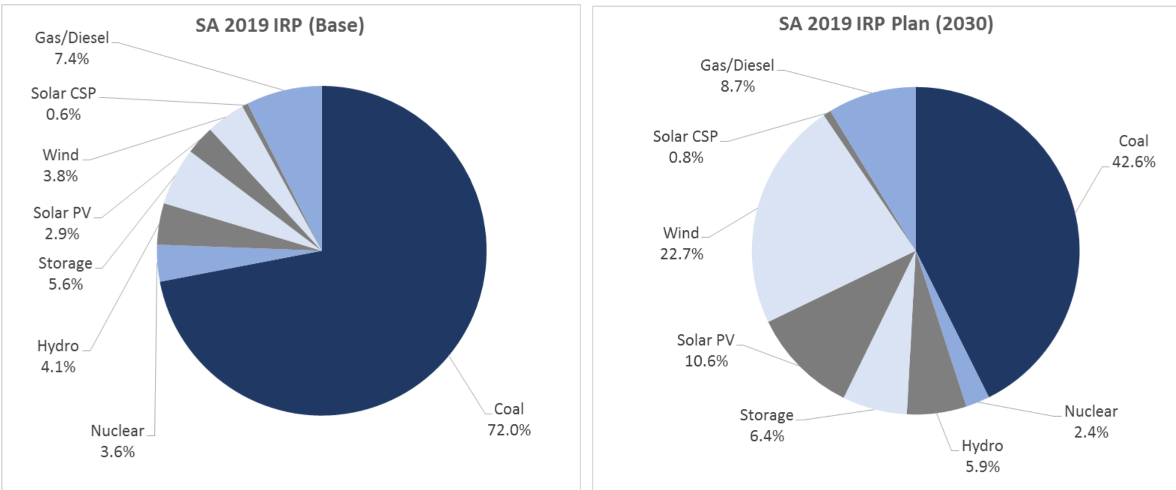


Figure 6 - SA planned Energy mix as per IRP2019

Since the publication of the IRP 2019, SA government has decided to extend the use of the Koeberg nuclear power station.

Recent policy changes have also created an enabling environment for power purchase from IPPs. Policy changes allow for an exemption which raises the registration threshold for self-generation facilities from 1MW to 100MW.

The amendment also allows a generation facility including an Independent Power Producer (IPP) of up to 100MW, to sell electricity to 'an end-use customer'. An important beneficiary of this change will be large industrial and mining companies who will be able to purchase electricity from an IPP and have the power 'wheeled' through the grid to facilities throughout the country

Preferred bidders for the Renewable Energy Independent Power Producer Procurement Program (REIPPPP) Bid Window 5 have been announced by the DMRE and Request For Proposals (RFP) for the REIPPPP Bid Window 6 is expected towards the end of March 2022.

Electricity Demand Forecast

The CSIR developed a SA electricity demand forecast up to 2050. The demand shows a compound annual growth (CAGR) of 1.15% rising to 355 TWh in 2050.

The updated forecast shows energy demand of approximately 7% to 8 % less than the 2019 IRP baseline.

The "Updated" demand forecast is a scenario developed by the CSIR which essentially assumes a slower uptake in demand in the short term. This demand forecast is based on the Eskom Medium Term System Adequacy Outlook demand forecast (until 2024) and assumes the same IRP2019 annual growth rates thereafter. The Updated demand forecast was assumed for all scenarios excluding the IRP2019 (DMRE) scenario for the "2020 Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system" a study done by the CSIR and Meridian Economics.

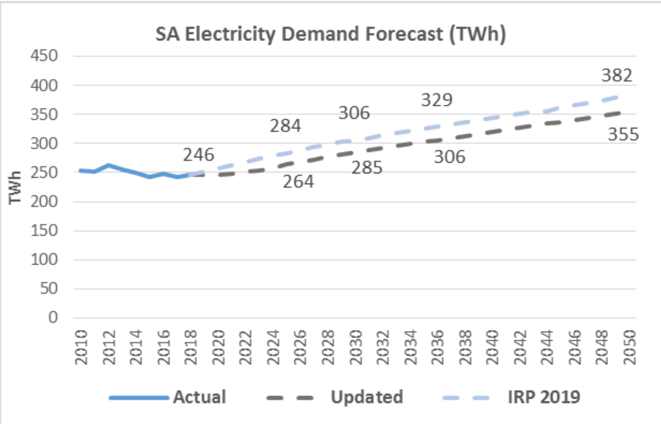


Figure 7 - SA Electricity Demand Forecast (CSIR)
Source: CSIR

Electricity Transmission Infrastructure

The figure below shows Eskom's electricity transmission infrastructure in South Africa – highlighting areas which needs to be expanded and reinforced to meet the anticipated growth in demand and supply from the future generation pattern.

The bulk of South Africa's electricity is still produced by Eskom's coal-fired power stations located in the coalfields of the Mpumalanga Highveld and near Lephalale, but the landscape for power generation is rapidly changing.

The Renewable Energy Independent Power Producer (REIPP) Programme has resulted in increasing amounts of electricity produced from renewable sources, mainly wind and solar projects located primarily in the Eastern Cape, Western Cape, and Northern Cape.

The transformation of the South African energy mix will continue as more electricity from renewable sources becomes integrated in the national grid in accordance with the Integrated Resource Plan (IRP) 2019.

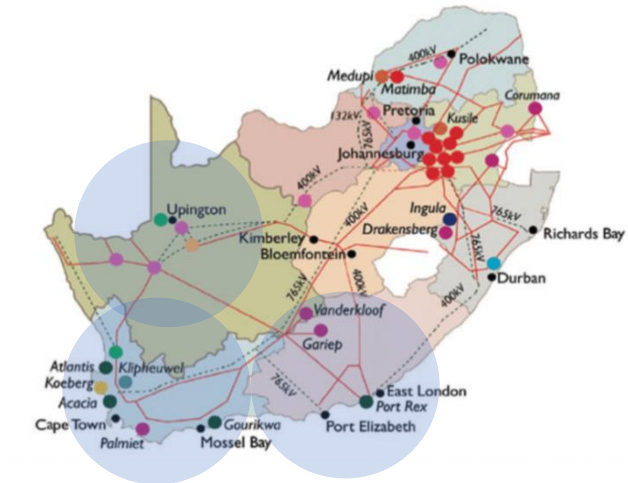


Figure 8 – South African Electricity Transmission Grid and Generation Locations

Petroleum Products Supply and Demand

South Africa imported approximately 7.6 billion litres of liquid fuels in 2019, while the balance of the local and regional demand was produced by South Africa crude oil refineries (20.1 billion litres crude oil) and from coal and gas at Sasol's synthetic fuels plant. The transport sector consumes the bulk of liquid fuel products.

It should be noted that Enref and PetroSA have since shut down with Sapref announcing they plan to shutdown at the end of March 2022. As a result, crude imports will be reduced and increased volumes of refined products will have to be imported.

The overall petroleum supply chain volumes (2019) are shown in the figure below.

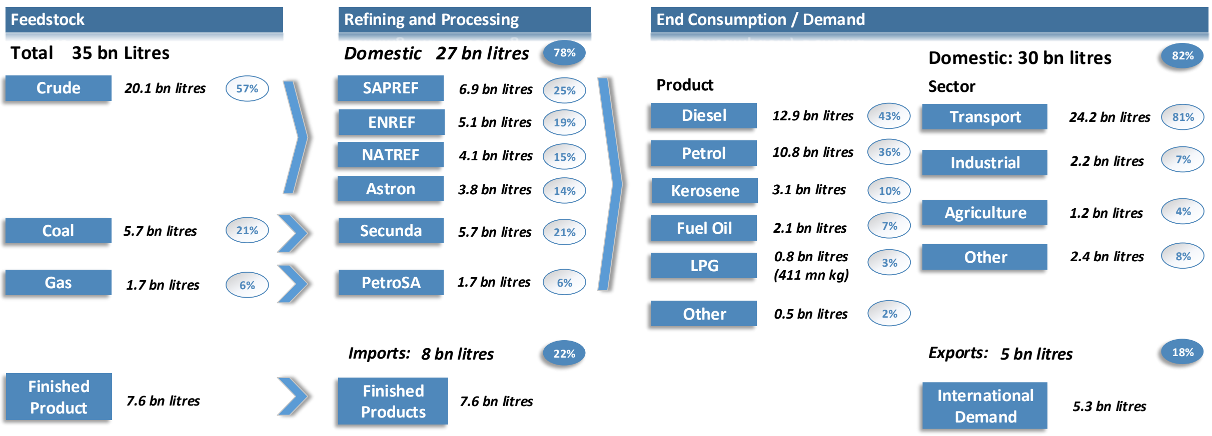


Figure 9 – Oil Industry Supply and Demand 2019
Source: SAPIA

The Green Transport Strategy for South Africa (2018-2050) developed by the Department of Transport committed to a 5% reduction of emission in the transport sector by 2050. When the strategy was developed the transport sector accounted for 10.8% of the country's total GHG emissions with road transport being responsible for 91.2% of the GHG emissions in the transport sector.

The key steps to achieve the reduction of emissions targets from road transport included:

- Shifting passengers from private transport to public transport
- Shifting freight from road to rail.
- Switching to cleaner fuels and adopting new technologies such as alternative energy vehicles.

SA Natural Gas Supply and Demand

The figures depict the Industrial Gas Users Association of Southern Africa's (IGUA-SA) view on gas supply and demand until 2030. There is a significant gap between the supply of gas and the demand resulting in a market shortfall. The IGUA-SA estimated the total demand for 2020 (including latent demand) to be 350 PJ p.a. whilst supply was limited to 191 PJ p.a.

Sasol's natural gas supply from Pande/Temane decreases from 2025 onwards due to depleting gas resources.

The LNG bridging imports for Risk Mitigation Independent Power Producer Programme (RMIPPP) from Coega is to start in 2022 and from the SA Government's Coega LNG terminal from 2027. The Matola Mozambique LNG terminal is introduced from 2024. Sasol supply increases from 2025 onwards at 30 PJ p.a. from the Production Sharing Agreement (PSA) development of the Inhassoro, Temane and Temane-East fields in the north of Inhambane province.

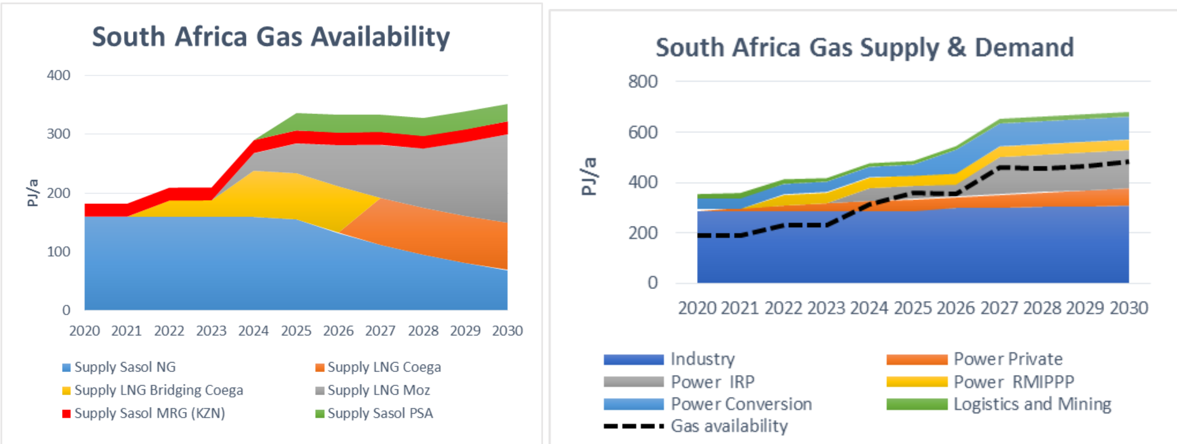
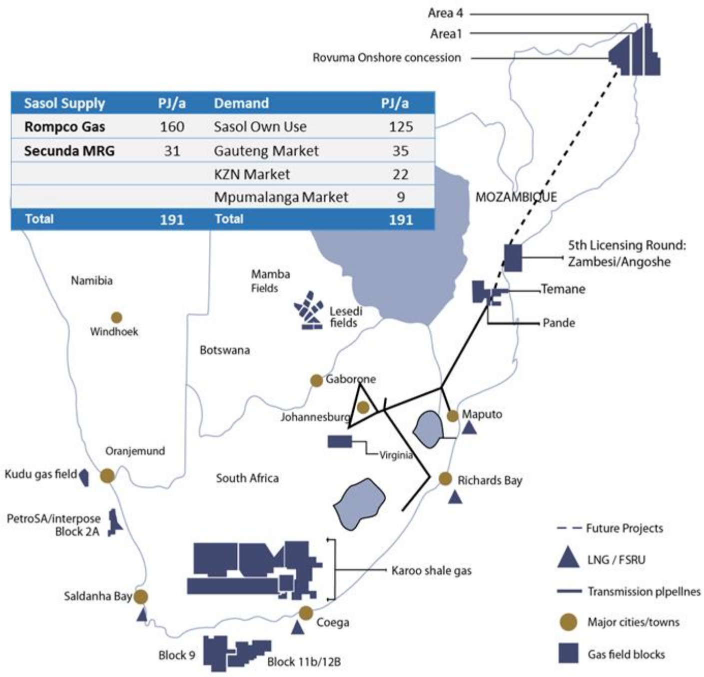


Figure 10 - SA Gas Availability and Supply and Demand
(Graph Source: IGUA-SA)

The estimated gas supply in the figure showing South Africa's gas supply and demand is indicated by the dotted black line. SA currently has a shortage of gas supply, notably the 72 PJ p.a. for PetroSA GTL refinery that is currently shut down due to low feedstock supply from its existing gas fields.

The following map depicts the regional gas landscape, highlighting the various existing gas fields, transmission pipelines and potential Liquefied Natural Gas (LNG) import locations. Included is a table showing the current supply and demand for Natural Gas (NG) in SA. Sasol is the major supplier and consumer of gas in the production of petrochemicals and its own power.



Sasol Supply	PJ/a	Demand	PJ/a
Rompco Gas	160	Sasol Own Use	125
Secunda MRG	31	Gauteng Market	35
		KZN Market	22
		Mpumalanga Market	9
Total	191	Total	191

Figure 11 - Regional Gas Infrastructure

(Map Source: IGUA-SA)

GHG EMISSION OVERVIEW

SA Greenhouse Gas Emissions

The figures below give an indication of SA GHG emissions for the period 2000 to 2017 in Mt CO_2e (CO_2 equivalent) and per sector. The South Africa GHG emissions are approximately 500 million tons CO_2e per annum.

Electricity generation from coal fired power stations is the largest contributor to GHG emissions followed by petrochemical production. The coal and gas to liquids process at Sasol's Secunda plants contributes approximately 90% of emissions in the petrochemical and chemical sector.

The transport sector is the third largest contributor to emissions through the use of liquid fossil fuels.

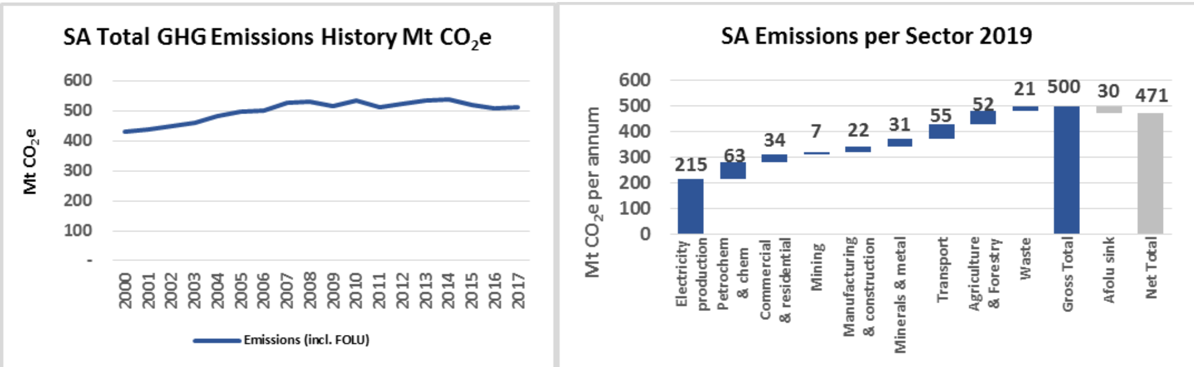


Figure 12 - SA GHG Emissions

Source: DFFE

Source: NBI

Emissions Due to Liquid Fuels Consumption

CO_2e emissions in various industry sectors are shown in the figures below. Road transport is the largest emitter in the transport sector. The transport sector contributes approximately 10% to South Africa's total national CO_2 emissions.

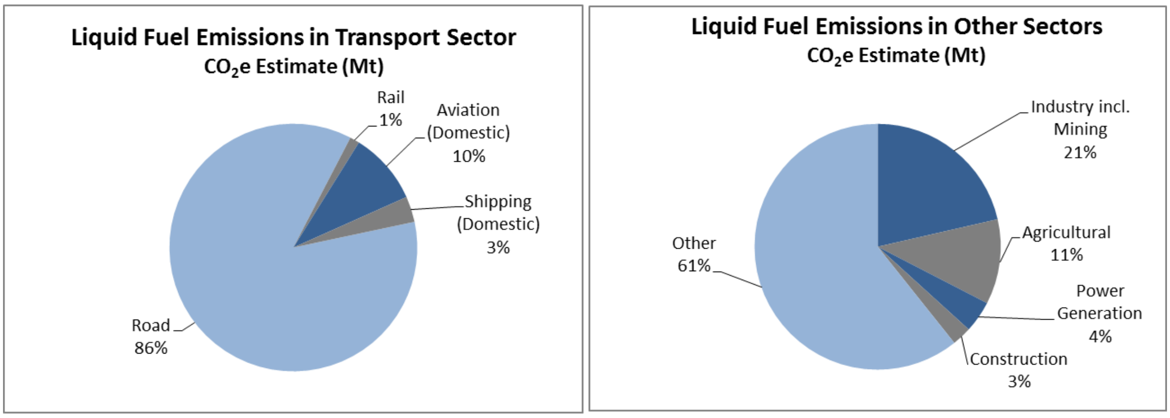


Figure 13 - Liquid Fuels Emissions

Source DMRE

GHG Emission Targets

The updated mitigation NDC approved by cabinet in September 2021 is a significant reduction in greenhouse gas emissions (GHG) target ranges up to 2030, with the 2025 target range allowing time to fully implement the national mitigation system, including those elements contained in the Climate Change Bill. It will also allow space for the implementation of IRP2019 and other key policies and measures, as well as the national recovery from COVID-19.

The updated SA National Declared Commitment (NDC) target range is between 398 and 510 Mt CO_2e in 2025, and between 350 and 420 Mt CO_2e in 2030 (South African Cabinet, 2021).

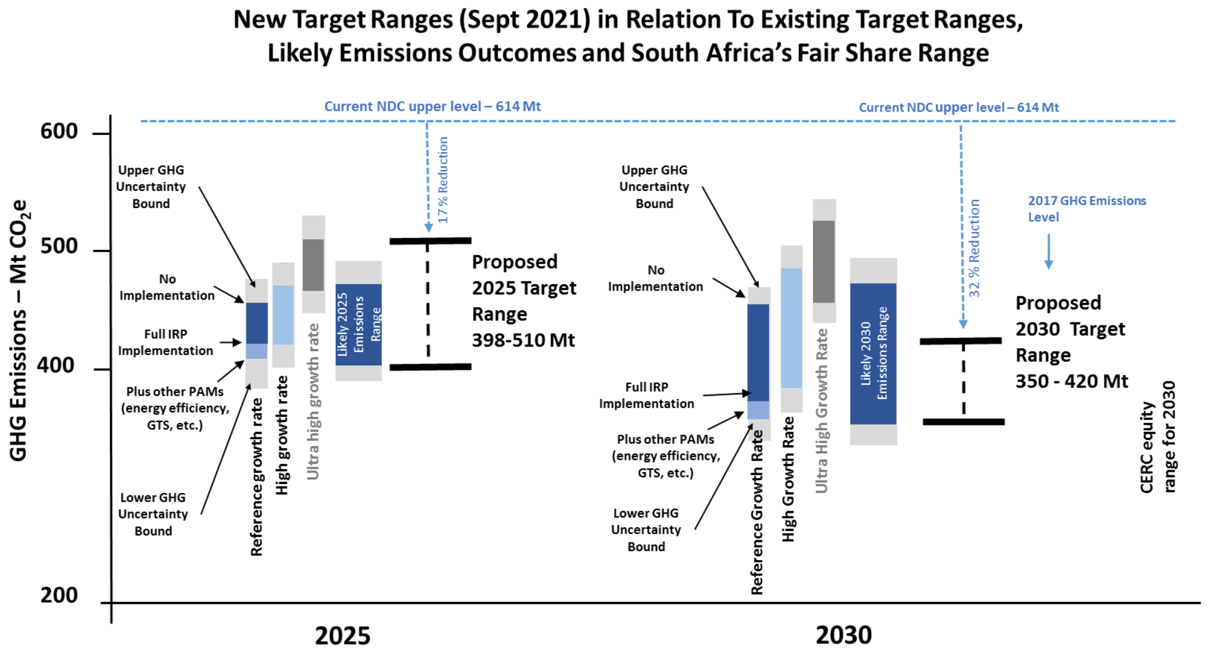


Figure 14 - SA National Declared Commitments (2021)

Source: DFFE Draft NDC, Adapted with New National Targets (Sept 2021)

The 2030 target range (350 - 420 Mt CO_2e) is consistent with South Africa's fair share, and also an ambitious improvement on the 2015 NDC target. The upper range of the proposed 2030 target range represents a 32% reduction in GHG emissions from the 2015 NDC targets.

The following table shows the various government plans, legislation and key initiatives in support of the NDC.

Key Government Approved Plans to Reduce GHG Emissions	Key Legislation to Reduce GHG Emissions	Status of Key Initiatives Towards Cleaner Energy
▪ IRP2019 (Integrated Resource Plan) ▪ Renewable Energy Independent Power Procurement Programme (REIPPP) ▪ The Green Transport Strategy, 2018-2050 ▪ Integrated Energy Plan 2019 ▪ National Development Plan 2030 ▪ National Energy Efficiency Strategy 2005	▪ Industrial Policy Action Plan (IPAP), 2018 ▪ Draft Climate Change Bill, introduced to the National assembly 18 Feb 2022 ▪ Carbon Tax Act 2019 ▪ National Greenhouse Gas Emission Reporting Regulations, 2017 ▪ National Pollution Prevention Plans Regulations, 2017	▪ NG/LNG imports - There are current initiatives by the DMRE to import LNG at Coega and by the DPE to import LNG at Richards Bay. ▪ Green Hydrogen - The South African Hydrogen Society Roadmap 2021 describes six key outcomes of the roadmap including four catalytic projects namely: The Platinum Valley Initiative, Coal CO_2 > X Project, Boegoebaai SEZ, SAF project. ▪ Carbon capture and storage –The CGS has started with a pilot project to research CCS in Mpumalanga

Table 1 - SA Government Plans and Key Initiatives in Support of NDP

OVERVIEW OF ROADMAP PROCESS

The objective of the roadmap process is to identify suitable technologies that could support a cleaner fossil fuels roadmap for SA, their impact and role within South Africa's energy framework and the estimated timeframe in which the technology is expected to be technically and commercially viable. Feasible technologies are identified through a ranking process using ranking criteria described in the sections below.

This outcome of this evaluation and ranking identifies feasible technology options for the short (less than 10 years), medium term (10 to 20 years) and long term (more than 20 years). When considered over a timeframe of 2022 to 2050, the outcome forms the basis of a cleaner fossil fuels roadmap for SA.

Fossil Fuel Value Chain Overview

The process of roadmap development begins with a scan and evaluation of the current value chains of different fossil fuels. It then considers opportunities for improvements in current technologies as well as technologies that strive to reduce and/or capture greenhouse gas emissions, thereby reducing the impact of fossil fuel usage. It also considers the alternative non-fossil fuel providers of energy that can displace or supplement fossil fuel options.

The integrated coal, oil and gas value chains in South Africa are illustrated in the two diagrams below.

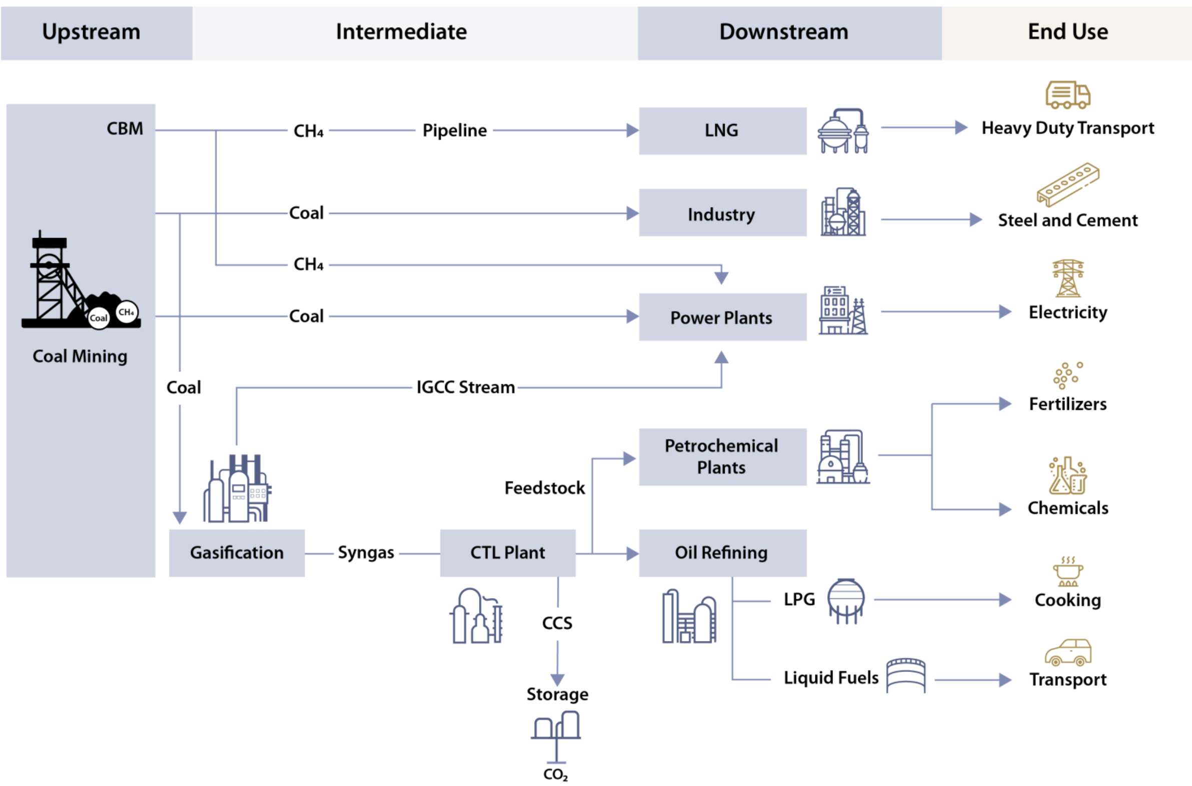


Figure 15 - Coal value chain and its applications

Source: Introduction to Coal Business, ETP Adapted

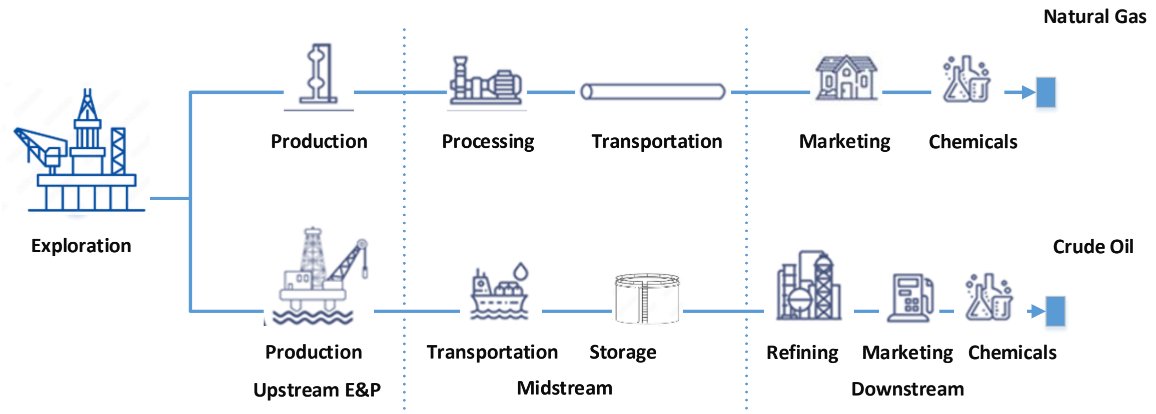


Figure 16 - Oil and Gas value chain
Source: cyleong.com

Different technologies are available for the processing and conversion of the fuels into more refined formats along the value chain. As part of the roadmap process, cleaner production technologies have been identified that could be used to improve efficiencies or reduce emission impacts. Each of these are presented in a high level summary, noting its relevance in the South African context with regard to its potential impact, role and suitability to contribute to a feasible, cleaner fossil fuels roadmap.

Potential Point Sources of CO_2

The applicable technology for the management of CO_2 is dependent on the source (location) and the concentration of the CO_2 in the flue gas stream.

The sources are typical power plants or industrial factories that utilise coal for heat or process applications. A higher concentration of CO_2 in the flue gas requires less infrastructure and costs to capture and process for compression, storage and transport to a suitable sequestration site.

Point sources for CO_2 capture from power generation and industrial sectors is shown in the table below.

Sources	Concentration of CO_2 in Flue Gas Streams	Typical Technology to be Used for CO_2 Capture
Power Plants – Natural Gas	Up to 4 %	Metal-organic frameworks or chemical systems.
Power Plants – Coal	8 to 10%	Chemical solvents, e.g. Amine processes.
Cement	15 – 20%	Physical solvents, solid sorbents, or membranes. Sodium carbonate, potassium carbonate and calcium carbonate processes. Membrane material includes zeolite, ceramic, polymer and silica.
Steel	20 %	Physical solvents, solid sorbents, or membranes. Sodium carbonate, potassium carbonate and calcium carbonate processes. Membrane material includes zeolite, ceramic, polymer and silica.
Hydrogen Plant	15 – 45%	Physical solvents, solid sorbents, or membranes. Sodium carbonate, potassium carbonate and calcium carbonate processes. Membrane material includes zeolite, ceramic, polymer and silica.
CTL	~ 80%	Benfield, Selexol and Rectisol processes - compression and dehydration, membranes, or physical solvents.

Table 2 – Potential Point Sources of Carbon Dioxide

Sources: NETL (USA); Sasol

TECHNOLOGY RANKING CRITERIA

Criteria for ranking of technologies that were considered is described in this section, it includes:

- Greenhouse gas reduction (relative cost and emissions impact)
- Technology maturity (research, pilot-demonstration, commercial status)
- Other criteria that were considered
    - Project development risk (legal challenge, lack of enabling infrastructure, policies and regulatory, funding)
    - Just transition (secure workers' rights and livelihoods)

Greenhouse Gas Reduction

The first ranking criterion considers the relative impact on GHG emission reductions.

The major harmful GHG are carbon dioxide (CO_2), methane (CH_4), nitrous oxides (NOx) and fluorinated gases, each with different global warming potential (GWP). Carbon dioxide constitutes the major human caused GHG today.

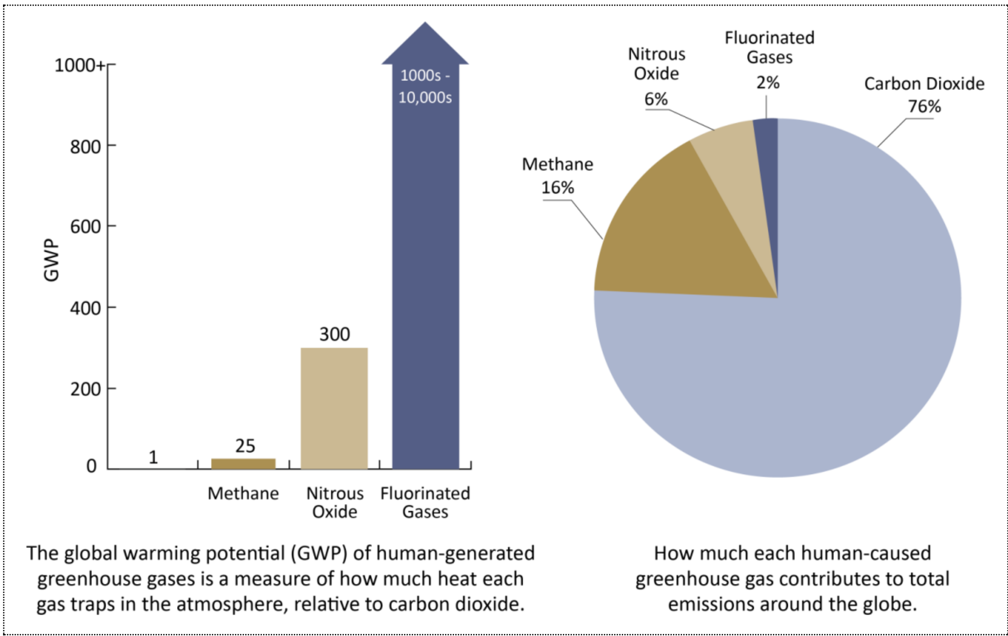


Figure 17 - *Warming potential of greenhouse gases*
Source: IPCC

Implementation of cleaner fossil fuel technology results in a range of reductions in greenhouse gas (GHG) emissions[1]. Technologies have been ranked based on their relative cost and emission reduction impact. For example, a technology that achieves a similar efficiency at significantly less cost compared to a competing technology would be ranked higher.

All technologies that improves efficiency of energy usage, will result in less fossil fuel usage, and by implication less CO_2 emissions. The more efficient, the higher the ranking for GHG reductions.

[1] A greenhouse gas is any gas that has the property of absorbing infrared radiation (net heat energy) emitted from Earth's surface and reradiating it back to Earth's surface, thus contributing to the greenhouse effect. The primary greenhouse gases in Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide, and ozone – Britanica.com

Furthermore, complete replacement of a fossil fuel-based technology with a non-fossil fuel one, for example renewable power replacing coal power, would receive the highest ranking for GHG reduction.

Similarly, technology that removes CO_2, such as Direct Air Capture and Storage, would receive the highest ranking.

Technology Maturity

Some technologies are still in research and development (R&D) phase in laboratories or subject to pilot plant demonstration units in the field to improve efficiencies, reduce costs or optimise outputs. Developers will be reluctant to use technology that is not economically viable or commercially operational around the globe.

While technology can be proven, it may not be developed to the scale required by the specific intended application in SA. For example, while water electrolysis is proven technology, the size and scale envisaged to produce millions of tons of green hydrogen has not been demonstrated yet due to the high costs of production, which is promoting ongoing research and technology improvements to reduce production costs.

Thus the broad descriptions of current technology are:

- **Research and Development (R&D):** technology being evaluated in the laboratory for technical feasibility
- **Pilot demonstration plant:** pilot scale plant to demonstrate the readiness and feasibility of scaling up technology to commercial operations.
- **Commercial Operations:** technology is offered commercially by engineering and technology companies with examples of plant operations at scale worldwide.

Other Considerations within South Africa Context

Project Development Risk

Within South Africa there's a range of risks or barriers to successful project development emanating from a number of sources, and thus it is prudent to highlight below:

- **Legal challenge** – fossil fuel developments such as exploration activities, new coal plants and expansion of existing carbon intensive plant operations are increasingly subjected to environmental legal challenges in SA courts. Legal challenges can significantly delay project development and can be a significant risk to the successful execution of projects.
- **Lack of Enabling Infrastructure** – certain technologies are dependent on the supporting infrastructure to enable the technology to be used in a specific location or at a designed rate of use. For example, natural gas must be available in sufficient quantities at a location of a Combined Cycle Gas Turbine (CCGT) development. This may require gas pipeline networks to deliver the gas from an import terminal to the site of the CCGT. Similarly, additional electricity grid and distribution infrastructure may be required to deliver renewable power from the generating site to users in areas where economic activity requires the energy
- **Policy and Regulatory Uncertainty** – many of the new technologies being considered for SA do not have associated policies and regulatory frameworks in place and/or require amendments to deal with current realities and economic imperatives. For example, carbon capture and storage (CCS), Underground Coal Gasification (UCG) and Biofuels blending in fuels have many regulatory issues and questions that need to be resolved before certainty is established for large scale developers of the technology.

- **Availability of Funding** – financial institutions carefully consider reputational damage in the event they are perceived to be funding environmentally damaging projects. Many fossil fuel projects, especially new coal plants, have experienced difficulty in finding project funding.

Where one or more of these risks are relevant for a technology, they are highlighted in the technology discussion below.

South Africa Just Transition

While the mining, industrial and transport processes associated with fossil fuels are prime sectors to target for GHG reductions in order to meet SA commitments for global GHG reductions, it must be acknowledged that these industries are significant contributors to SA GDP and employment opportunities. It is therefore a reality that fossil fuels are forecast to remain the major source of primary energy over the medium term. The transition to cleaner technology must therefore comprehend SA's economic reality and has to incorporate "just transition" principles.

Just transition is a framework that was developed to encompass a range of social interventions needed to secure workers' rights and livelihoods when economies are shifting to sustainable production, primarily combating climate change and protecting biodiversity[2]. Thus technology that prevented large scale losses of jobs, or has the potential to create many jobs, is ranked high.

The development of a biofuels industry, for example, has the potential for creating many jobs in the biofuel value chain, while at the same time leveraging SA's natural biomass resources and offsetting US$-based imports.

The suitability of developing renewable solar and wind power in SA is ranked high, because SA is richly endowed with solar and wind resources and large expanses of suitable land required for these technologies. It also has significant potential for employment creation[3].

Generally large infrastructure development projects are major contributors to employment opportunities. Furthermore additional power capacity is critical for SA economic growth, which means further job opportunities. Thus most of the technologies considered are supportive of a just transition. In the technology discussions below, where a technology choice has a significant positive or negative impact for a just transition, it is highlighted for that technology.

Coal and Gas Power Design and Efficiency Improvement Technology

Four technologies were identified with potential to improve the efficiency and reduce the carbon impact of power station design and operations. These are Super Critical (SC), Ultra Super Critical[4] (USC), Open Cycle Gas Turbines (OCGT) and Combined Cycle Gas Turbines (CCGT). Details of the technology are available in TECHNOLOGY OVERVIEW section. Although Advanced Ultra Super Critical (AUSC) and Integrated Gasification Combined Cycle (IGCC) offered higher efficiency operation, when assessed against the technology maturity criteria, they present more risk for successful implementation due to their lack of commercial operations at scale.

The coal and gas technology relative efficiency and maturity are provided in the figure below.

- All coal technologies, except Advanced Ultra-Supercritical (AUSC) and Integrated Gasification Combined Cycle (IGCC) are mature proven technologies with commercial operations around the world.

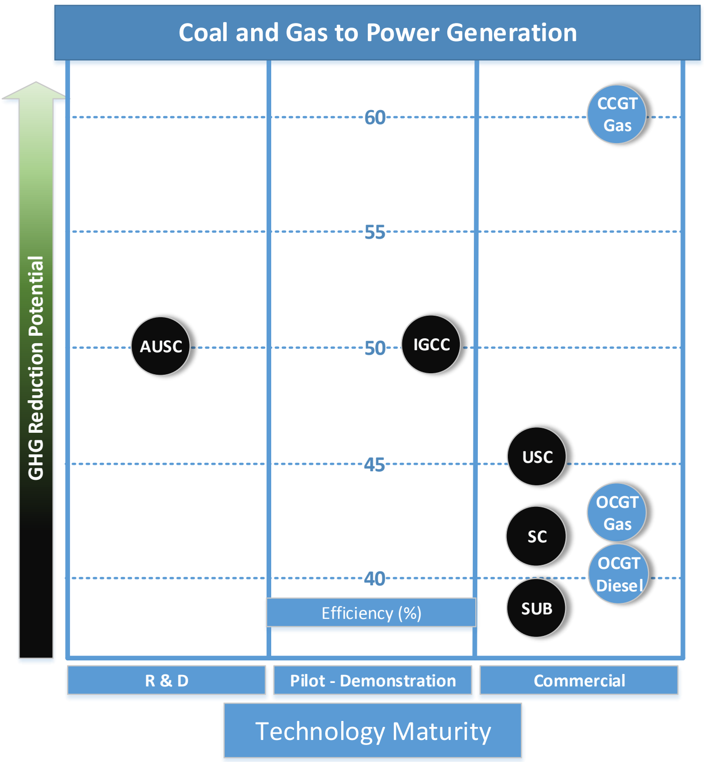
---

[2] International Trade Union Confederation principles

[3] IRENA study: https://www.irena.org/publications/2021/Oct/Renewable-Energy-and-Jobs-Annual-Review-2021

[4] SC plants operate at temperatures of 565-593 deg C and pressures of > 22Mpa. USC plants operate at 593-610 deg C and 25-30 Mpa. Higher temperatures and pressures increase plant efficiencies.

- Ultra-Supercritical (USC) plants deliver higher design efficiencies than Super Critical (SC) plants and so are preferable to SC plants.
- CCGT gas turbine technology offers the highest efficiency at 60%, provided there is a reliable gas supply to the power plant. CCGT plants are usually designed for mid-merit to baseload power, whereas OCGT have more flexible operation with quick start-up times and thus more suited for peaking load operation.
- The risk for a successful natural gas power project in SA is the lack of supporting gas infrastructure to support a CCGT power station i.e. transporting gas from an LNG import facility to the site of the power plant. The current imported gas by Rompco pipeline is insufficient to meet additional power generation demands. Unfortunately SA does not have proven oil and gas resources that could be commercialised. Total's recent discovery of gas and condensate in Brulpadda and Luiperd requires years of development before production can begin.
- Since all coal technologies continue to use the huge coal resources of SA and offers reliable base load power and continuing employment opportunities in the value chain, it supports a Just Transition for SA.



SUB = Subcritical; SC = Supercritical; USC = Ultra Supercritical; AUSC= Advanced Ultra-Supercritical; IGCC = Integrated Gasification Combined Cycle; OCGT = Open Cycle Gas Turbine (diesel and gas); CCGT = Combined Cycle Gas Turbine

Figure 18 – Technology Ranking - Coal and Gas Power Generation

- The technologies above (SC, USC, AUSC) refer to the overall power plant design. Within these designs, there are coal combustion options i.e. **pulverised coal (PC)** and **circulating fluidised bed combustion (CFB)**. CFB technology is suited to combusting lower grade coals and/or biomass and is therefore considered the better option for South Africa.

Air and Flue Gas Cleanup and Carbon Capture Technology

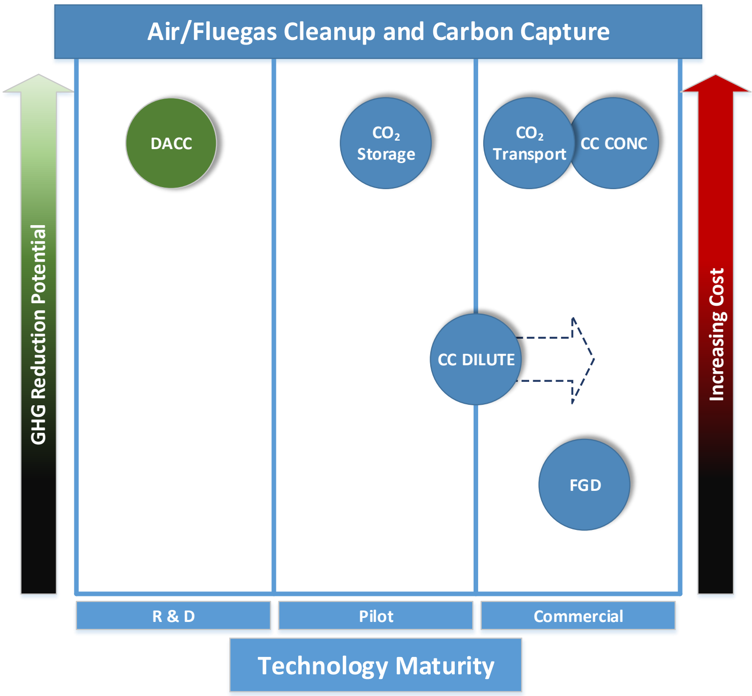
These technologies include removal of pollutants from flue gases and are referred to collectively as flue gas desulphurisation (FGD). This includes removal of sulphur oxides (SO_x), nitrous oxides (NO_x), ash particulates (PM) and other toxic compounds such as mercury. It should be noted that SO_x and NO_x are not GHGs[5] but pollutants, and their emissions are regulated by various environmental regulations. All new plants must comply with minimum SA emission standards regarding pollutants and it is a given that FGD technology is included in all new plants where required.

Carbon capture technology refers to removal of carbon dioxide (CO_2) from flue gases, or directly from the air (Direct Air Carbon Capture DACC). Flue gas CO_2 removal has been split into 2 types – streams with high

[5] Although NO_x themselves are not GHGs, nitrogen oxides act as indirect greenhouse gases by producing the tropospheric greenhouse gas ozone via photochemical reactions in the atmosphere.

concentration of CO_2 (CC-CONC) and streams with low concentrations (CC-DILUTE). Associated with carbon dioxide capture technology, is the compression and transportation of CO_2 and the eventual storage of CO_2 in suitable geological structures underground.

Air, Flue Gas Clean-up and Carbon Capture technology GHG reduction potential is plotted against Technology Maturity in the figure below. A description of the various clean-up and carbon capture technologies is provided in the section TECHNOLOGY OVERVIEW.



FGD = Flue Gas Desulphurisation; CC-CONC = Carbon capture from concentrated CO_2 streams; CO_2 TRANSP = Carbon dioxide transport; DACC = Direct Air Carbon Capture; CC-Dilute = Carbon capture from dilute CO_2 streams; CO_2 Store = Storage of CO_2

Figure 19 - Technology Ranking - Air/Fluegas Clean-up and Carbon Capture

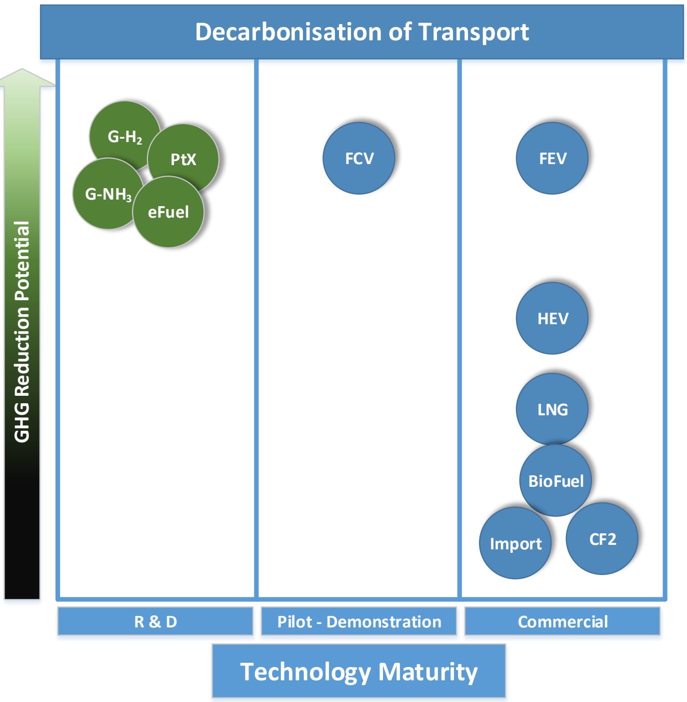
- FGD technology is mature proven technology and should be designed into any new plant that emits pollutants. However, it provides minimal GHG reduction.
- Removal of CO_2 from streams with high CO_2 concentrations is proven technology and is used extensively globally. The nature of coal to liquids, cement and iron and steel processes deliver gas streams with high concentrations of CO_2. If the CO_2 is captured and not released to atmosphere as in currently practiced, the GHG reduction potential is major. The technology works best and is more cost effective when used on concentrated CO_2 streams, and thus coal and gas to liquids, cement and iron and steel applications should be considered.
- Coal plants use air for combustion and as a result, the flue contains large amounts of inert nitrogen which dilutes the concentration of carbon dioxide. The removal process (CC-DILUTE) is more costly (larger plants required for larger volumes of flue containing nitrogen) and less efficient capture of CO_2. Thus the GHG reduction is less than CC-CONC and is riskier due to the variability of flue gas composition of coal plants. CC-CONC technology is therefore preferred over CC-DILUTE.
- Transport and storage of carbon dioxide is commercially operational world-wide, especially when used in depleting oil production fields for Enhanced Oil Recovery (EOR) purposes. In SA suitable sites for carbon storage must still be evaluated and is the subject of current pilot study by the Council for Geoscience.
- DACC technology has not reached the level of cost efficiency at the scale required for significant industrial applications however, it is viewed as a significant enabler of carbon reduction in the medium to long term.
- All technologies require significant energy input and thus carry significant capital and operational costs.

Decarbonisation of Transport

The use of fossil fuels in transport contributes to a significant portion of SA GHG emissions. Reducing these emissions require either blending with sustainable biofuels or transition to non-fossil fuel engine technology such as electric vehicles. In the longer term, technology may be developed to produce fuels using renewable energy to combine captured carbon and green hydrogen into sustainable E-Fuels.

Various fuel and engine technology GHG reduction potential versus technology maturity is shown in the figure below. More detailed descriptions of the various technologies are provided in the **TECHNOLOGY OVERVIEW** section.

- The refinery Clean Fuels 2 programme, despite requiring large capital investment, has little impact on GHG emissions when the products are used in transportation. While engine efficiency may be marginally improved by using lower sulphur fuels, the impact on GHG emissions is minor and is not viewed as a transport decarbonisation strategy.
- Shutting down refineries and importing clean fuels carries low risk as a significant proportion of fuel is already imported through Durban, Cape Town, Richards Bay, Maputo and Mossel Bay. However, in a scenario of all crude refinery shutdowns, the ability of the Durban harbour import infrastructure (berths and back of port) and the pipeline capacity (NMPP and Crude Oil Pipeline) to supply the main Gauteng inland demand region would have to be confirmed. Any constraints in this supply corridor would increase the risk to security of fuel supply. Refinery shutdowns and full imports would be an unsuitable socio-economic scenario for SA.
- Internationally Brazil has an ethanol market and the US and EU have blended biofuels for many years. In SA, however, current issues revolve around sustainable development of suitable crops by disadvantaged people at scale, subsidisation of manufacturing, supply chain issues and price regulation. There is still uncertainty whether biofuels will be able to be manufacture products cost efficiently and make a reasonable margin. Biofuels supports SA's Just Transition.
- The choice of LNG vehicles over fuel cell vehicles do have the risk of "locking in" technology for their companies. LNG technology also assumes a reliable and efficient supply of LNG in SA which is currently a constraint. Potential users are also concerned there is a risk of LNG attracting fuel levies and taxes in future.
- Current vehicle and battery technologies carry low to medium risk as these are proven technologies currently available. There are concerns, however, for the lack of enabling charging infrastructure countrywide that would support deployment of the technology at scale. Without this certainty of "available charging facilities", the time period required for charging and the cost of such facilities will



CF2 = Clean Fuels 2; IMPORT = Import clean fuels/shutdown refineries; BIOFUELS = Blend biofuels in transport fuels; LNG = LNG vehicles; HEV = Hybrid electric vehicles; FEV = Full electric vehicles, FCV = Fuel cell vehicles; G-H_2 = Green hydrogen; G-NH_3 = Green ammonia, EFUELS = E fuels produced from green hydrogen and captured carbon, PTX = Power to transport fuels produced from green hydrogen

Figure 20 - Technology Ranking – Decarbonisation of Transport

continue to dampen the use of electric driven transport in SA, thereby limiting the impact on GHG reduction. The high cost of these vehicles is also a barrier to technology use. It is also uncertain whether Eskom has the capacity to support large scale transition of public and commercial vehicles to electric drive.

- Electric vehicles should use green electricity to achieve effective GHG reduction. If charged from coal power, GHG reduction is minimal, if not worse (dependant on the percentage coal based power in the energy supplied).
    - Also electrical grid and distribution redevelopment must be at scale, such as demonstrated by the major investments in China and other countries to effect this. It should be noted that this includes the infrastructure owned and operated by Municipalities.
- SA also needs to consider the capital cost of switching from a “single” energy source and single point of dispensing petrol/diesel at filling stations to multiple energy source/technologies.
    - EV Charging (slow/fast/home)
    - EV Battery exchanges
    - Hydrogen
    - LNG
    - CNG
    - Petrol/Diesel

  Doing this will lose economies of scale and different classes might require different solutions, for example, diesel conversion to hybrid/fuel cell/LNG technology for heavy long haul transport and petrol conversion to hybrid/full electric for short haul and passenger transport.
- E-Fuel technology is all related to green hydrogen technology which is produced using renewable solar PV and wind power in an electrolysis process to split water to H_2 and oxygen. The green hydrogen can be subsequently used as an energy carrier to drive fuel cells or combined with carbon to produce fuels (PtX fuels), sustainable aviation fuel (SAF) or fed to an ammonia plant to make green ammonia. Manufacturing green hydrogen in this way avoids the commonly used steam methane reforming (SMR) process to make hydrogen, which is a large GHG emissions process[6].
- The cost of green hydrogen manufacture is relatively high around US$8+/kg, whereas a level of US$2/kg or less would enable large scale deployment of the technology. It is expected that this will be achieved in the medium to long term.
- Fuel Cell Vehicles (FCV) assumes a reliable and efficient supply of Green Hydrogen, which is not available at scale currently in SA. All hydrogen produced in SA is grey (fossil fuel based) and no excess hydrogen exists.
- Green hydrogen and ammonia production and subsequent E-Fuels manufacture potentially provides net zero carbon fuel for transportation. All these remain the subject of research and development to optimise processes to reduce costs and prove commercially viable at scale.
- Replacing a proportion of coal feedstock with natural gas in CTL plants (CTL-GAS) has a direct positive impact on GHG emissions as methane is less carbon intensive than coal. Assuming that additional natural gas is available in suitable quantities, use of this technology has good GHG reduction potential.

[6] SMR process make grey hydrogen. If SMR operates with CCS, the hydrogen is blue.

Hydrogen manufacturing process is described by ascribing colours i.e. brown and grey hydrogen is made from coal and natural gas, respectively, without carbon dioxide emissions capture and storage (CCS). Blue hydrogen is sourced from natural gas, but in this case, carbon dioxide emissions are captured and stored. Green hydrogen is produced using renewable power and is carbon free.

Thus blue hydrogen fulfils and equally important role as green hydrogen in reducing GHG emissions. The cost of carbon sequestration significantly adds to the cost of blue hydrogen production

Non-Fossil Fuel Power Generation

Non-Fossil Fuel Power plants include plants feeding biomass, nuclear plants and renewable solar and wind energy plants. All these technologies are commercially available at scale and have many plants operating worldwide. Nuclear and renewable power plants are carbon free and is part of many country strategic plans to reach net zero carbon by 2050[7]. Nuclear provides reliable baseload power while renewable power must be integrated with battery energy storage systems to smooth out power supply. Biomass power is considered renewable and replace carbon emissions from existing fossil fuels.

A description of the various non-fossil fuel technologies is provided in TECHNOLOGY OVERVIEW section.

- The relative costs[8] of non-fossil power plants are biomass < PV Solar/Wind < Nuclear.
- Nuclear provides base load power with zero carbon emissions and therefore must be considered as a transition energy technology. However, nuclear over and above the high capital cost does provoke strong public reaction and can be expected to raise a number environmental and other legal challenges.
- Renewable solar PV and wind power are now common in SA. The expansion of generating capacity from these sources faces the risk of inadequate grid and distribution infrastructure capacity, depending on the locations of the facilities.
- To enable renewable power to provide “baseload power”, battery infrastructure and other systems are required to supplement supply for continuous power requirements.
- Successful implementation of biomass power plants will largely depend on sustainable and reliable biomass and supply logistics solutions, which may be challenging to achieve.

Summary of Preferred Technologies

The following tables provide a brief summary of the preferred technology choices.

COAL POWER VALUE CHAIN

	Steam Technologies			Coal Gasification	Combustion Technology		
Technology	**SC**	**USC**	**AUSC**	**IGCC**	**UGC**	**CFB**	**PC**
1st Choice		✓				✓	
2nd Choice	✓						✓
Timeframe	**ST**	**ST**				**ST**	**ST**

SC = Supercritical; USC = Ultra-Supercritical; AUSC = Advanced Ultra-Supercritical; IGCC = Integrated Gasification Combined Cycle; CFB = Circulating Fluidised Bed; PC = Pulverised Coal

Timeframe: ST = short term less than 10 years; MT = medium term 10 to 20 years; LT = long term greater than 20 years

[7] Countries with nuclear in their plans include USA, France, Brazil, Russia and Ghana – source: International Atomic Energy Agency

[8] Power Generation Technology Data For Integrated Resource Plan Of South Africa, EPRI-DMRE, 2017

GAS POWER VALUE CHAIN

Prerequisite for technology: LNG import infrastructure in SA ports and associated gas transmission pipelines to demand centres.

Technology	OCGT Diesel	OCGT Gas Note 1	CCGT Gas Note 2
1st Choice		✓	✓
2nd Choice	✓		
Timeframe	ST	ST	ST

Note 1: OCGT preferred technology for peaking loads
Note 2: CCGT preferred technology for baseload and mid-merit loads
OCGT Diesel = CCGT Diesel Fuel; OCGT = Open Cycle Gas Turbine Gas Fuel; CCGT = Combined Cycle Gas Turbine
Timeframe: ST = short term less than 10 years; MT = medium term 10 to 20 years; LT = long term greater than 20 years

DECARBONISATION OF TRANSPORT

Prerequisites:

- SA electricity transmission and grid capacity expansion for electric vehicles
- LNG vehicles require LNG imports and associated gas pipeline infrastructure
- Renewable power at scale for production of green hydrogen, ammonia and E-Fuels

	Current Fuels			Drive Train Options				Future Fuels		
Technology	Clean Fuels CF2	Import	Biofuels	LNG ICE Vehicles	HEV	FEV	FCV	G-H_2	G-NH_3	PTX
1st Choice	✓		✓			✓	✓	✓	✓	✓
2nd Choice		✓		✓						
Timeframe	ST	ST	ST	ST	ST	ST	MT	LT	LT	LT

CF2 = Clean fuels 2; IMPORT = import fuels/shutdown refineries; BIOFUEL = Biofuels blending into fuels; HEV = Hybrid Electric Vehicles; FEV = Full Electric Vehicles; FCV = Fuel Cell Vehicles; G-H_2 = Green Hydrogen; G-NH_3 = Green Ammonia; PtX = Fuels made from green H_2; E-FUELS = Fuels made from green H_2 and Captured Carbon.
Timeframe: ST = short term less than 10 years; MT = medium term 10 to 20 years; LT = long term greater than 20 years

NON-FOSSIL FUEL POWER

Technology prerequisite: SA electricity transmission and grid capacity expansion to link renewable power.

Technology	SOLAR PV	WIND	NUCLEAR
1st Choice	✓	✓	
2nd Choice			✓
Timeframe	ST	ST	ST to MT

SOLAR PV = Solar photovoltaic power; WIND = Wind Power; NUCLEAR = Nuclear Power

Timeframe: ST = short term less than 10 years; MT = medium term 10 to 20 years; LT = long term greater than 20 years

CARBON CAPTURE, STORAGE AND USE TECHNOLOGIES

Technology Prerequisites:

Suitable geological site for carbon dioxide storage. Pipeline infrastructure to transport carbon dioxide from source to storage site.

Technology	CC-DILUTE	CC-CONC	DACC	CO_2 TRANSP	CO_2 STORE	CO_2 USE
1st Choice		✓		✓	✓	
2nd Choice	✓					✓
Timeframe	MT	ST		MT	MT	LT

CC-DILUTE = Dilute CO_2 gas streams; CC-CONC = Concentrated CO_2 streams; DACC = Direct air carbon capture; CO_2 TRANSP = CO_2 transport by pipeline; CO_2 STORE = Storage of CO_2 underground; CO_2 USE = Using captured carbon dioxide to make products

Timeframe: ST = short term less than 10 years; MT = medium term 10 to 20 years; LT = long term greater than 20 years

FOSSIL FUELS TECHNOLOGY PATHWAYS TO REDUCED GHG EMISSIONS

Context of Cleaner Fossil Fuels

The current reality for South Africa is that the country is highly dependent on fossil fuels for its energy needs and will remain so for many years to come.

Notwithstanding, SA's Nationally Determined Contribution (NDC) to the global effort to reduce GHG emissions and combat climate change obligates the SA government to embark on a programme that guides energy technology selection that is aligned with and contributes to the overall goal of GHG emissions reduction that meets the NDC targets in a sustainable and affordable way.

Technology Guided by GHG Reduction Philosophy

It is within this context that the Cleaner Fossil Fuels programme seeks to identify technology pathways that reduces GHG emissions from the use of fossil fuels. Technology selection is guided by the following basic GHG reduction philosophy:

- Processes that achieve improvements in operational and energy efficiencies. Higher efficiencies require less energy input which, in turn, results in less GHG emissions.
- Feedstock co-firing or substitution of fossil fuel with less carbon intensive fuels or biomass reduces GHG emissions.
- Replacement of fossil fueled energy with non-fossil fueled energy (renewables and nuclear) eliminates carbon emissions.
- Using fossil fuels with carbon capture technology reduces and/or eliminates the impact of fossil fuel use on GHG emissions.
- Capturing, storing and subsequent use of carbon dioxide in beneficial products and processes achieves net zero and/or net negative carbon emissions (carbon circular economy).

Fossil Fuel Sector Value Chain Analysis

The following fossil fuel sector value chains are analysed and discussed in the ensuing sections:

- Power generation
- Liquid fuels, gas and petrochemicals
- Carbon capture, storage and usage

In the sector analysis, the relationships between different technologies are shown diagrammatically. Where relevant, pathways show optional technologies for efficiency improvements, GHG reduction technologies using alternative feedstocks, potential integration with renewable and/or nuclear power with fossil fuel processes and where carbon capture, storage and usage opportunities (CCUS) exist in the value chain. In effect, the pathway diagrams represent the basis of a technology roadmap for Fossil Fuels in a future reduced GHG scenario for South Africa.

Challenges and Barriers for Technology Execution

Where significant challenges or barriers exist for the successful implementation of technologies, these are indicated in the pathway diagrams. In most cases, the successful implementation of technology requires **enabling infrastructure** which is **absent and/or lacking sufficient capacity to support** the new projects. A typical example of these barriers is the requirement to increase the capacity of the electricity transmission and distribution grids, and the development of LNG/natural gas import infrastructure and the expansion of SA's primary gas distribution pipeline network.

In these cases, new technology cannot proceed without prior or parallel development of the supporting infrastructure and will, by necessity, constitute the critical path for the development of the new technology i.e. ***the timeframes for the development of supporting infrastructure will determine the timeframe of the execution of GHG reduction projects.***

COAL POWER GENERATION VALUE CHAIN OVERVIEW

An overview of the coal power generation value chain is shown in the figure below. It could apply equally to gas or biomass fired generation. The technology pathways to achieve GHG reduction follows the previously discussed GHG reduction philosophy i.e. efficiency improvement, less carbon intensive feed material, carbon removal through capture, transport and storage and finally, conversion of CO_2 to commodity products to achieve net zero or negative carbon emissions.

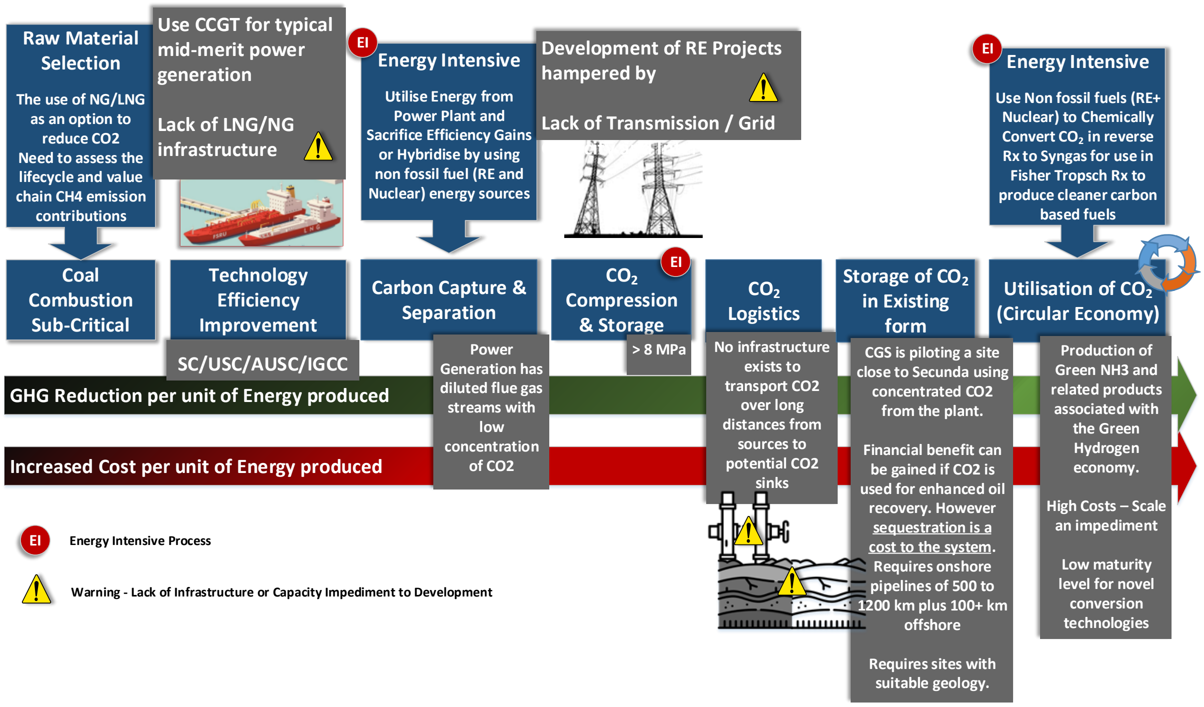


Figure 21 - Coal Power Generation Value Chain Overview

Key Messages from the Coal Power Value Chain Overview

- The combustion of fossil fuels is an easy process to liberate huge amounts of energy with the associated release of GHG emissions. It is therefore expected that the reverse processes of capturing the carbon, transporting and storing it and conversion to other chemicals requires large energy intensive processes.
- Coal technology has shown significant efficiency improvements over current sub-critical technology. The supercritical boiler designs (USC, AUSC and IGCC) pushes efficiency up to 50%, from the current 38% for sub-critical plants.
- Less carbon intensive fuel such as natural gas has a GHG reduction potential of 20% to 40% over coal firing, depending on the quality of the coal. This suggests that NG firing could be retrofitted to retiring coal plants. However, the cost of refurbishing old coal plants may be uneconomical, and thus developing modern designed combined cycle gas turbines with efficiencies of 60% may be a better option. Currently the lack of LNG imports and gas pipeline infrastructure constrains the use of gas in coal plants.
- The downstream coal value chain encompassing the capture, transport, storage and usage of CO_2 is hugely energy intensive and requires major development of carbon capture technologies, CO_2 gathering, compression and pipeline infrastructure and a suitable geological site for storage.
    - *It is prudent to identify and develop additional large scale suitable geological storage sites in SA before any CCUS technologies are implemented at scale. The timeline for this is anticipated to be up to 10 years.*

- *Not all sources containing CO_2 may be suitable for carbon capture. Streams that contain high concentrations of CO_2 (60% plus) perform best in capture plants. This implies that coal powers stations in SA would not meet the criteria (CO_2 concentration of about 13%). Coal power station flue gas would have to be cleaned first (impurities removed), then captured and concentrated and finally pressurised for transportation.*

The Council for Geoscience is developing a CCS pilot programme in Leandra Mpumalanga near the Sasol Secunda plants.

Over the next 2 to 5 years, the pilot will evaluate transporting Secunda CO_2 by truck to the site and pumping it underground into basalt geological structures.

The aim is to store 10,000 tons of CO_2, while monitoring the site to determine success of using basalt formations for carbon storage. Should the basalt geology prove to be successful in storing the carbon dioxide, the location in Mpumalanga is well suited as a carbon sink for other industries in the area, including coal power plants and other industries.

The transport infrastructure will be far less than required for offshore sinks.

POWER GENERATION PATHWAYS

The Power Generation value chain GHG reduction pathways are shown in the figure below. Current base load power is provided by coal and nuclear plants, while peaking power is provided by diesel fired OCGT plants and a selection of small capacity renewable power (hydro, pumped storage, solar and wind) which is not shown.

Key Messages from Power Generation Technology Pathways

Majority of SA coal plants are sub-critical designs averaging around 38% efficiency. High grade coals are scarce and most of coal stock today is low grade material.

- **GHG reduction** is achieved through **improved technology efficiencies**, ranging from 42% to 50%, provided by a range of supercritical coal plants operating at higher temperatures and pressures.
- There are options to use **circulating fluidised bed (CFB)** technology which is better suited for **low grade coal and biomass feedstock**.
- Diesel feeding peaking OCGT power plants is sourced from crude refineries. Converting OCGT's to **natural gas firing results in lower GHG emissions** due to the lower CO_2 emissions for natural gas (28% less CO_2 than diesel fuel). A significant efficiency gain of 20% over OCGT is obtained by a using a Combined Cycle Gas Turbine (CCGT) plant on natural gas. These plants are able to provide mid-merit to baseload power, on the assumption that there is a reliable supply of natural gas at scale.

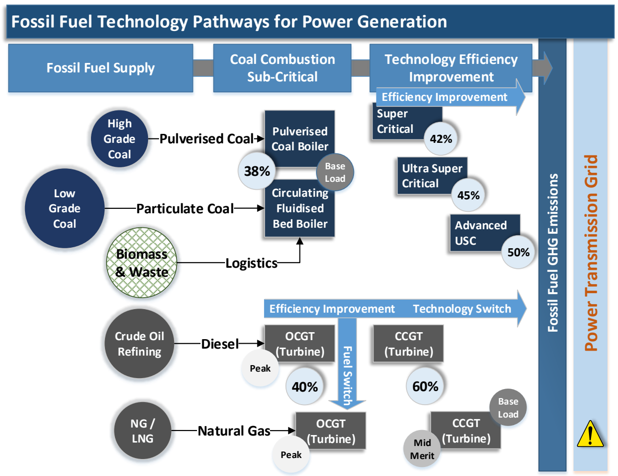


Figure 22 – Fossil Fuel Technology Pathways

  - *Critical enabling LNG import infrastructure in ports (LNG FSRU) and associated natural gas distribution pipelines are required to fully leverage CCGT technology. It is estimated that development of gas infrastructure will take 4 to 5 years to implement, thereby setting the timeline for gas power at scale.*

- With the planned shutdown of baseload Eskom coal power stations over the next 20 years (approximately 18GW) additional generation capacity must be developed. Part of the capacity will be provided by renewable solar PV, wind and battery energy storage systems (IRP19 provides for 6,400 MW of solar PV and 14,400 MW of wind by 2030).

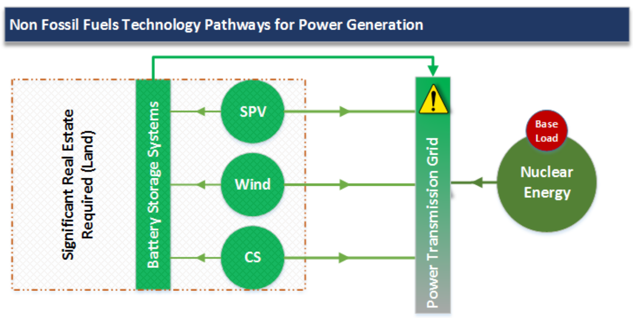


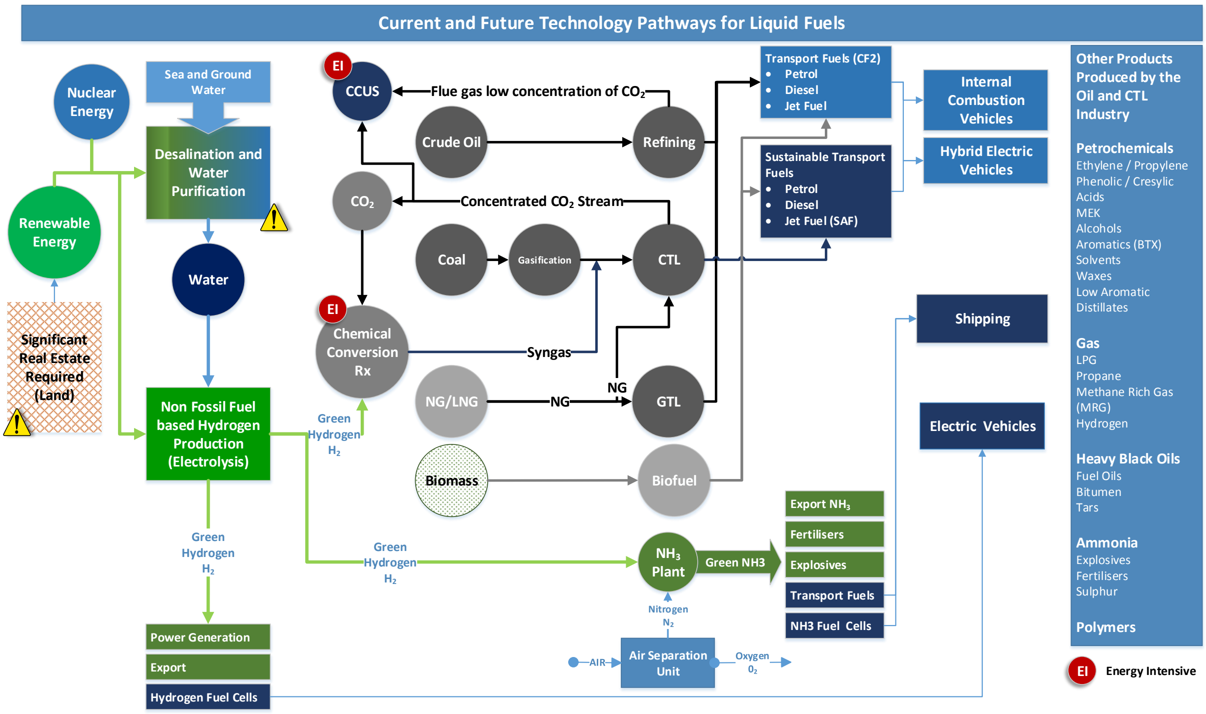
Figure 23 - Non Fossil Fuel Technology Pathways

  - *Critical enabling electrical transmission and distribution infrastructure capacity needs to be developed to support the integration of renewable power into the SA system. The cost of this is significant and will require 6 to 8 years to upgrade the capacity and reliability of the system. This sets the timeline for executing renewable power at scale.*
  - *Substantial land area is required for development of renewable power. At 1.5 ha/MW for solar PV and 20 ha/MW for wind, total land requirement, excluding battery storage systems, is estimated at approximately 370,000 ha, or 60km x 60 km.*

CLEANER LIQUID FUEL PATHWAYS

The liquid fossil fuels value chain GHG reduction pathways are shown in the figure below. Petrol, diesel, jet fuel and other transportation fuels are either manufactured in crude oil refineries and coal/gas to liquids plants or imported from international suppliers. A range of petrochemicals are also manufactured via the CTL plant. While the manufacturing plants do emit GHG's, it is the use of fossil fuels by users for transport and as energy sources that contributes to significant GHG emissions in SA.

Thus GHG reduction pathways therefore include options for feed material substitution to less carbon intensive feedstock, transition of engines to hybrid or non-fossil fuel engine technology, incorporation of renewable power in the production processes and ultimately leveraging the production of green hydrogen and green ammonia to make sustainable E-fuels. Capturing CO_2 in production processes and recycling it as a carbon source in the production of E-fuels is another option.



CTL = Coal to Liquids; GTL = Gas to Liquids; CCUS = Carbon Capture Utilisation and Sequestration; CF2 = Cleaner Fuels 2 Programme EI = Energy Intensive; NG = Natural Gas.

Figure 24 - Cleaner Liquid Fuels Pathways

Key Messages from Liquid Fuels Pathways

- There are few opportunities to reduce crude refinery GHG emissions, however, substituting natural gas for coal in the CTL process provides good GHG reduction potential in the short term.
  - *Critical enabling LNG import infrastructure in ports (LNG FSRU) and associated natural gas distribution pipelines are required to fully leverage this CTL opportunity. It is estimated that development of gas infrastructure will take 4 to 5 years to implement, thereby setting the timeline for gas feed to CTL at scale.*
  - *Transition to LNG/CNG vehicles will also be impeded by the lack of gas infrastructure.*
- Transition to hybrid and full electric vehicles is currently slow due to various barriers such as high cost of vehicles and lack of enabling infrastructure.

- *Uncertainty of future car charging facilities, charging time, location of networks, battery performance and technology support in future are various impediments to market penetration.*

- Introduction of biofuels blended into fuels provides GHG reduction potential.
- It is only in the long term with the development of green hydrogen and ammonia **at scale** that significant GHG reduction is possible with the production of sustainable E-fuels i.e. fuels made from combining green hydrogen and carbon sourced from biomass or carbon previously captured.
    - *Green hydrogen production requires significant renewable power resources which require significant land areas which are close to fuel production facilities. The option of using nuclear power for hydrogen production is available. Electrolysers manufacturing the green H_2 requires a minimum of 9kg water per kg H_2 produced. Water will have to be sourced from the sea or underground resources and will require energy intensive demineralisation processes before being used in the electrolysis process. Due to the demineralisation process, water consumption may double to 18 kg water or more per kg H_2.*
    - *Significant green H_2 production at scale will require critical enabling hydrogen infrastructure across SA to transport the H_2 to regions of demand as well as ports if an export market is developed.*
- Green H_2 is an enabler for the development of fuel cell technology as an energy source.
- Combining green H_2 with nitrogen in an ammonia plant produces green ammonia which presents a significant opportunity for fuels and chemicals production and for the hydrogen export market.
- The CTL process already incorporates the capture of CO_2 and thus has the opportunity of using this as a source of carbon for the production of sustainable fuels. Sasol have plans to make sustainable aviation fuel (SAF) from green H_2 in the medium to long term.
    - *It is estimated that the production of 8,000 bpd or 1,272 m^3/day of jet fuel will require about 145 tons of green H_2/day. Electrolysis power capacity required is in the order of 670MW assuming 50% load factor. Solar PV or wind power land requirements is estimated to be 22 km^2 and 67 km^2, respectively. This can be compared to current Secunda footprint of 9 km^2.*
    - *Production plants are continuous processes; thus a large battery storage energy system is required to provide 24/7 electricity supply.*

CARBON CAPTURE STORAGE AND UTILISATION PATHWAYS

In the medium to long term, achievement of GHG reduction targets and ultimately net zero by 2050 will require the removal of carbon dioxide from processes and the ambient air. If this can be economically used in the manufacture of commodity goods to "fix" the carbon, it will potentially offset the cost of capture, transport and storage.

Currently there are no carbon capture and storage operations in SA and most CO_2 is released to atmosphere. However, CO_2 capture technology is readily available commercially and is used extensively in oil refining and petrochemical plants around the world. In some cases, carbon dioxide is captured in power stations and used in oil fields in Enhanced Oil Recovery (EOR) processes, where CO_2 is pumped into the reservoirs and creates pressure to improve the flow of oil to the surface.

However, the carbon capture processes, development of CO_2 transport infrastructure and the development of suitable storage sites are very costly projects. The implementation of more carbon capture solutions on existing fossil fuel power generation capacity internationally will drive the cost down. Furthermore, the use of carbon dioxide in the manufacture of chemicals involve energy intensive chemical processes and is the subject of much research to find innovative ways to optimise these processes to the point where they can become commercially viable. Various carbon pathways from capture to use are shown below.

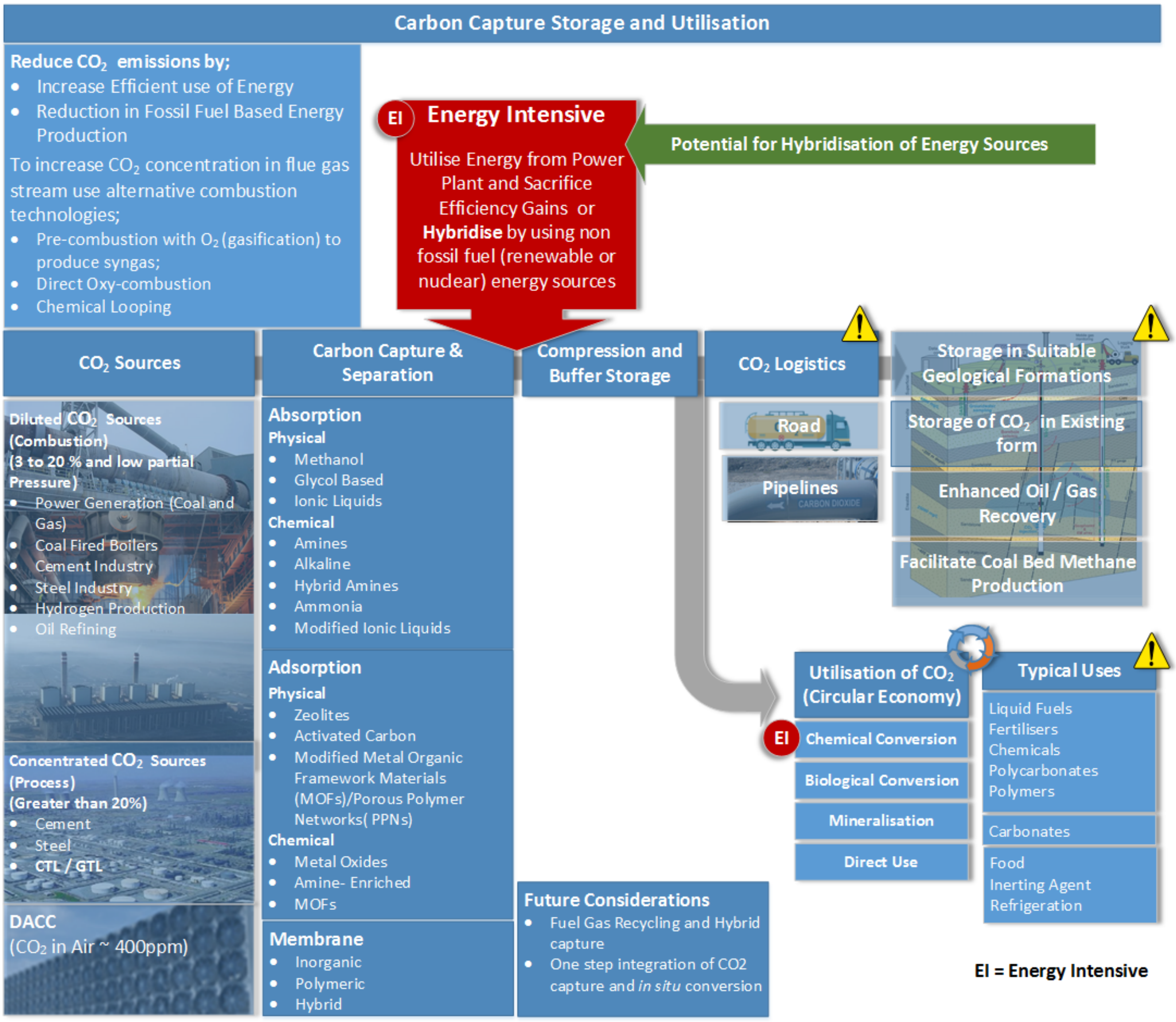


Figure 25 - Carbon Capture Storage and Utilisation Pathways

Key Messages from Carbon Capture Storage and Use Pathways

- Carbon capture and sequestration currently remains the only technology to implement a step change in emissions reduction for existing fossil fuel based power generation. Carbon capture provides an opportunity for fossil fuels to remain part of the energy mix and mitigate the current intermittent RE supply profile.
    - *Only retrofit efficient power stations with a significant useful life or new very efficient fossil fuel power stations.*
    - *There needs to significant policy, regulatory and financial support for CCS to drive the implementation*
- Carbon capture from streams with high concentrations of CO_2 is much more efficient and cost effective than dilute streams. All SA coal power plants fall into the dilute category (13% or less CO_2 in flue gas).
- There is a large range of CO_2 capture processes however all of them are energy intensive processes because the absorbed CO_2 has to be stripped out using heat and/or pressure swings which require energy input. <u>An undesirable consequence of this fact is a net efficiency penalty in power plants if generated power is used in the process.</u> Alternatively energy can be provided by non-fossil fuel sources for the capture processes.
- If CO_2 is moved over significant distances to places of storage, transport infrastructure in the form of compression and pipelines are required.
    - *Carbon dioxide is usually transported under supercritical conditions i.e. 8 MPa or higher pressure to avoid two phase flow. This requires large compression energy input and depending on the distances, may require multiple compressor stations along the way.*
    - *Primary pipeline transport networks will be costly to develop and CO_2 capture at scale will not be serviced by other transport means such as road or rail trucking. Distances could be between 500 and 1,000 km on land and an additional 100 km plus if storage sites are located offshore.*
    - *Storage sites require suitable geological structure to ensure that CO_2 remains sealed underground and does not leak or cause environmental damage to water or soil.*
- Conversion of CO_2 to chemicals and other commodities is a challenge chemically due to the high energy requirements. Until these processes become economically feasible (only expected in the medium to long term), CO_2 use will be limited to current demand by direct use in the food and beverage industry.

TECHNOLOGY OVERVIEW

Technology Metrics Comparison Descriptors

This section provides an overview of all technologies that have been considered for the Cleaner Fossil Fuels Roadmap. A short description is provided together with relevant process metrics and examples of any global commercial or pilot sites planned or in operation.

The suitability of applying the technology in South Africa is evaluated considering various factors, including whether it supports a Just Transition in SA. An estimate of project execution schedules, complexity and risk is given. Finally, a summary table of the overall key metrics for the technology is provided for comparison purposes with other technologies. Technology metrics considered and their comparison rankings are provided in the table below.

Table 3: Technology metrics comparison ranking descriptors

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium or Long Term Prospect	Overall Risk for Execution
Ready Commercially Available	**Penalty** Reduction In Efficiency	**Low** Minor or No Reduction in GHG	**$** Acceptable For Business Case Development	**Minor** Little or No Supporting Infrastructure Required	**ST** Short Term Less Than 10 Years	**Low** Low Uncertainty, Good Project Transparency
Demo Demonstration Plants Globally	**Reasonable** 5% Improvement Over Sub-Critical Coal Plants	**Acceptable** <50% Reduction in GHG Emissions	**$$** Requires Consideration of Options for Business Case Development	**Significant** Project Requires Supporting Infrastructure For Execution	**MT** Medium Term 10 To 20 Years	**Medium** Project Uncertainties Require Mitigation and Clarification
Pilot Pilot Programs Operational	**Good** 5 To 10% Improvement Over Sub-Critical Coal Plants	**Good** >50% Reduction in GHG Emissions	**$$$** High Cost Requiring Detailed Justification and Consideration of Options	**Major** Extensive High Cost Infrastructure Required for Execution	**LT** Long Term Greater Than 20 Years	**High** Major Uncertainties Requiring Further Study and Mitigation Strategies
R&D In The Lab	**Excellent** >10% Improvement Over Sub-Critical Coal Plants	**Excellent** Carbon Free Emission				

Table 4 – Technology Metrics Comparison Descriptors

COAL POWER STATIONS DESIGN AND EFFICIENCY IMPROVEMENT

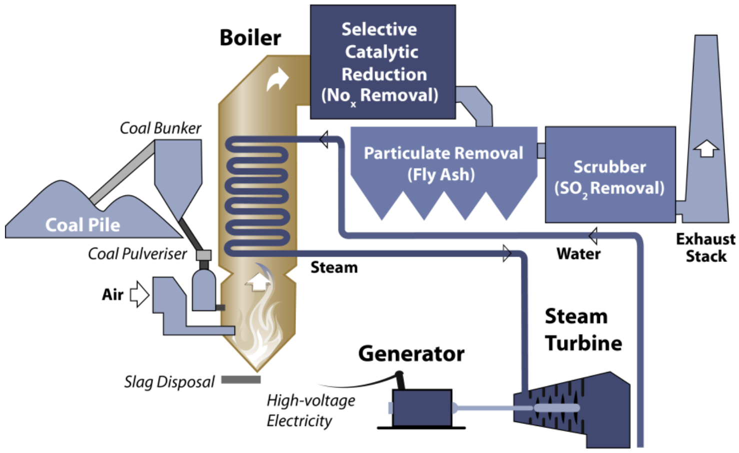
Supercritical Coal Power Plant (SC)

Description	Technology Metrics	Local and International Examples
▪ Coal power steam generators operating above the water critical point i.e. > 20 Mpa and > 374 deg C. Supercritical boilers are once through steam generators that don't require a steam drum to separate water and steam, which makes it more thermally efficient. ▪ Supercritical plants operate in the range of 565 to 593 deg C and > 22 Mpa.	▪ Thermal efficiency up to 42% - about 4% higher than subcritical plants. ▪ Note: on average, the following designs are expected[9] ▪ Sub-critical plant efficiency = 38% ▪ Supercritical efficiency = 42% ▪ Ultra-supercritical efficiency = 45% ▪ Advanced ultra-supercritical efficiency = 50% ▪ CO_2 emissions 800 to 880 gCO_2/kW, compared to subcritical plants at >880 g CO_2/kW. ▪ Cost: R37,000/kW (source: DOE IRP Technology Costs, 2017)	▪ South Africa Medupi and Kusile plants are based on supercritical plant technology with efficiencies of 40%. ▪ There are hundreds of supercritical coal plants currently operating around the world. ▪ Note: Most new plants been built today are Ultra-Supercritical Coal plant designs because they achieve higher efficiencies.

Applicability to South Africa and Impacts on Other Issues

Well established technology with many operating plants globally. SA has experience with Medupi and Kusile and can learn from this experience based on the operational and design issues that have been experienced. Leverages SA's coal resources while taking advantage of coal plant efficiency technology – supports Just Transition principles.

The downside of retrofitting flue gas desulphurisation technology on Kusile is a 2.5% reduction in efficiency i.e. from 40% to 37.5%. This is due to the increased energy required by the desulphurisation process, meaning less energy goes into electricity generation.



Source: safeenvironment.wordpress.com

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule
Coal plants typically involve design and engineering for 2 to 3 years, followed by construction of 5 years. Total 7 to 8 years.

Complexity and Ease of Implementation
SA has experience with Medupi and Kusile and should learn from these projects. Many plants currently operational worldwide – proven technology

Project Risks
While World Bank recognises that transitioning away from coal is important to fight climate change, they acknowledge that phasing out coal is complex and difficult and must achieve a "Just Transition". Notwithstanding, coal plants could face risks of financial institutions withholding finance for fossil fuel projects. Coal projects may face environmental legal challenges.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	REASONABLE	ACCEPTABLE	$$$	MINOR	ST	MEDIUM

9 *Fossil Fuel Foundation, Response to Draft IRP2018, Presentation to Parliament Portfolio Committee, 26 Oct 2018*

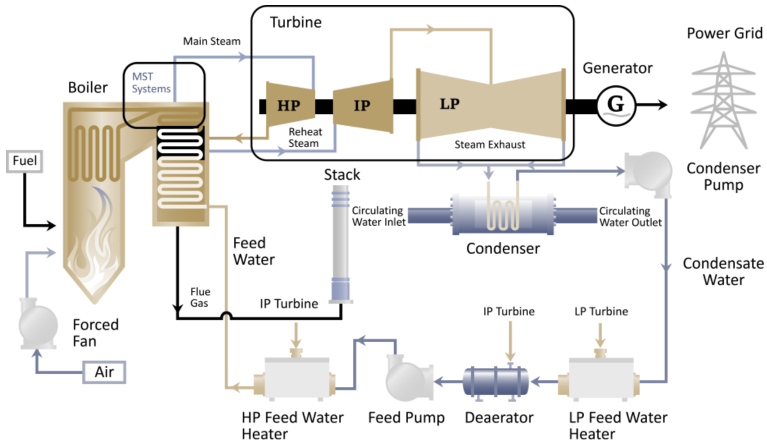
Ultra-Supercritical Coal Power Plant (USC)

Description	Technology Metrics	Local and International Examples
▪ Ultra-Supercritical boilers are once through steam generators that don't require a steam drum to separate water and steam, which makes it more thermally efficient. ▪ Ultra-Supercritical plants operate in the range of 593 to 610 deg C and 25 to 30 Mpa.	▪ Thermal efficiency of up to 45%, some 3 to 4% higher than supercritical plants. ▪ CO_2 emissions 740 to 800 g CO_2/kW ▪ Cost: Up to 10% higher than SC plants. Uses super alloy materials of construction to withstand the extreme temperatures and pressures.	▪ There are more than 400 USC plants operating globally. A record-high efficiency of 47.5% was achieved by the 912 MW RDK unit 8 in Karlsruhe Germany[10], which operates at 600 to 620 deg C and 28.5 MPa.

Applicability to South Africa and Impacts on Other Issues

Leverages SA's coal resources while taking advantage of coal plant efficiency technology – supports Just Transition principles.

Suitable technology for SA. The 4% increase in efficiency and 10% reduction in CO_2 emissions appear to justify the 10% increase in cost over SC plants.



Source: researchgate.net

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Coal plants typically involve design and engineering for 2 to 3 years, followed by construction of 5 years. Total 7 to 8 years.

Complexity and Ease of Implementation

Proven technology so suitable for SA.

Project Risks

While World Bank recognises that transitioning away from coal is important to fight climate change, they acknowledge that phasing out coal is complex and difficult and must achieve a "Just Transition". Notwithstanding, coal plants could face risks of financial institutions withholding finance for fossil fuel projects. Coal projects may face environmental legal challenges.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	GOOD	GOOD	$$$	MINOR	ST	MEDIUM

10 https://www.ge.com/steam-power/coal-power-plant/usc-ausc

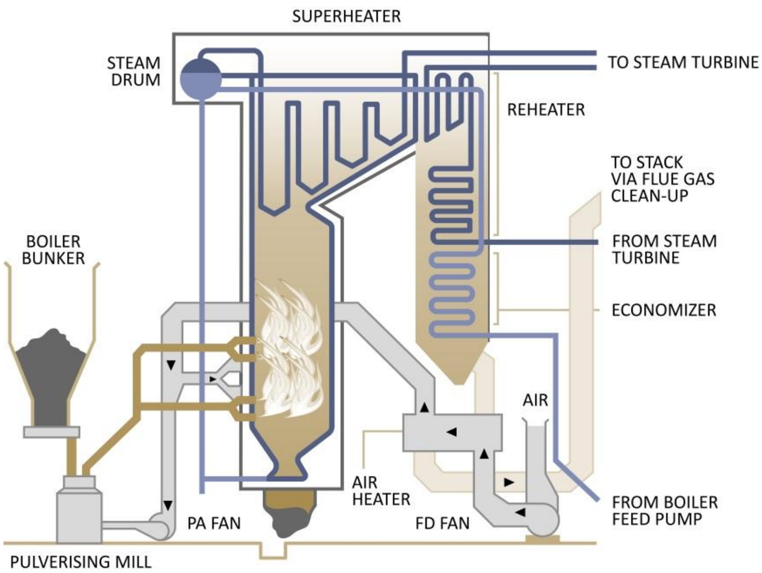
Advanced Ultra-Supercritical Coal Power Plant (AUSC)

Description	Technology Metrics	Local and International Examples
▪ Advanced Ultra Supercritical plants are designed to operate in the range of 700 to 760 deg C and 35 to 36 Mpa. The plants are envisaged to be the highest efficiency coal plants.	▪ Thermal efficiency of >50% is expected. ▪ CO_2emissions 670 to 740 g CO_2/kW ▪ Costs would be higher than USC plants due to the high nickel super-alloys required in the equipment materials.	▪ Currently no commercial operations of coal AUSC plants exist globally. GE Steam offers AUSC technology called SteamH based on their USC design with key components upgraded[11]. ▪ They are the subject of ongoing research and design to find the best materials of construction that would provide equipment strength and reliability at the high temperatures and pressures in the plant.

Applicability to South Africa and Impacts on Other Issues

Technology not commercially operational, thus not a suitable choice for SA.

The materials under development are non-ferrous alloys based on nickel, which cost much more than the steel materials used in SC and USC plants. Developing super-alloys and reducing their cost are the main challenges to commercialisation of AUSC technology.



Source: researchgate.net

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Expected to be similar to other coal plant project timelines – total 7 to 8 years

Complexity and Ease of Implementation

Pilot plants and research programmes only.

Project Risks

Technology not proven commercially at scale.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
DEMO	GOOD	GOOD	$$$	MINOR	ST	MEDIUM

11 https://www.ge.com/steam-power/coal-power-plant/usc-ausc

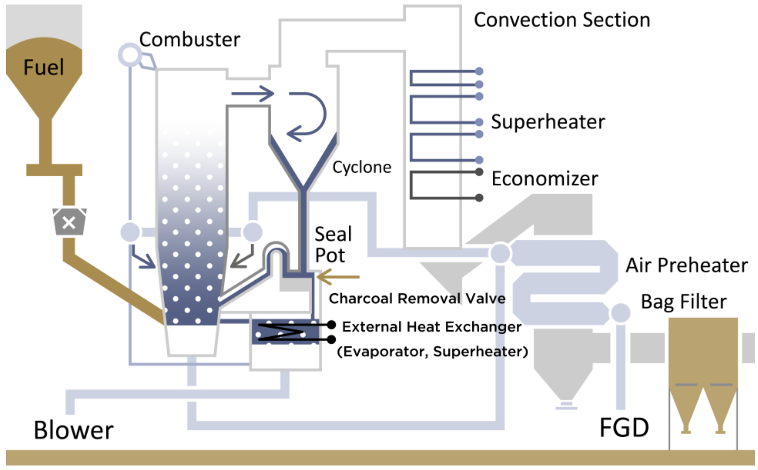
Circulating Fluidised Bed Combustion (CFB)

Description	Technology Metrics	Local and International Examples
▪ CFB design is an alternative coal firing design to pulverised coal boilers. ▪ In CFB plants, coal and limestone are fed into a bed of hot particles suspended in turbulent motion (fluidised) by combustion air, blown in through a series of distribution nozzles. Combustion takes place at lower temperatures than in Pulverised Coal systems. ▪ CFB's can be used in SC or USC plants.	▪ Efficiency depends on the type of boiler technology used i.e. SC, USC etc. Refer to the SC and USC designs for expected design efficiencies. ▪ Cost: 30% higher than pulverised coal SC plant with no FGD. ▪ CO_2 emissions will depend on the steam boiler design i.e. SC or USC design, refer SC and USC technology.	▪ A few ultra-supercritical circulating fluidised bed units are now operating globally including the Sam Cheok (4 x 550 MW) plant in South Korea (2016), and several 350 MW supercritical units (SC) which are operational in China in the last decade. ▪ CFB is a mature technology; supercritical CFB plants are now in operation or under construction in China, Poland and Russia.

Applicability to South Africa and Impacts on Other Issues

Technology allows for flexibility of feedstock and handles poorer quality coals and other biomass, which suits SA coal conditions.

Emissions of NO_x in CFB systems are intrinsically low because the combustion temperature is relatively low. Limestone is fed into the combustion system to control SO_2 emissions, typically achieving 95% abatement. Notwithstanding, depending on the feedstock quality, additional NO_x and SOx removal processes can be installed in downstream flue gas system as with other coal plant designs.



Source: allrefractory.com

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Coal plants typically involve design and engineering for 2 to 3 years, followed by construction of 5 years. Total 7 to 8 years.

Complexity and Ease of Implementation

Proven technology with plants built around the world.

Project Risks

Coal plants project could face the risk of financial institutions being reluctant to finance fossil fuel projects without substantial motivation, which will lean heavily on support for a Just Transition. Coal projects may face environmental legal challenges.

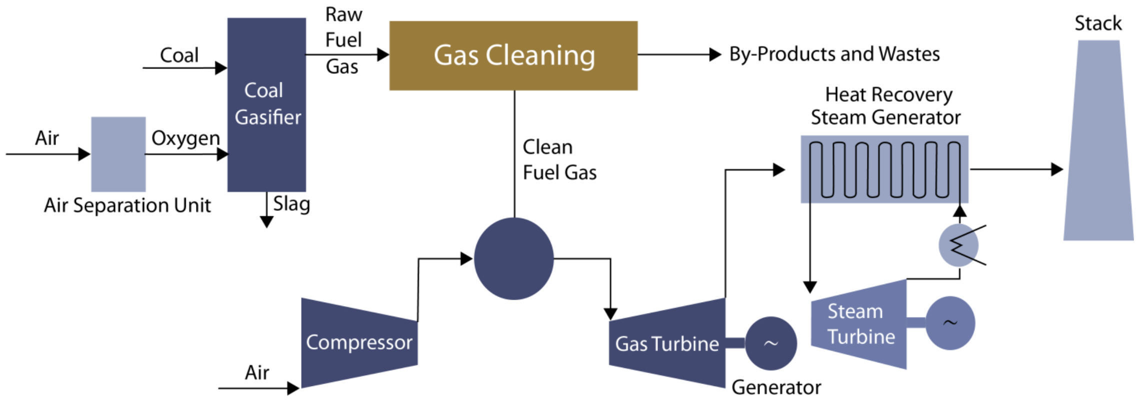
Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	REASONABLE	ACCEPTABLE	$$	MINOR	ST	MEDIUM

Integrated Gasification Combined Cycle Coal Power Plant (IGCC)

Description	Technology Metrics	Local and International Examples
▪ Coal is partially oxidised in air or oxygen at high pressure to produce a syngas, comprising CO and hydrogen. After gas treatment, the syngas is burnt in a gas turbine to generate electricity. The combined cycle heat recovery design maximises thermal efficiency.	▪ Thermal efficiency of up to 48% ▪ Cost: 68% more than SC plant – R62,000/kW with air separation unit (2017) ▪ CO_2 emissions 670 to 740 gCO_2/kW	▪ Successful 250 MW demonstration plant in Japan. Mitsubishi Power building 2 x 540 MW plants in Nakoso and Hirono plants with a design efficiency of 48%.

Applicability to South Africa and Impacts on Other Issues

Air separation to produce oxygen adds to the capex, but results in a smaller plant. Although technology is still in demonstration stage, it is perceived to be a chemical plant combined with a power plant and thus complex to operate. Notwithstanding, Sasol Secunda uses similar coal gasification technology. Full commercial operation unproven at this stage. Similar efficiencies to USC plants, but at 50% higher cost.



Source: IEA

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
Considered a complex plant and expected to take longer than a SC plant – possible 8 to 10 year project from design to commissioning.	Gasifier technology is complex, similar to Sasol Secunda gasifiers. Complex project to manage.

Project Risks

Large scale commercial operation unproven. Coal plants project could face the risk of financial institutions being reluctant to finance fossil fuel projects without substantial motivation. Coal projects could face environmental legal challenges.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
DEMO	EXCELLENT	GOOD	$$$	MINOR	ST	MEDIUM

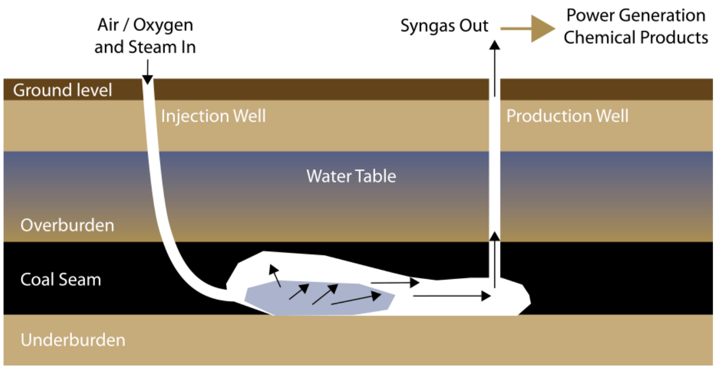
Underground Coal Gasification (UCG)

Description	Technology Metrics	Local and International Examples
▪ UCG involves burning (reacting) coal in situ/in-seam, using a mixture of air or oxygen, possibly with some steam, to produce a syngas, mainly CO and hydrogen. The syngas is sent above ground and subsequently used to drive gas turbines generating electricity, similar to IGCC technology.	▪ Efficiency could be similar to IGCC technology i.e. up to 48%. ▪ Cost: undefined. ▪ The advantages in the use of this technology - especially in the emerging markets of China, India, and South Africa - are the low plant costs (as no surface gasifiers are required) and the absence of coal transport costs. ▪ Potential source of hydrogen production.	▪ Extensive trials in Europe, the U.S., Russia, and Australia, have proven the technology on many occasions. The South African Underground Coal Gasification Association (SAUCGA) developed a draft SAUCGA roadmap[12] for SA. ▪ Eskom operated Majuba 15,000 Nm3/h UCG pilot plant, which achieved ignition and first flaring of gas in January 2007. ▪ In 2013 Eskom and Sasol New Energy signed a research agreement to jointly explore UCG technology development in South Africa.

Applicability to South Africa and Impacts on Other Issues

UCG in combination with CCS shows considerable promise as a low cost solution to carbon abatement. The composition of the syngas is particularly suited to CO_2 capture and the high pressure from deep UCG will require a smaller and less costly plant.

Regulatory clarity and certainty for the commercial development of UCG projects is required on a number of aspects[13] relating to the extraction of UCG gas, namely: the licensing framework; environmental framework (i.e. possible contamination of water through fractured rocks [similar to shale gas]); water use licenses and technical (production wells, design requirements, equipment etc.); and resource and reserve valuation standards for funding requirements by investors or bankers.



Source: IEA

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
Unknown - undefined	Many uncertainties have to quantified and defined to ensure a successful project

Project Risks

Environmental and safety risks associated with combustion processes deep underground and subsequent syngas release to the surface would have to be evaluated and mitigated through effective engineering design and environmental management plans, to the satisfaction of SA regulatory authorities.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
DEMO	REASONABLE	GOOD	$$	MAJOR	MT	HIGH

12 http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S2225-62532018001000001&lng=en&nrm=iso

13 The future of underground coal gasification in South Africa, Mining and Minerals Alert, Cliffe Dekker Hofmeyr, 24 Aug 2015

FLUE GAS CLEANUP

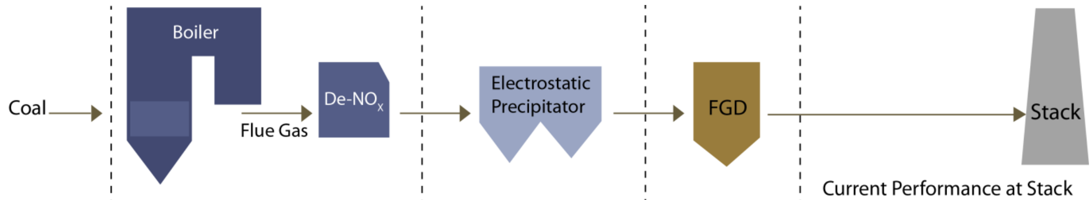
Flue Gas Pollutant Reduction

Description	Technology Metrics	Local and International Examples
▪ Removal of pollutants SOx, NO_X, fly ash, mercury, from flue gases, using various chemical processes. For NO_X – staged air and fuel mixing combustion. Also post combustion Selective Catalytic Reduction (SCR). For SO_X – flue gas desulphurisation (FGD) through wet or dry scrubbing with limestone. Particulates – electrostatic precipitators and fabric filters. Mercury – fabric filters and injection of activated carbon.	▪ Pollutant reduction achieved as per table below with current technology ▪ Cost: FGD is 24% higher per kW compared to non-FGD SC plant.	▪ Many commercial operations worldwide, not only on power plants, but other industrial and petrochemical sites, for example, ESP's on crude oil refinery Fluid Catalytic Units, stack scrubbers on ships, SCR removal on nitric acid plants.

Applicability to South Africa and Impacts on Other Issues

Note: Flue gas cleanup technology applies to all industries using fossil fuel as energy and is subject to SA pollutant emissions regulations, i.e. Oil and Gas industry, Iron and Steel, Cement, Petrochemicals etc.

Retrofitting FGD technology to Kusile resulted in 2.5% reduction in thermal efficiency for the plant, due to the additional energy required by the FGD process. FGD is also planned for Medupi. It is preferable to design and build future plants with flue gas treatment technology from the outset.



NO_x (mg/Nm³)	<500 - 1 000 → <50 - 100		
SO_2 (mg/Nm³)	<1 000 - 5 000		<20 - 100
$PM_{2.5}$ (mg/Nm³)	<20 000	< 50	< 10

Current Performance at Stack
<50 - 100
(<0.16 - 0.42 g/kWh)
<20 - 100
(<0.05 - 0.42 g/kWh)
<10
(<0.032 - 0.042 g/kWh)

Source: IEA

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
Part of plant design and construction.	Commercially proven technology. Retrofitting technology more challenging on existing plants and may impact thermal performance negatively.

Project Risks

All new plants are subject to minimum emission standards as per SA regulations - technology is a given for future projects. Coal projects will not happen without this technology.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	PENALTY	LOW	$	MINOR	ST	LOW

Coal Power Plant with Carbon Capture and Storage

Description

- CO_2 is captured via amine chemical processes, either post, pre combustion or through oxyfuels. Pre combustion and oxyfuels uses air separation units to use pure oxygen in the process, thereby concentrating the CO_2 stream and making capture more efficient.

Technology Metrics

- Cost: SC plant with CCS is 2.3x cost of SC pant without CCS – R86,000/kW (2017). Excludes CO_2 pipeline transport and storage site.
- CO_2 capture rate 85 to 95%

Local and International Examples

- Proven technology used extensively in petrochemical plants.
- However, limited coal power plants with CCS, due to the high costs involved. Currently 37 CCS projects in operation, under construction or advanced development around the world with a total capacity of 78 million ton CO_2 pa (includes all fossil fuel plants, not just coal). Major CCS hubs are located USA, China, Scandinavia, UK and Saudi Arabia/UAE.

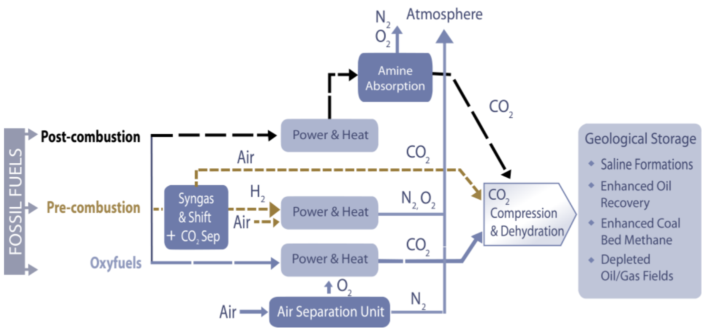
Applicability to South Africa and Impacts on Other Issues

Process is energy intensive – amine stripper uses steam and large auxiliary power required to compress CO_2 from near atmospheric pressure to pipeline pressure of 15 Mpa. The additional energy for CCS is the cause of the 7 to 12% drop in thermal efficiency of the coal power plant, which is a huge disadvantage for CCS.

Technology inclusion would probably have to be incentivised through subsidies, high carbon taxes, "green funding" in order to be economically viable.

Post combustion removal: flue gas amine treatment.

Pre-combustion removal: IGCC plants where syngas (H_2) is separated from CO_2 before combustion in the turbine. Oxyfuel combustion: coal is burned with pure oxygen (ex air separation unit) making CCS more effective



Source: researchgate.net

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Capture technology can be included in the design and construction as per other coal plants. However, the transportation and storage engineering and construction may add a few years to this timeline due to uncertainty inherent in this design.

Complexity and Ease of Implementation

The capture technology is well understood, however, the transportation and storage site location and performance presents much uncertainty. This is particularly relevant when the plant is located far from the storage site. The site requires suitable geology to ensure CO_2 is securely trapped underground.

Project Risks

Very high costs. Potential cost overruns due to unforeseen issues with storage.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	PENALTY	EXCELLENT	$$	MAJOR	MT	LOW

Direct Air Carbon Capture (DACC)

Description

- Large fans draw in air from the atmosphere and via two technology approaches, removes CO_2 from the atmosphere.
- Liquid DAC systems pass air through chemical solutions (e.g. hydroxide solution) which removes the CO_2. The system regenerates the solvent and releases the CO_2 by applying high-temperature heat while returning the rest of the air to the environment.
- Solid DAC technology uses solid sorbent filters that chemically bind with CO_2. When heated and placed under a vacuum, they release the concentrated CO_2, which is then captured for storage or use.

Technology Metrics

- Capture cost, from US$ 100 / ton to US$ 1 000 / ton.
- Liquid solvent systems require 900 degrees C to release captured CO_2, whereas solid sorbent systems require 80 degrees C to 120 degrees C. This means that solid sorbent systems can use lower-grade waste heat.

Local and International Examples

- There are currently 19 direct air capture (DAC) plants operating worldwide, capturing more than 10,000 ton CO_2/year, and a 1Mt CO_2/year capture plant is in advanced development in the United States. Most plants are small scale pilot and demonstration stage.
- Two plants are selling carbon commercially. The latest plant to come online, in September 2021, is capturing 4,000 CO_2/year for storage in basalt formations in Iceland.

Applicability to South Africa and Impacts on Other Issues

Sasol is considering DAC technology as a sustainable carbon feedstock option towards their net zero 2050 pathway, however, it is not currently cost competitive for large scale implementation.

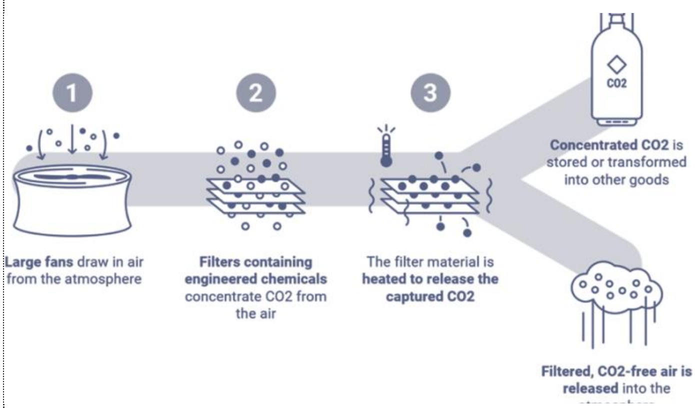
DAC is not an alternative to decarbonisation but can have a significant role to play in future to reduce hard to abate carbon if the technology becomes affordable at large scale.

Technology inclusion would probably have to be incentivised through subsidies, high carbon taxes, "green funding" in order to be economically viable.

Public and private funding for development and implementation is becoming more available worldwide.

The availability of sorbents and hydroxide solutions could become restrictive if DAC is employed at a large scale worldwide.

Some benefits of DAC include its limited land (excluding RE generation) and water footprint and the viability of locating plants close to suitable storage.



Source: CNBINSIGHTS

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Depending on the rate of deployment, which can accelerate through supportive policies and market development, costs for DAC could fall to competitive levels over the next 10 to 15 years.

Complexity and Ease of Implementation

Technology is in development and operating at a very small scale, in part because current methods are prohibitively expensive and energy intensive. The CO_2 in the atmosphere is dilute, this contributes to DAC's higher energy needs and cost relative to other CO_2 capture technologies and applications. Storage or use of CO_2 adds complexity.

Project Risks

Uncertainty regarding time when technology will be economically viable at scale.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
PILOT	-	EXCELLENT	$$$	SIGNIFICANT	LT	HIGH

Carbon Capture from Concentrated Gas Streams

Description	Technology Metrics	Local and International Examples
▪ Carbon dioxide is removed from gas streams using chemical solvents such as mono-ethanolamine (MEA) in an absorber tower, then routed to a stripping tower where the CO_2 is released from the solvent and the CO_2 is captured. The lean solvent is recycled to the absorber tower. ▪ If the CO_2 has a high concentration in the feed stream, the process is more efficient and plant size is minimised because other inert gases like nitrogen does not take up space and energy. ▪ Industries with concentrated CO_2 streams include Sasol, cement and iron and steel industries.	▪ The process requires energy to remove the CO_2 in the stripper and energy for plant utilities. ▪ The cost of carbon capture from concentrated sources is much lower than from diluted sources. The cost is estimated to be well below US$ 50 per ton CO_2.	▪ CO_2 capture will be used at facilities where the intention is to store the CO_2 underground in enhanced oil recovery operations and/or suitable geological formations that will trap the CO_2 permanently. Thus all current CCS sites will be using the technology e.g. USA, China and UK.

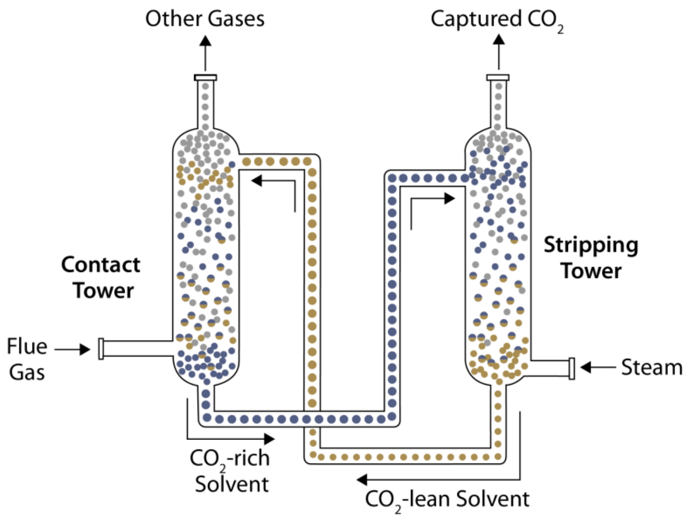
Applicability to South Africa and Impacts on Other Issues

Sasol's processes for liquid fuel and chemical production from coal and gas produce capture ready CO_2 streams.

CO_2 will be captured at the Sasol Secunda plant for the pilot CCS project done by the CGS where CO_2 will be stored in an underground storage site near Leandra.

Other concentrated streams opportunities are cement and iron and steel industries.

The technology will only be implemented if there is a plan to deal with the captured CO_2 i.e. the CO_2 is transported to a geological storage site and is pumped underground.



Source: American Chemical Society

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Design and construction 2 to 3 years

Complexity and Ease of Implementation

The technology is proven and offered to many industries.

Project Risks

Low risk as technology is proven

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	PENALTY	EXCELLENT	$$	MINOR	ST	LOW

Carbon Capture from Dilute Streams

Description	Technology Metrics	Local and International Examples
▪ Technologies (membranes, solvents, sorbents, and cryogenic) developed for coal and natural gas based systems can be adapted for most dilute industrial sources. ▪ In post combustion capture, the CO_2 is removed after combustion of the fossil fuel. CO_2 is captured from flue gases .	▪ The cost of carbon capture from dilute CO_2 sources is higher than from concentrated streams and range US$50 to above US$ 100 per ton CO_2 captured.	▪ The Petra Nova project (2017) is large scale commercial electricity-generating plant. Petro Nova is reliant on enhanced oil recovery to be commercially viable. ▪ The Boundary Dam project (2014), a Canadian venture operated by SaskPower, was the first commercial-scale power plant with CCS. The final project was smaller than earlier plans, the larger-scale project was discontinued because of the escalating costs. ▪ The Abu Dhabi CCS Project (2016) in the United Arab Emirates (UAE) was the first large scale iron and steel CCS project in the world. Tata Steel implemented a 5 tonnes per day carbon capture plant in India (2021). It extracts CO_2 directly from the Blast Furnace gas.

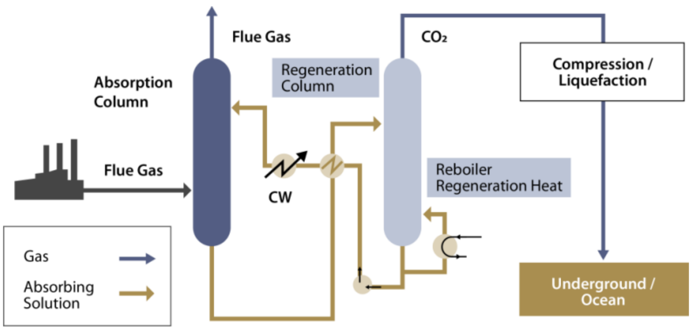
Applicability to South Africa and Impacts on Other Issues

For existing power plants and other industrial installations that emit CO_2 in a flue gas stream, the most suitable method of retrofitting carbon capture is post combustion capture using solvent.

In cement manufacturing up to 70% of CO_2 emissions is generated from the calcination of lime, which relies on fossil fuels. Cement kilns are the heart of this production process

In iron and steel manufacturing CO_2 is generated due to the dominance of coal as a reducing agent and a fuel. Emissions stream from the blast furnace and accounts for approximately 70 per cent of all steel mill emissions to the atmosphere.

Flue Gas Carbon Dioxide Capture



Source: *chiyodacorp.com*

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Capture technology can be included in the design and construction or retrofitted. However, the transportation and storage engineering and construction may add a few years to this timeline due to uncertainty inherent in this design.

Complexity and Ease of Implementation

Post-combustion capture is a mature technology and has been demonstrated on full-scale power and industry plants. There were, however, several other unsuccessful initiatives to demonstrate the technology at large scale.

Project Risks

CCS is an additional cost to any industry, and they will have to absorb these costs which may result in the increased costs of goods and/or services being passed on to the consumer.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	PENALTY	EXCELLENT	$$	SIGNIFICANT	ST	MEDIUM

Carbon Storage

Description

- Geo-sequestration involves injecting CO_2, generally in supercritical form to depths greater than about 800 meters. The high pressure keeps the injected CO_2 supercritical. Oil and gas fields, saline formations, un-mineable coal seams, and saline-filled basalt formations are possible alternatives. Overlying cap-rock or relatively impermeable formations that form geochemical trapping mechanisms prevent the CO_2 from escaping to the surface.
- Injecting CO_2 into deep geological formations uses existing technologies developed and used by the oil and gas industry.

Technology Metrics

- The suitability of any particular site depends on many factors, including proximity to CO_2 sources and other reservoir-specific qualities such as volume, porosity, permeability, and potential for leakage.

Local and International Examples

- Carbon storage into underground geological structures are in operation worldwide, enhanced oil recovery plays a major role in the commercial viability of CO_2 storage at many of these sites.
- There are 65 CCS facilities of which 26 are operating; the balance is under construction (3), in advanced development reaching FEED phase (13), and some still in early development (21), the rest has suspended operations due to economic downturn or fire. The current operations can capture and permanently store around 40 Mt of CO_2 every year.
- There are also 34 pilot and demonstration-scale CCS facilities in operation or development and eight CCS technology test centres.

Applicability to South Africa and Impacts on Other Issues

Large scale carbon storage reservoirs in South Africa include the Zululand Basin, the Algoa basin off-shore of Mossel Bay and the Orange basin on the West Coast of South Africa.

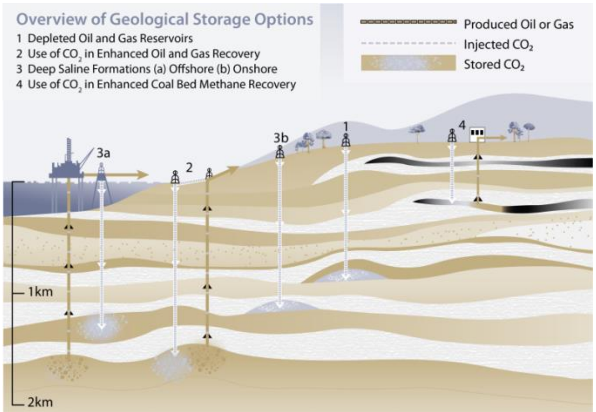
The Council for Geoscience (CGS) is implementing the CCUS Pilot Project by conducting research that aims to identify apposite geological storage formations that would be appropriate for storing carbon dioxide. This work is funded by the South African government and the World Bank. The selected pilot site is 9 km from Leandra in Mpumalanga in close proximity to emission sources of the Sasol Secunda plant and Eskom power stations. Storage will be in a basalt formation, a layer of porphyritic lava is targeted for the storage, the olefin rich rock in the layer is expected to react quickly with CO_2.

The pilot project aims to store 10 000 tons of CO_2 at the site, CO_2 will be transported by truck to the site during the pilot phase.

Methane replacement in un-mineable coal seams is also being investigated by the CGS.

There is currently no legislation in South Africa giving guidance on CO_2 sequestration, this is a legal hurdle that needs to be overcome and a framework guiding sequestration will need to be developed.

Potential CO_2 Storage Options



Source: IPPC

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

The CGS pilot project aims to start injections in 2 years' time where after monitoring of at least 2 years will be required to determine the viability of continuing with commercialization at the pilot site. The timeline and cost for CCS can only be determined based on the results of the pilot project.

Complexity and Ease of Implementation

Research by the CGS is ongoing for carbon storage in South Africa to gain understanding of complexity of implementing CO_2 storage in South Africa. Transport to large reservoirs such as the Zululand Basin will also add complexity and cost. However, if suitable sites can be identified in Mpumalanga, these transport costs may be reduced.

Project Risks

Requires legislative guidance which is currently lacking.
The cost of carbon storage is very high, and it is not expected to be commercially viable without appropriate financial intervention or incentive.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	EXCELLENT	$$$	MAJOR	LT	HIGH

Carbon Dioxide (CO_2) Transport

Description

- Technically, CO_2 can be transported through pipelines in the form of a gas, a supercritical fluid or in the subcooled liquid state. Operationally, most CO_2 pipelines used for enhanced oil recovery transport CO_2 as a supercritical fluid.
- Alternative modes of transport are road or rail tankers and ships.

Technology Metrics

- Costs for pipeline construction vary, depending upon length and capacity, servitude costs, whether the pipeline is onshore or offshore, the terrain it should cover and injecting and delivery infrastructure.
- Road and rail CO_2 transport are uneconomical compared to pipelines and ships, except on a very small scale.
- Marine tanker costs for CO_2 shipping might be feasible for distances greater than 1,000 km, if volumes don't justify pipeline costs.

Local and International Examples

- Pipelines today operate as a mature market technology and are the most common method for transporting CO_2.
- Marine tankers transport CO_2 today, but on a small scale due to limited demand.

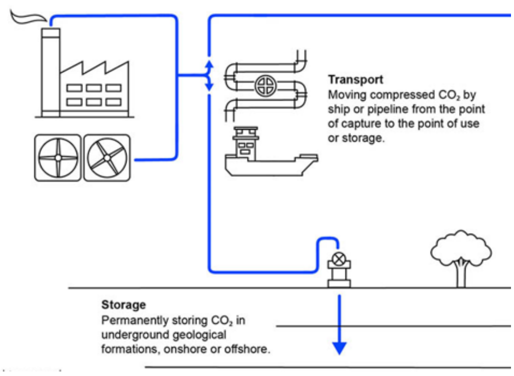
Applicability to South Africa and Impacts on Other Issues

Pipeline infrastructure would be required to gather and transport CO_2 to large reservoirs not co-located to the major CO_2 sources

South Africa's pipeline infrastructure is currently used for refined fuels, crude oil and gas transport. It is unlikely that the infrastructure would be repurposed for CO_2 transport, unless new pipelines are built for natural gas that could accommodate higher demand which could be supplied from imported LNG or commercialisation of offshore gas fields. The crude oil pipeline (COP) to Sasolburg would be most likely be required for refined fuel transport in case of the Sasolburg refinery shutting down, rather than an expansion of the existing NMPP multiproduct pipeline.

Sasol has evaluated the possibility of converting the ROMPCO pipeline for CO_2 transport once the Pande and Temane fields in Mozambique are depleted; this was found not to be a viable option.

A study investigating the use of existing PetroSA pipelines to the FA platform is not suitable for CO_2 transport due to the age and integrity of the pipeline.



Source: IEA

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Depending on distance and project scale, pipeline and associated equipment construction can take 4 years or more.

Complexity and Ease of Implementation

South Africa has experience in pipeline construction and transport.

Project Risks

Construction of new pipelines will add considerable cost to CCS projects, and it is not expected to be commercially viable without appropriate financial intervention or incentive.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	-	$$$	MAJOR	LT	LOW

POWER GENERATION HYBRID[14] AND TRANSITION TECHNOLOGIES

Conversion to Gas Firing in Coal Plants

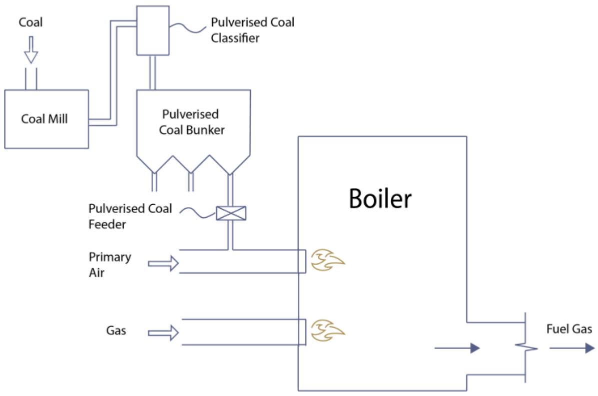
Description	Technology Metrics	Local and International Examples
▪ Coal plants can be converted to natural gas firing, or gas is co-fired with coal. Gas burner technology is mature. The lower carbon intensity of gas provides a lower carbon footprint for the electricity produced	▪ Natural gas CO_2 emissions are 20% less than sub-bituminous coal i.e. 0.18 $kgCO_2/kWh$ versus 0.22 $kgCO_2/kWh$. For higher carbon content coal, the NG emissions are 36 to 40% less. ▪ Cost is variable and will be site specific.	▪ Globally many coal power station were converted to natural gas firing for improved efficiencies. However, these were complete conversions to OCGT or CCGT technology which has much higher efficiencies.

Applicability to South Africa and Impacts on Other Issues

The value of beneficial effects should be weighed against the cost of gas relative to coal as an energy source. The net benefit will depend on a variety of site-specific factors. These include the location and volume of the nearest gas supply, load and capacity factors, coal properties, and emissions control requirements.

Thus each power station under consideration would have to be evaluated and no general conclusion can be made for all coal power stations.

Complete conversion to gas would compete against the option of new OCGT/CCGT technology. Unlikely that coal station retrofit could match the efficiency of new CCGT/OCGT. SA future natural gas supply is uncertain and the best alternative to the current limited NG supply ex Pande-Temane Mozambique is LNG imports.



Source: researchgate.net

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Retrofitting design and construction – 2 to 3 years.

Complexity and Ease of Implementation

Co-firing not considered a major project. Complete conversion to gas is more complex.

Project Risks

Lack of natural gas supply. SA requires imported LNG infrastructure. Cost of gas must be affordable for viable project.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	GOOD	GOOD	$	MAJOR	ST	LOW

14 Hybrid is defined as mixed technology, for example co-firing coal and gas or biomass, renewable power integrated with coal plants etc.

Solar Water Pre-heating Systems for Boiler Feed Water

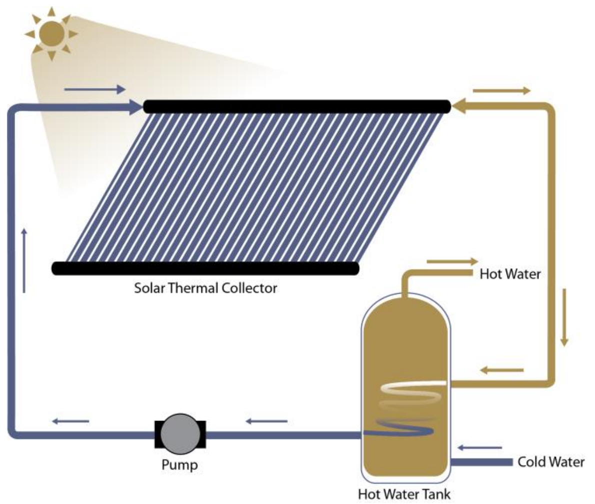
Description	Technology Metrics	Local and International Examples
▪ Use direct solar heating for low temperature heating requirements (40 to 100 °C).	▪ Preheat water from 20 °C to 65 °C saves 2% on baseline energy consumption on coal boiler. ▪ Investment payback of 5 years. If company liable for carbon tax, payback can be reduced to 4 years. ▪ The maximum capacity of ratings of commercially available photovoltaic (PV) panels are 150W/m2	▪ Local and International examples ▪ Results shown are based on Sanedi Report Appraisal of Implementation of Fossil Fuel and Renewable Energy Hybrid Technologies in South Africa, Nov 2017. ▪ Many installations locally and globally.

Applicability to South Africa and Impacts on Other Issues

Solar can provide heat energy for only 30% of the time.

The provision of high temperature thermal energy services (>100°C) from solar resources, such as a concentrated solar thermal plant (CSP) to augment steam generation in a coal fired boiler is currently not viable on an industrial scale.

A price on carbon is necessary to create an incentive for investing in hybridisation of this type, as a commercially viable project.



Source: researchgate.net

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Depends on size of installation, but can be completed in weeks or months

Complexity and Ease of Implementation

Fairly easy implementation

Project Risks

Low risk: this is mature technology

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	REASONABLE	EXCELLENT	-	MINOR	ST	LOW

Solar Photovoltaic (PV) to Produce Renewable Electricity

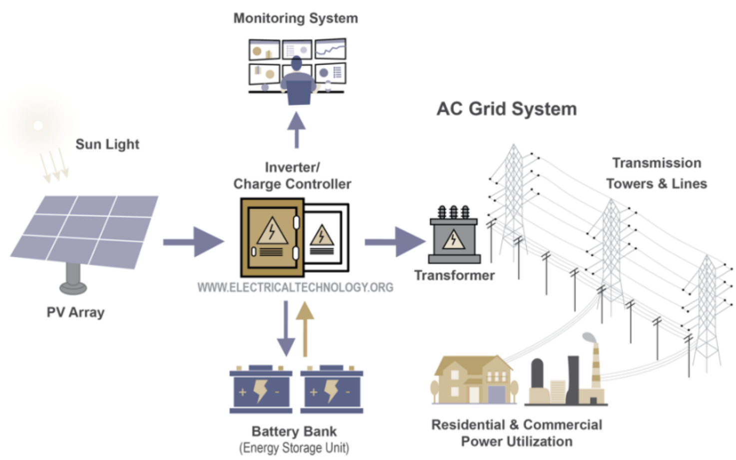
Description	Technology Metrics	Local and International Examples
▪ Use solar PV installation to generate renewable electricity to replace fossil fueled electricity.	▪ Plant cost R51,000/kW for 10 MW (2017). ▪ Depending on the technology, the land area required is 1.5 ha/MW[15]. ▪ Solar PV systems for electricity provision can replace about 20% of the electricity requirements of a commercial or industrial facility from the national grid. The payback periods range between 4 to 6 years. ▪ The levelised cost of electricity from solar PV is competitive with municipal tariffs in South Africa[16].	▪ Results shown are based on Sanedi Report Appraisal of Implementation of Fossil Fuel and Renewable Energy Hybrid Technologies in South Africa, Nov 2017. ▪ Many installations locally and globally.

Applicability to South Africa and Impacts on Other Issues

The initial capital outlay of PV technologies presents a barrier for implementation at a large scale, as many companies are attracted to projects that can show benefits in the same financial year.

However, solar PV costs are on a downward trajectory as is evident from the more than 80% reduction in actual average tariffs for solar PV from the first to the last bid window in the Renewable Energy Independent Power Producer Procurement Programme.

Grid connection is required to compensate for variable electricity supply, when storage is either not available or is costly.



Source: researchgate.net

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
Weeks to months depending on size of installation	Fairly easy implementation

Project Risks

Electrical transmission and grid capacity may be lacking at location of solar PV site.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	EXCELLENT	$$	MAJOR	ST	MEDIUM

15 Utility-Scale Solar Photovoltaic Power Plants, Project Developers Guide, IFC World Bank, 2015

16 DOE IRP Technology Costs, 2017

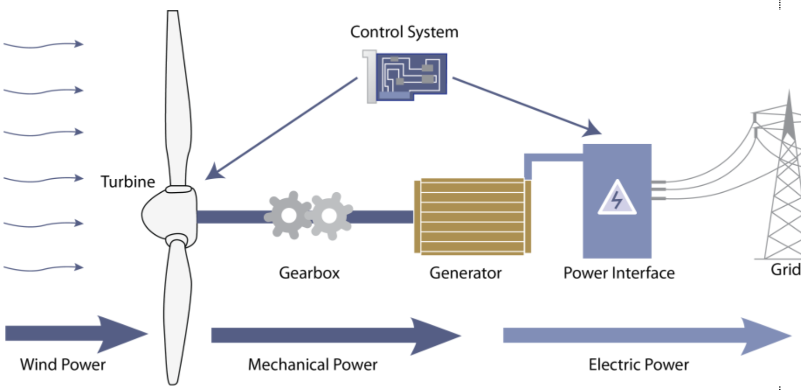
Wind Turbine Power to Produce Renewable Electricity

Description	Technology Metrics	Local and International Examples
▪ Use wind turbine installation to generate renewable electricity to replace fossil fueled electricity.	▪ Cost R27,000/kW for 2x50MW (2017) ▪ Land required is 25ha/MW[17]	▪ Many installations locally and globally ▪ Today, the most common wind turbine configuration is the three-blade, upwind, horizontal-axis design with a three-stage gearbox, variable-speed generator and power electronics to generate 50 or 60 Hz power.

Applicability to South Africa and Impacts on Other Issues

Main barriers are availability of land, environmental permitting process, Nersa licensing process. Challenge to address the grid and distribution infrastructure to link wind farm locations with end users.

Offshore wind farms are more expensive due to the harsher environment. SAWEA thinks that commercial offshore wind projects are 10 to 15 years in the future.



Source: Wikimedia

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
Design and installation 1 to 3 years	The completion of regulatory processes can be complex and time consuming

Project Risks

Electrical transmission and grid capacity may be lacking at location of solar PV site

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	EXCELLENT	$$	MAJOR	ST	MEDIUM

17 https://sciencing.com/much-land-needed-wind-turbines-12304634.html

Battery and Energy Storage Systems (BESS)

Description	Technology Metrics	Local and International Examples
▪ Design and use of utility sized electrical storage systems to provide solutions and support along the electrical system value chain. This includes generation support to transmission and distribution support and end-user uses.	▪ Battery types include lithium ion (Li-ion), sodium sulphur (NaS) lead acid batteries. ▪ Currently battery systems have relatively high capex costs but is expected to reduce as technology development and scale advances.	▪ Li-ion batteries are commonly used in smaller applications such as laptops, mobile phones etc. ▪ The largest single installation of NaS is the 34 MW Rokkasho wind-stabilization project in Northern Japan that has been operational since Aug 2008. There are over 300 MW (1800 MWh) of NaS installations deployed globally at 170 sites as of 2013. ▪ Lead acid batteries is the oldest form of batteries technology commonly used in cars, boats and planes. ▪ DMRE have received first bids for utility energy storage in SA.

Applicability to South Africa and Impacts on Other Issues

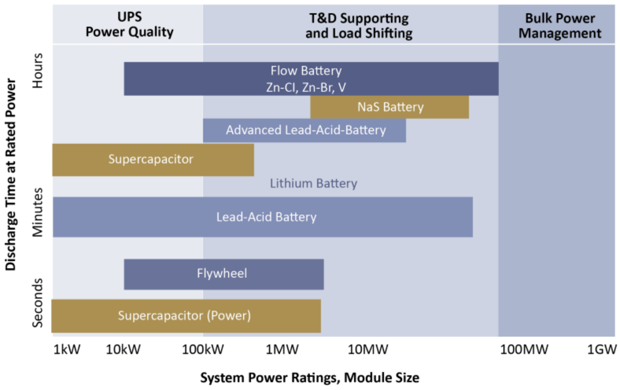
Major stakeholder groups for energy storage systems include utilities, customers, independent system operators (ISOs), wholesale market participants including intermittent generators, retail service providers, ratepayers, regulators, and policymakers.

Li-ion use for industrial management and utility size applications have capacity up to 4 MWh and power of 1 MW for 4 hours duration. Large amount of R&D is going into Li-ion to optimise use in energy storage and manufacturing scale is reducing Li-ion costs.

Sodium Sulphide (NaS) batteries are only available in multiples of 1-MW/6-MWh units with installations typically in the range of 2 to 10 MW. NaS batteries exhibit a long service life requiring less maintenance. Disadvantages of NaS batteries in energy storage include its relatively high cost.

Lead acid batteries for industrial management and utility size applications have capacity up to 4 MWh and power of 1 kW for 4 hours duration. The environmental and safety hazards associated with lead require a number of regulations concerning the handling and disposal of lead-acid batteries. Most lead-acid technologies are best suited for relatively limited cycle applications requiring shallow depth of discharge such as backup power and limited peak shaving.

Comparison of Power Output (in watts) and Energy Consumption (in watt-hours) for Various Energy Storage Technologies



Source: Korea Battery Industry Association 2017 - "Energy storage system technology and business model".

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

2 to 4 years for design and construction

Complexity and Ease of Implementation

Global examples exist – rapid technology development

Project Risks

Low risks

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
DEMO	-	EXCELLENT	$$	MAJOR	ST	LOW

Open and Combined Cycle Gas Turbines

Description

- Use natural gas Open Cycle or Combined Cycle (OCGT and/or CCGT) to generate electricity.
- Open cycle generates electricity from gas turbine combustion, whereas a combined cycle recovers heat from the turbine exhaust in a heat recovery steam generator (HRSG) to generate additional electricity, thereby increasing efficiency.

Technology Metrics

- OCGT 132 MW plant cost – R9,000/kW (2017)
- CCGT 732 MW plant cost – R10,000/kW (2017)
- Thermal efficiency: OCGT = 40%, CCGT = 60%
- Natural gas CO_2 emissions are 28% less than diesel i.e. 0.18 kg CO_2/kWh versus 0.25 kg CO_2/kWh
- CO_2 emissions up to 50% less than coal fired power stations[18]

Local and International Examples

- Eskom has local OCGT located around SA which use kerosene/diesel fuel
- Mature technology globally
- NG is viewed as a key decarbonisation technology globally and in SA, especially by Sasol.

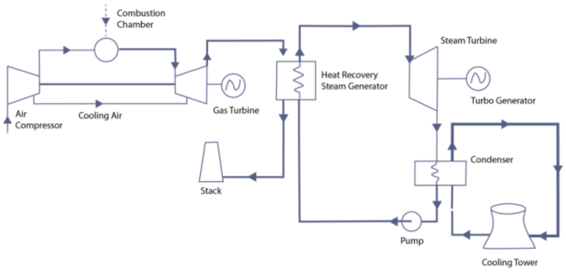
Applicability to South Africa and Impacts on Other Issues

OCGT running on gas would emit lower GHG and the fuel would cost less than diesel under the current fuel regulatory framework. They are designed for quick startup so best suited for peaking power operation.

CCGTs have a more complex design and require longer periods of time to startup and shutdown. Hence they are best suited for baseload to mid-merit electricity supply.

SA future natural gas supply is uncertain and the best alternative to the current limited NG supply ex Pande-Temane Mozambique is LNG imports. LNG imports and increased demand for NG will require LNG import infrastructure (FSRU) and new capacity gas pipelines. The cost of this development is high, and the key uncertainty is who will fund this development.

Gas economics will depend largely on the price of LNG supplied to SA. Industry also fear SA government may add gas levies and taxes to NG in future if revenues drop due to diesel consumption falling.



Source: researchgate.net

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Design to installation 4 years. Supporting gas infrastructure may take longer.

Complexity and Ease of Implementation

Mature technology but supporting gas infrastructure is required, which may take long time – 4 to 6 years.

Project Risks

High gas prices. Lack of gas infrastructure.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	EXCELLENT	GOOD	$	MAJOR	ST	MEDIUM

[18] Mitsubishi Power CCGT; https://power.mhi.com/products/gtcc

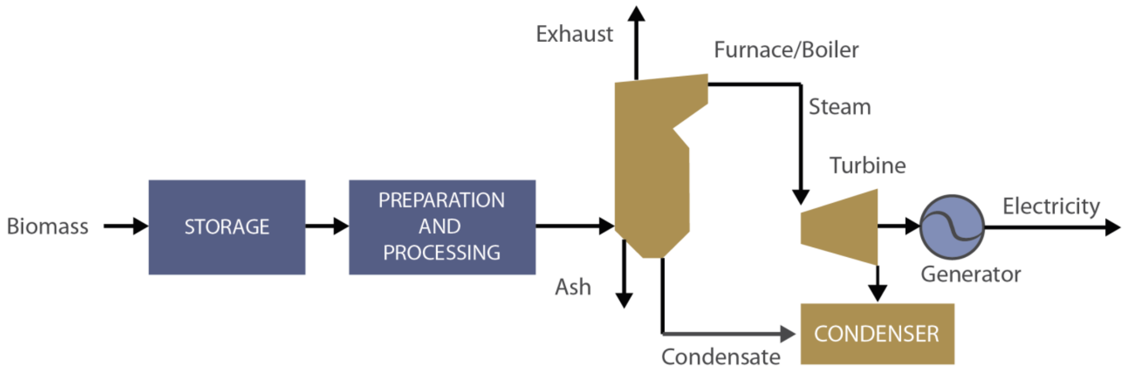
Biomass Fired Power Generation

Description	Technology Metrics	Local and International Examples
▪ Biomass is used as fuel in a steam boiler and turbine generator plant. ▪ Renewable fuel is used in place of fossil fuels.	Technology costs 2017 (source: DOE IRP Technology Costs, 2017) ▪ Municipal Solid Waste MSW (25 MW) – R160,000/kW ▪ Forestry Waste (25 MW) – R82,000/kW ▪ Landfill Gas Reciprocating Gas Engines (5 MW) – R85,000/kW	▪ Globally mature technology

Applicability to South Africa and Impacts on Other Issues

It is anticipated that nearly 1500 MW of biomass-generated power could be installed within South Africa. Of this, nearly half is expected to come from municipal solid waste. Landfill gas is currently used in South Africa more typically for rural heating application than for electricity generation.

Size of biomass generating units is generally limited by the availability of biomass fuel and the cost of transporting fuel to the site. Biomass fuels are either gathered up or harvested from diffuse sources and concentrated at a given location. Consequently, there are practical limitations on the quantities that can be obtained at a location before becoming too costly.



Source: wgdg.org

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
As with any other boiler plant design – design and construction 4 to 5 years.	The fuel must be carefully defined and prepared to obtain optimum performance. This can be a challenge.

Project Risks

Availability and reliability of supply of suitable biomass fuel

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
MATURE	REASONABLE	GOOD	$$	MINOR	MT	HIGH

Nuclear Power Stations

Description	Technology Metrics	Local and International Examples
▪ Nuclear fission of uranium U235 generates heat for steam that drives turbines for electricity generation. ▪ Nuclear power is a carbon free energy, however, it is not considered a renewable energy source because uranium resources are finite.	▪ No carbon emissions ▪ Koeberg thermal efficiency 32.4% ▪ Cost: R100,000/kW (2017), or 2.7x cost of SC coal plant	▪ SA has Koeberg a 1940 MW nuclear power station. ▪ There are 442 nuclear power plants in commercial operation in the world today. Mature technology. ▪ Internationally interest in small scale and modular reactors.

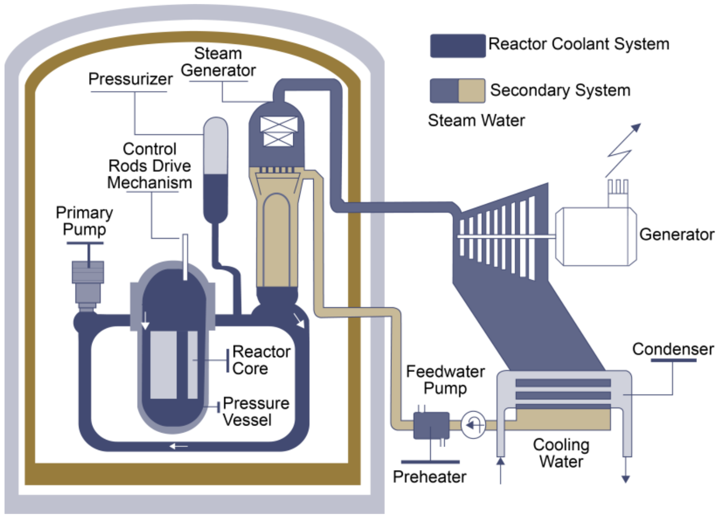
Applicability to South Africa and Impacts on Other Issues

Process delivers carbon free energy, however, nuclear waste disposal is difficult and expensive to manage.

Provides reliable baseload electricity and has a long lifetime.

Expensive technology and projects are subject to extensive delays and cost overruns. However, once operational, running costs are relatively low.

Industry has poor image and is often the subject of environmental protest and legal action.



Source: Westinghouse

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

The main disadvantage of nuclear power is the capital cost of nuclear power stations and the relatively long time to bring projects online. Construction costs constitute two-thirds of nuclear generation costs, and construction delays are a key driver of higher costs.

Complexity and Ease of Implementation

Construction delays usually result from intensified regulatory scrutiny, anti-nuclear advocacy and building first-of-a-kind designs.

Project Risks

Project risks are high due to the controversial nature of nuclear technology and the perceived risks, as well as past major incidents, associated with it

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	EXCELLENT	$$$	MINOR	MT	HIGH

Carbon Tax / Offset Credit

Description

- The Carbon Tax Act No 15 of 2019, which came into effect from 1 June 2019. The primary objective of the carbon tax is to reduce greenhouse gas emissions in a sustainable, cost effective and affordable manner.
- The polluter-pays-principle applies for large emitters. Through the tax mechanism (SARS will be administering) firms are incentivised towards adopting cleaner technologies over the next decade and beyond.

Technology Metrics

- The Carbon Tax is R120 per ton CO_2 equivalent (CO_2e). During the first phase (originally 2019-2022) the rate of R120 per ton will be adjusted each year by CPI plus 2%. Thereafter, it will increase annually by CPI.
- The Finance Minister announced in Feb 2022 that phase 1 will be extended to Dec 2025.
- Significant tax-free emission allowances ranging from 60% to 95% in this first phase. This includes a basic tax-free allowance of 60% for all activities i.e. net rate is R48/ton.

Local and International Examples

- The tax with its current generous allowances in phase 1, is not viewed as onerous compared to Europe e.g. average around €36/ton CO_2 (R612/ton).
- Sweden has the highest tax at €109/ton CO_2.

Applicability to South Africa and Impacts on Other Issues

Companies will also be able to purchase carbon offsets to reduce tax liability. These are investment projects that reduce, avoid or sequester emissions.

Major emitters could have major liability e.g. Eskom current emissions would incur around R26 billion pa at R120/ton CO_2e. In addition, SA companies may be subject to carbon border taxes imposed by trading partners in EU and other regions.

With time SA companies will have to incorporate strategies and plans to minimise the costs of carbon emissions if they are to stay competitive, as well as relevant to an environmentally informed market. It's anticipated that once the allowances are reduced significantly, the negative economic impact on large emitters of greenhouse gases will force them to react with emissions mitigation plans.

national treasury

Department:
National Treasury
REPUBLIC OF SOUTH AFRICA

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Will be project specific

Complexity and Ease of Implementation

The regulatory framework is complex, and many questions remain regarding the implementation and monitoring of programmes.

Project Risks

Tax levels may be set too low to incentivise companies to invest in GHG emissions abatement programmes.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	ACCEPTABLE	$	-	ST	-

DECARBONISING TRANSPORT EMISSIONS IN COAL VALUE CHAIN

Use of Ultra Low Sulphur Diesel (10ppm)

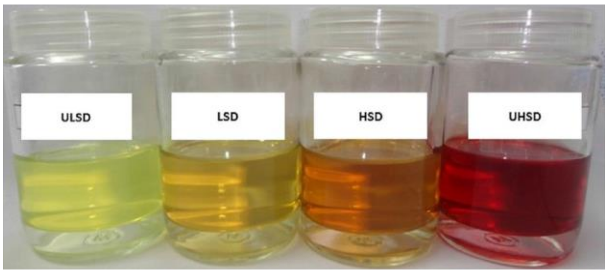
Description	Technology Metrics	Local and International Examples
▪ Change fuel of transport trucks to ultra-low sulphur diesel (ULSD 10ppm sulphur), to replace the current 50ppm sulphur diesel used. The Clean Fuels 2 specifications come into effect Sept 2023.	▪ Current diesel sulphur levels marketed in SA are 500ppm and 50ppm sulphur. A reduction to 10ppm sulphur gives 80% reduction in SO_x emissions from transport. Minimal impact, however, on CO_2 emissions. ▪ ULSD is expected to cost more than 50ppm diesel.	▪ ULSD, although not manufactured in SA, is freely available from international traders and manufacturers.

Applicability to South Africa and Impacts on Other Issues

ULSD may provide some degree of engine efficiency improvement using latest engine technology, but by and large, does not have significant impact on CO_2 emissions.

Clean fuels regulations requiring ultra-low sulphur petrol and diesel come into effect in 2023. Most SA refineries are unable to manufacture ULSD economically and require major upgrades to achieve this. Shutting down refineries does expose SA to international supply risks.

SAPIA are currently engaging DOE to agree on CF2 refinery investment recovery mechanisms, without success, to date.



Source: sciencedirect.com

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
N/A	Requires simple switchover to ULSD fuel for the consumer. However, the fuel marketer would have to make changes to his supply chain logistics, depending on the number of grades.

Project Risks

Refineries may not be able to maintain economic operations under the new CF2 specifications and may shutdown. Exposes SA to international supply risk.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	LOW	$$	MINOR	ST	LOW

CNG/LNG Fueled Vehicles

Description	Technology Metrics	Local and International Examples
▪ Convert vehicles from diesel to natural gas fuel (either CNG or LNG). ▪ NG fuel is a less carbon intensive fuel (13% less CO_2 per kg LNG) and costs less than diesel.	▪ LNG CO_2 emissions are 0.18 kg CO_2/kWh versus diesel at 0.25 kg CO_2/kWh, or 28% less than diesel. ▪ Cost of LNG is currently about 18% less than cost of diesel on an R per heating value (R/GJ) basis[19]. LNG currently does not attract fuel levies, but the future of this status is uncertain.	▪ There are many LNG trucks around the world. ▪ Locally Renergen and Total have plans with logistics companies (Imperial and Black Knight) to roll out LNG truck fueling programmes along major national road routes.

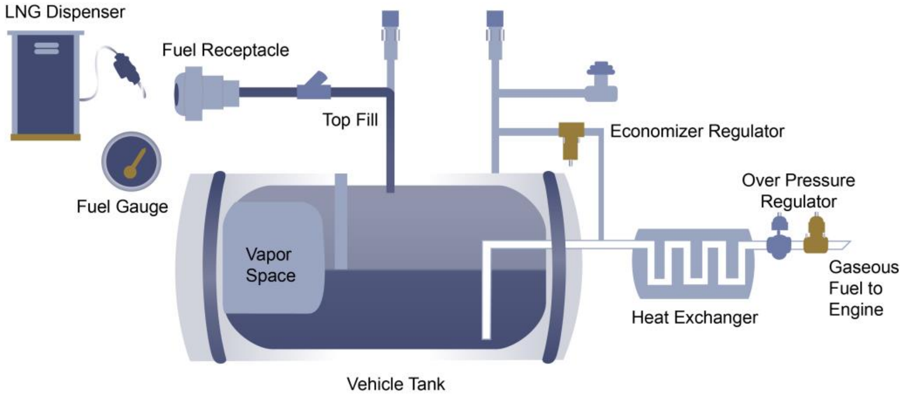
Applicability to South Africa and Impacts on Other Issues

Although NG drive technology is seen as a transition enabling technology in transport, Anglo America and Toyota have decided to focus on hydrogen fuel cell drive technology, rather than natural gas drive vehicles.

The technology will be subject to NG availability at an affordable price, and the short to mid-term outlook is LNG imports into SA as the best option to supplement the limited gas supply from Temane-Pande fields in Mozambique.

Key requirement for successful take up of technology is development of LNG infrastructure in SA, including import facilities, supply chain to demand points, refilling stations along highway routes etc. Who carries the responsibility for these high development costs is uncertain.

Government imposing taxes and levies on LNG to offset the revenue loss from the reduction in diesel sales is viewed as a high risk for LNG by SA freight transport industry.



Source: Chart Inc

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
LNG FSRU import facility is a 4 year project. LNG refilling infrastructure 2 years.	Rolling out LNG infrastructure is complex project and requires cooperation between government and private sectors.

Project Risks
Subject to availability and affordable cost of imported LNG.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	ACCEPTABLE	$	SIGNIFICANT	ST	LOW

19 Based on March 2022 SA diesel 50ppm of R19.55/l and LNG JKM $30/mmBtu. Exchange R15.23/US$

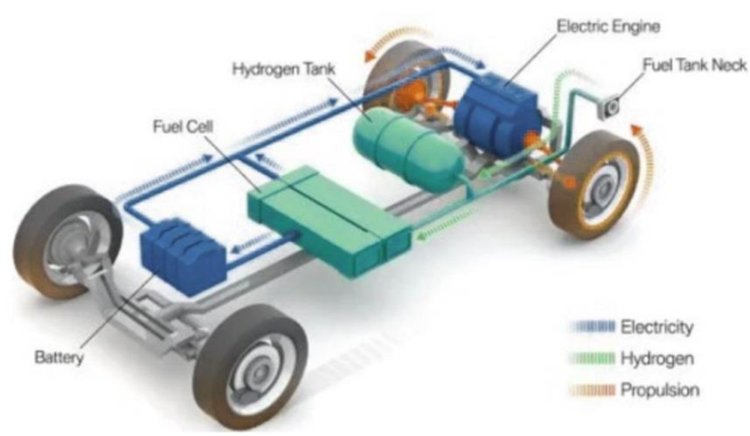
Fuel Cell Powered Vehicles

Description	Technology Metrics	Local and International Examples
▪ Hydrogen is used to convert its chemical energy into electricity and to use this to power an electric motor to drive the vehicle, or any other electrically powered device. The conversion of the hydrogen into electricity is achieved in a fuel cell. ▪ Fuel cells make environmental sense only if it makes use of green hydrogen i.e. hydrogen produced from renewable energy.	▪ Fuel cell drives produce carbon free energy. Fuel cell systems can generate electricity at efficiencies up to 60 percent. Hydrogen fuel cell vehicles, which use electric motors, are much more energy efficient, resulting in more than a 50% reduction in fuel consumption, compared to ICE. ▪ Cost of green hydrogen is high and only becomes commercially economic at around US$2/kg or less[20].	▪ Anglo American is testing a 290 ton mining truck on a hybrid high voltage electric drive system powered by a hydrogen fuel cell and a lithium-ion battery. The truck will have over 1,000 kWh of energy storage. Supplementing the vehicle's battery with hydrogen fuel cells will allow the truck to run for longer periods of time without recharging. ▪ Many global examples of fuel cell driven vehicles, including cars, buses, ships and industrial trucks.

Applicability to South Africa and Impacts on Other Issues

Most green hydrogen and fuel cell programmes are in pilot stage in SA and the focus is on refining the technology to make green hydrogen commercially affordable.

Roll out of hydrogen infrastructure (pipelines, storage, transport, dispensers) is also required to enable large scale use by the transport industry. Development of hydrogen infrastructure will be expensive as it would involve high pressure compression and pipeline transportation from areas of manufacture to regions of consumption. Thus the full scale implementation of the technology is seen only in the mid-term scenario.



Source: eetimes.eu

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
Green hydrogen manufacture seen as a mid to long terms project	Hydrogen infrastructure development will be complex undertaking.

Project Risks

Availability of renewable power at sufficient scale to manufacture green hydrogen. Alternatively sufficient supply of blue hydrogen for fuel cell use.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
DEMO	-	EXCELLENY	$$	MAJOR	MT	MEDIUM

20 Super High H_2 Road for SA, IHS Markit, 2021

SOUTH AFRICA OIL INDUSTRY CLEAN FUELS MANUFACTURE

Cleaner Fuels 2 Manufacturing

Description	Technology Metrics	Local and International Examples
▪ While petrol and diesel Clean Fuel specifications are numerous, the predominant change is the lower sulphur specification on petrol and diesel i.e. 10ppm sulphur for both petrol and diesel. The net effect is an 80% or more reduction of sulphur oxide emissions. Diesel from 50ppm S to 10ppm S and petrol from 500ppm to 10ppm S.	▪ SAPIA have estimated the cost of all refinery upgrades to make clean fuels is US$2.5 billion (R37.5 billion). This assumes that Enref is shut down and Sapref refinery shuts down at end of March 2022. More desulphurisation capacity will require more hydroprocessing reactor capacity and more hydrogen and/or more expensive low sulphur crude.	▪ The major international refining centres in Middle East and SE Asia already manufacture low sulphur fuels and a large percentage of SA fuel demand is already imported. ▪ Clean fuels programme does not reduce CO_2 emissions – in fact, if hydrogen plants are built to make more hydrogen for petrol and diesel desulphurisation, the refinery will emit more CO_2. ▪ SAPIA indicates, however, that refiners are not looking at hydrogen plant options, rather optimizing current hydrogen systems and plants to achieve low sulphur products.

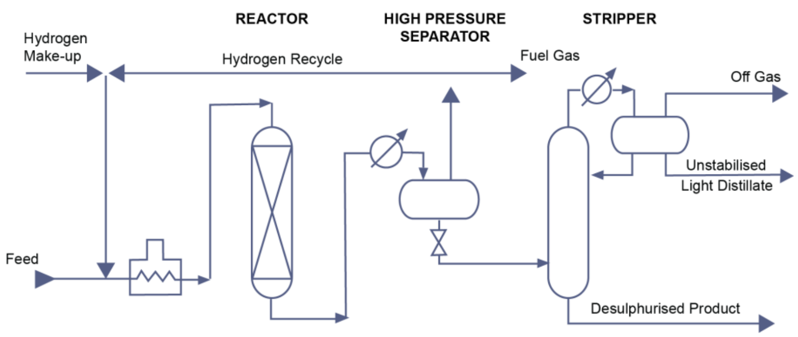
Applicability to South Africa and Impacts on Other Issues

Clean fuels programme does not reduce GHG emissions – it reduces SO_X.

SA crude oil refineries are unable to manufacture CF economically without major upgrades to their plants. Currently there's an impasse between SAPIA and government on CF investment recovery mechanisms, thus no commitment has been made to date to upgrade refineries (Enref and PetroSA are shut down and Sapref is planning to shut down end March 2022).

Crude refinery clean fuels manufacture may increase CO_2 emissions if new steam methane reformer (SMR) hydrogen plants are built. However, this may be avoided is more hydrogen is extracted from Platformer operations and hydrogen system is carefully managed.

A viable option for oil refiners is to shut down their refinery and import product to meet their market requirements. However, this has major direct and indirect job losses implications for the refineries and their service providers.



Source: Wiley Publishers

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule
Major refinery upgrades have a lead time from design engineering and construction to commissioning of at least 4 to 6 years.

Complexity and Ease of Implementation
Brownfields upgrades of crude refineries are complex projects.

Project Risks
High risk of project delays and cost overruns for brownfields projects.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	LOW	$$$	MINOR	ST	LOW

Import Clean Fuels and Shutdown Crude Oil Refineries.

Description	Technology Metrics	Local and International Examples
▪ Crude oil refineries are shut down and the clean fuels demand is imported into SA through the ports. Currently 10 billion litres of petrol and diesel is already imported, which constitutes about 33% of SA and BELN fuel demand. GHG emission from crude oil refineries will be eliminated.	▪ Crude refinery GHG emissions make up less than 1% of total SA emissions, thus reduction is relatively small. The cost of refinery upgrades of US$2.5 billion will be avoided. However, the impact on job losses and SA economy can be significant – refer below. ▪ Security of SA fuel supply may be compromised (import infrastructure capacity limiting).	▪ Many crude oil refineries around the world have been shut down because they are not economically viable in the face of stiff competition from large, efficient export refineries in Middle East and SE Asia.

Applicability to South Africa and Impacts on Other Issues

SAPIA provided the following economic impacts, which includes refining and marketing:

171,358 jobs (1,1% of employment in 2019). The industry supported 1.5% of country total employment - for every 1 job created in the industry, a further 1.52 jobs are supported elsewhere in the economy. The industry contributed R94 billion in capital expenditure and R197 billion in operating expenditure.

Enref is already shut down and Sapref is shutting down end March 2022.

If Natref follows, there is significant concern that the import infrastructure (back of port) in Island View Durban and the NMPP pipeline capacity does not have the capacity to carry imports into the inland Gauteng markets.

Source: africaports.co.za

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
Upgrading of Island View back of port and NMPP pipeline projects: 2 to 4 years.	NMPP pipeline would need booster pumps. Transnet TM1 terminal requires rebuild – these are major projects.

Project Risks

Central Energy Fund CEF view is that refinery shutdowns increase security of supply risks[21]

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	LOW	$$	MAJOR	ST	LOW

21 https://www.news24.com/fin24/economy/government-is-contemplating-saving-sapref-but-should-it-20220303

Biofuels Blending into Petrol and Diesel

Description

- Biofuel is any fuel that is derived from biomass—that is, plant or algae material or animal waste and is a renewable source.
- Bioethanol is potentially produced from sugar cane while biodiesel is made from vegetable oils e.g. soyabeans.
- Bioethanol is blended into petrol up to 20% by volume and biodiesel is blended into diesel up to 100%.

Technology Metrics

- Bioethanol is also believed to give 19% to 48% greenhouse gas reduction compared to petrol.
- Biodiesel also produces less GHG emissions but has lower heat content resulting in higher consumptions.
- Biofuels cost more to make than fossil fuels and industry must be incentivised to manufacture and use it as fuel blendstock. Biofuels transfer price will be set at BFP.

Local and International Examples

- There are many global examples of biofuels blended into fossil fuels, but with varying degrees of success and depends largely on government subsidies.
- Globally, the use of biofuels as a transport fuel is enabled by national mandatory blending policies and sometimes subsidies to reduce the negative environmental impact of transport fuel use.
- No commercial biofuels manufacture in SA.

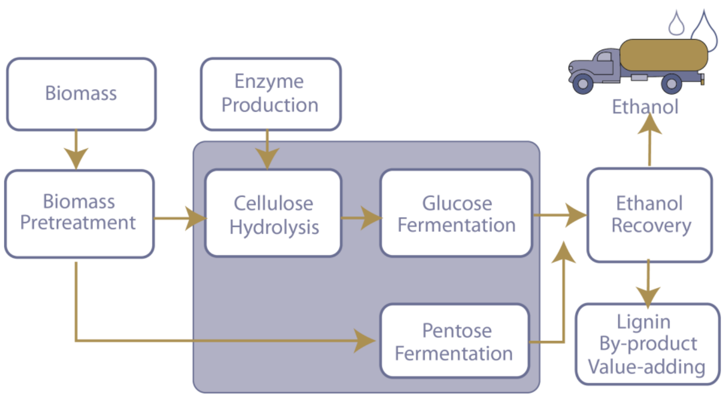
Applicability to South Africa and Impacts on Other Issues

SA biofuels regulatory framework updated and published 7 Feb 2020 by DMRE. It compels licensed manufacturers and wholesalers of petroleum products to buy and blend locally produced bioethanol and biodiesel at a minimum of 2% of their petrol and 5% of their diesel market demand, respectively. The levy on biofuels would be in the region of 3.5 to 4 ZAR cents per litre (cpl) on all petrol and diesel sold in South Africa. The regulations also contain the National Biofuels Feedstock Protocol.

DMRE must still issue a determination of the blending infrastructure required, the acceptable capital costs that will be incurred by the blender as well as the operating costs of blending.

Sapia have highlighted a number of regulatory issues in conflict with current excise duties which must be resolved before the technology can be implemented.

Bioethanol Production Process



Source: bioenergyconsult.com

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Due to the uncertainty for blenders with regard to recoverable costs, is likely to limit the sector development in the interim.

Complexity and Ease of Implementation

Not an easy project since much of the regulatory issues has to be resolved and required infrastructure must be defined.

Project Risks

Biofuels potentially offer significant benefits and opportunities, but also poses very real risks if not managed properly. Supply logistics and blending, economies of scale may not be achieved and opportunity to alleviate poverty may be missed.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
READY	-	GOOD	$$	MAJOR	MT	HIGH

Power to X Fuels (Green Hydrogen Technology)

Description

- Green hydrogen is produced via electrolysis of water from renewable energy and combined with captured CO_2, or biological material to provide a carbon source. The H_2 and carbon is converted via Sasol type FT process to make so-called Power to X Fuels, also known as sustainable synthetic fuels.

Technology Metrics

- Green H_2 electrolyser requires 48 to 55 kWh to produce 1 kg H_2, at a cost of US$5-8/kg H_2. This is expensive and focus is on reducing this cost.
- Commercial electrolysers are available in modular sizes of 20MW, which can be added together to provide larger capacity.

Local and International Examples

- Numerous Green Hydrogen initiatives in SA and around the world. Challenge is to produce green H_2 at US$2/kg or less to make it economically viable.
- Sasol piloting a sustainable aviation fuel (SAF) programme to prove the concept, using their FT plants.

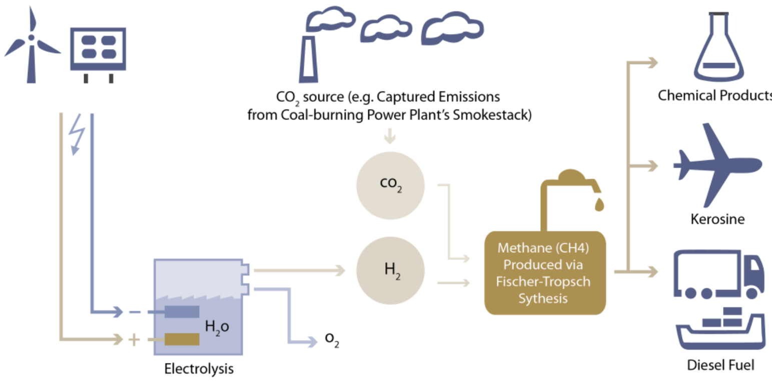
Applicability to South Africa and Impacts on Other Issues

SA is well suited to produce green hydrogen due to its favourable solar and wind resources. The Sasol SAF initiative is well placed to prove the PtX concept, however, a suitable fossil free carbon source is required.

Although biomass would be a good sustainable carbon source, the ultimate carbon source could be CO_2 itself, which is captured via direct air capture (DACC) technology or from captured CO_2 from a chemical process (amine plants).

The reaction process which is been researched is the reverse water gas shift reaction, which converts CO_2 and H_2 to CO and H_20 and the CO is subsequently synthesized with H_2 in FT plant to make sustainable liquid fuels.

Low-Carbon Synthetic Liquid Fuels Production (Power-to-Liquids)



Source: dw.com

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

Commercial Green H_2 production is 5 to 10 years off. Another 6 to 10 years for SAF.

Complexity and Ease of Implementation

A sustainable carbon source must be identified and proven to work at scale. Complex project.

Project Risks

Challenge to reduce current high costs of green H_2. Also challenges to optimise the reverse water gas shift reaction in terms of the energy required and catalyst selectivity.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
R&D	-	EXCELLENT	$$$	MAJOR	LT	HIGH

Green Hydrogen Manufacture

Description	Technology Metrics	Local and International Examples
▪ Green hydrogen is produced via electrolysis of water using renewable energy sources such as solar or wind. If the hydrogen is combined with nitrogen in a Haber process plant, green ammonia (NH_3) is made.	▪ 1 kg H_2 is enough to keep a fuel-cell car running for around 100 km. Therefore for 500 km range, 5 kg H_2 is needed, which will require 275 kWh of electricity ▪ Cost of green H_2 production currently about US$5-8/kg. Economically viable at $2/kg or less.	▪ Many local SA green H_2 initiatives and pilot programmes on the go.

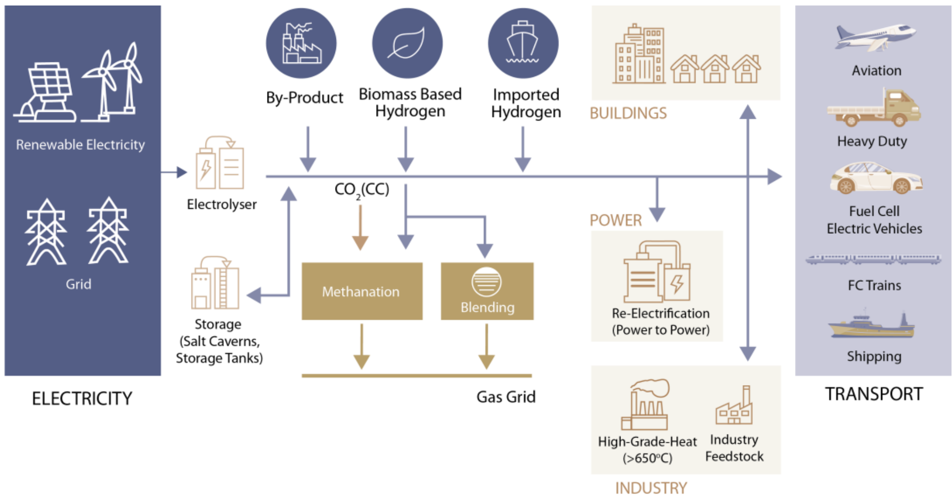
Applicability to South Africa and Impacts on Other Issues

Hydrogen can be burned as a fuel to produce carbon free energy (combustion product is water). It can be used as feedstock for sustainable fuels manufacture (refer Power to X Fuels).

Hydrogen is also used in fuel cell technology to deliver power in the transport sector.

Would require major effort to develop hydrogen infrastructure to handle and transport H_2 from place of manufacture to where its needed. Requires high pressure gas pipelines.

SA can potentially become a global exporter of green hydrogen because of favourable SA solar and wind resources. Will attract green funding.



Source: IRENA

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
Commercial Green H_2 production is 5-10 years off	Much research in electrolyser technology to reduce costs. This can only be achieved by building at industrial scale, providing the potential to become a global exporter.

Project Risks

The logistics of moving hydrogen and ammonia requires optimisation depending on scale.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
R&D	-	EXCELLENT	$$$	MAJOR	LT	HIGH

Transition to Hybrid Electric and Full Electric Vehicles

Description	Technology Metrics	Local and International Examples
▪ Hybrid vehicles use both a small internal combustion engine (ICE) and an electric motor to obtain maximum power and fuel economy with minimum emissions. ▪ Hybrids have the ability to generate electric current, store it in a large battery, and use that current to help drive the car. ▪ Hybrids capture electrical energy produced by a regenerative braking system, and their engines can power a generator, too.	▪ Plug-in hybrids feature larger batteries that can be charged at any ordinary 220-volt electrical socket. The development of new, smaller, high-capacity lithium-ion batteries that can be recharged many times is the key to making plug-in hybrids available to the general public. ▪ Charge 15 to 20 kWh per 100km. ▪ To electrify South Africa's minibus taxi fleet, Toyota says converting the current minibuses to BEVs would mean they would weigh 30% more and cost 50% more.	▪ Current EVs available in SA are very expensive (R600 000) due to high import duties and is thus beyond the average consumer. ▪ Toyota is offering hybrid Toyota Corolla Cross for R350 000, although they are subsidising the car on the assumption that SA government will provide support packages to make the price of EVs more accessible. ▪ Different SA companies are choosing different technologies e.g. Anglo are focusing on fuel cell mining vehicles, while Imperial and other logistics companies are trialing LNG trucks

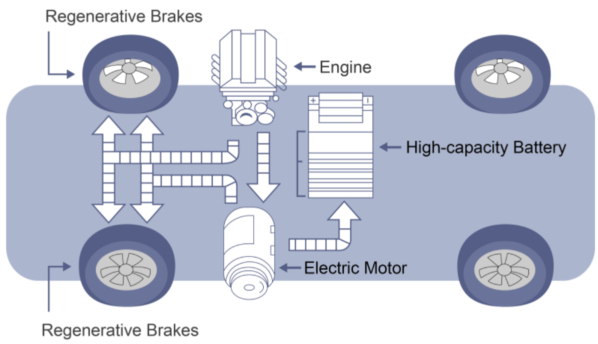
Applicability to South Africa and Impacts on Other Issues

EVs only have green value if powered by renewable or non-fossil fuel power. Fossil fuel based electric charging negates the value proposition of EV's.

As for electrified vehicles – this term referring to battery electric vehicles (BEVs), plug-in-hybrids (PHEVs), hybrid electric vehicles (HEVs) and fuel cell electric vehicles (FCEVs) – the hurdles to local introduction include establishing the necessary refuelling and charging infrastructure.

Toyota believes that in SA, sales ratio of electric vehicles will be one BEV/FCEV to ten HEVs/PHEVs. Sapia also agrees that HEV's is the best transition technology for the fossil fuel industry. However, ICE will be in SA for a quite a while.

Impact of BEV charging on Eskom capacity needs to be determined.



Source: dummies.com

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

The development of recharge infrastructure, including electricity distribution, will be costly and will take time.

Complexity and Ease of Implementation

Major concern is the availability of charging stations and charge time and range of travel between charging. Uncertainty creates reluctance to market penetration.

Project Risks

Take up of technology - it is uncertain if SA can support all types of EV vehicles

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
DEMO	-	EXCELLENT	$$	SIGNIFICANT	MT	LOW

Green Ammonia

Description	Technology Metrics	Local and International Examples
▪ Ammonia is widely used to make agricultural fertilisers. Green ammonia is produced using hydrogen from water electrolysis and nitrogen separated from the air. The H_2 and N_2 are chemically converted at high pressure and temperature in a Haber-Bosch process, powered by sustainable electricity, to produce green ammonia. ▪ Currently, it is most commonly made from methane, water and air, using steam methane reforming (SMR) to produce the hydrogen via the Haber process.	▪ Approximately 90% of the carbon dioxide produced from conventional ammonia manufacturing is from the SMR process. This process consumes significant amounts of energy and produces around 1.8% of global carbon dioxide emissions. ▪ Ammonia has a higher energy density than Hydrogen. Comparable with methanol, but significantly lower than transitional carbon based fuels (petrol and diesel)	▪ Production of ammonia is a mature technology and used internationally, mainly to produce feedstock for fertiliser and explosives. ▪ New applications as energy storage to replace transport fuels and for generation of electricity is in research and pilot phases ▪ Hive Hydrogen is proposing to build a 780,000 t/y, $4.6-billion green ammonia plant – with its own dedicated green power supply at the Coega SEZ alongside the Port of Ngqura.

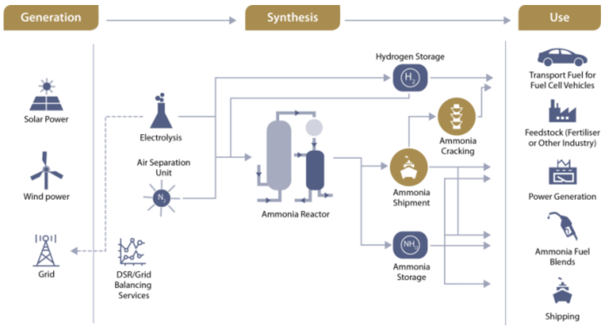
Applicability to South Africa and Impacts on Other Issues

Energy storage – ammonia is easily stored in bulk as a liquid at modest pressures (10-15 bar) or refrigerated to -33°C. This makes it an ideal chemical store for renewable energy. There is an existing distribution network, in which ammonia is stored in large, refrigerated tanks and transported around the world by pipes, road tankers and ships.

Green ammonia is a viable green fuel for the global shipping industry (sustainable bunker fuel). It can serve as an energy carrier which is more easily handled and transported than hydrogen and is easily "cracked" to hydrogen gas when it is required.

Zero-carbon fuel – ammonia can be burnt in an engine or used in a fuel cell to produce electricity. When used, ammonia's only by-products are water and nitrogen. The maritime industry is likely to be an early adopter, replacing the use of fuel oil in marine engines.

Hydrogen carrier – there are applications where hydrogen gas is used (e.g. in PEM fuel cells), however hydrogen is difficult and expensive to store in bulk (needing cryogenic tanks or high-pressure cylinders). Ammonia is easier and cheaper to store, and transport and it can be readily "cracked" and purified to give hydrogen gas when required.



Source: Siemens

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule	Complexity and Ease of Implementation
Linked to production of green hydrogen at scale for commercial processes	Development of Electrolyser technology to produce green hydrogen at scale with RE footprint to match. Require sufficient energy for conversion process as well (high pressure and temperatures)

Project Risks

The logistics of moving hydrogen and ammonia requires optimisation depending on scale. Availability of renewable power at scale.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
R&D	-	EXCELLENT	$$$	MAJOR	LT	HIGH

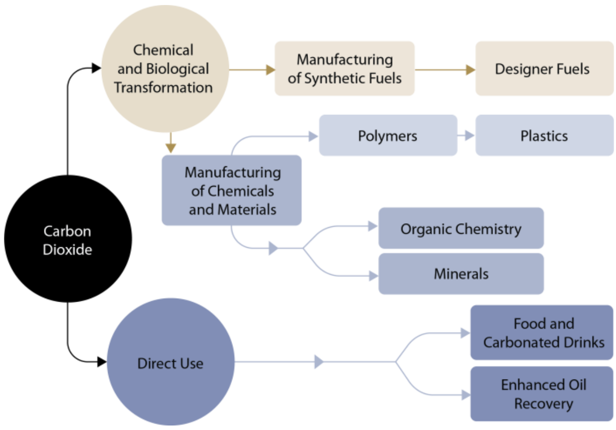
Carbon Utilisation

Description	Technology Metrics	Local and International Examples
Technology involves the capture of CO_2 by processes described previously (Solvent, DACC) and subsequently processed via chemical and/or biological processes to various commercial commodities and products. This will help to offset the cost of carbon capture. The options include: ▪ The chemical conversion of CO_2 to synthetic fuels, Petro-chemicals and fertilisers ▪ Direct use for food and beverages, wastewater treatment, concrete curing and enhanced oil and gas recovery. ▪ Mineralisation to construction materials	▪ CO_2 must be combined with hydrogen sourced from renewable sources (green H_2). ▪ Thus, to produce products at scale would require green H_2 to be produced at scale, which requires solar PV and wind at scale. ▪ Thus, technology is only expected in mid to long term.	▪ Direct use of CO_2 in beverages/food and in enhanced oil recovery (EOR) operations is commonplace word-wide. Unfortunately, SA does not have operational oil/gas wells where EOR can take place, nor is CO_2 transport infrastructure in place. Food use is very limited in scale. ▪ Chemical and biological conversion is the subject of ongoing R&D. Technology is currently energy intensive and costly.

Applicability to South Africa and Impacts on Other Issues

Any goal of achieving net zero carbon must include carbon storage and/or usage. If viable processes are available to convert CO_2 cost effectively into commercial products, it will offset the cost of capturing the CO_2. This is a prime example of a circular economy where waste product (CO_2) is used as feedstock to produce additional products.

The scale up of CO_2 utilisation technologies to pilot scale and beyond is emerging but at a slow rate with large amounts of investment needed. With a few exceptions, e.g. Carbon Recycling International, none of the discussed projects has yet reached large scale production of chemicals from CO_2.



Source: royalsociety.org

Overview of Typical Technology Implementation Project Metrics

Timeline / Schedule

CO_2 conversion to products would constitute a full-scale chemical plant – 6 years for design and construction.

Complexity and Ease of Implementation

Fairly complex project as with other petrochemical plants

Project Risks

Cost effective CO_2 Conversion technologies at scale not available.

Maturity Readiness	Efficiency Improvement	GHG Reduction Potential	Relative Cost	Enabling Infrastructure Required	Short Medium Long Term Prospect	Overall Risk for Execution
R&D	-	EXCELLENT	$$$	MAJOR	LT	HIGH

ANNEXURE

STAKEHOLDER ENGAGEMENTS

Eskom

- Eskom uses a risk based approach to determine coal plant shut down schedule (Eskom emphasises shutdown, not decommissioning).
- **By 2035, nine coal plants are scheduled to be shut down, removing some 18GW of baseload generation capacity**. If renewable power is to replace this lost capacity, 60GW of capacity must be developed, taking into account the lower load factor of renewable power (~33%). By 2035, only six coal plants will be in operation and by 2050, only Medupi and Kusile will be operating.
- The **current transmission and distribution infrastructure capacity is a constraint** and needs to be upgraded to support the new generation capacities.
    - It's not adequate to support transmission of renewable power projects in Northern and Western Cape to demand centres.
    - **Funding is required to upgrade the infrastructure.**
    - It could take up to 8 years to upgrade and the Environmental Impact Assessment (EIA) process is the critical path for these projects.
- Coal Technologies
    - Carbon Capture and Storage (CCS) are being investigated. They are **targeting Kusil**e as a possible Carbon Capture site.
    - Eskom decided they will **not pursue underground coal gasification** (UCG) at Majuba. There are too many uncertainties for this project.
- Natural Gas for power generation
    - Natural Gas is currently not available.
    - **Boilers are at end-of-life and will need to be replaced** which greatly increases the cost to convert end-of-life coal plants to gas firing.
    - Combined Cycle Gas Turbine (CCGT) generation is a more efficient, cost effective option. Locating the CCGT plant at the coast is preferred as turbine performance is better at the coast (higher atmospheric pressure) and required gas infrastructure feeding the plant is much less than for an inland plant.
    - Development of gas pipeline infrastructure could take 5 to 8 years.
- Pollution Control Technology
    - Flue Gas Desulphurisation plant for Medupi will cost approximately R40 billion and they are looking at alternatives to reduce cost.
    - For emissions standards compliance, they will be **upgrading electrostatic precipitators (ESPs),** not bag filters.
    - Planned for low NO_x burners at older plants but lack of funds have stalled these projects.
    - Short term focus is to get the **Energy Availability Factor (EAF) from current 62% to 72% +** through planned maintenance.

Sasol

- Secunda operations are currently emitting approximately 60 Mt CO_2e and Sasolburg 4 Mt CO_2. Sasol's target is a 30% emissions reduction by 2030 and to reach net-zero emissions by 2050.
- Fuel switching from coal to gas:
  - Sasol will replace 25% of Secunda coal feedstock with 40 to 60 PJ incremental LNG over the next 10 years.
  - Reforming gas has a 70% carbon efficiency whereas combusting of coal has a 40% carbon efficiency. The result is less GHG emissions for the Secunda plant.
- Use of Biomass
  - Approximately 2% coal can be replaced by biomass in the slurry phase coal gasifiers; beyond that dedicated gasifiers are required for biomass.
  - The challenge with biomass is the supply logistics and it must be certified green. Furthermore, CO_2 is emitted during the transport of biomass.
  - The role of biomass in Sasol remains uncertain.
- Green Hydrogen
  - Production of green hydrogen from renewable energy and electrolysis will be viable if the cost is US$2 per kg or lower. Current production cost is approximately US$7 to 8 per kg.
  - Sasol's expected time for producing green H_2 is from 2030 onwards.
  - There are funding initiatives for green H_2 production globally. Sasol will participate in the H_2 Global Auction. The German government provides incentives for green H_2 production.
- Sustainable Aviation Fuels (SAF) production at Secunda
  - Sasol plans to produce SAF at their Secunda petrochemical plant using the FT process and green H_2. Production of petrol and diesel can be replaced by SAF. They also have the option to replace carbon fuels production with sustainable chemical production.
  - The plan is to supply the OR Tambo airport with SAF and thereafter supply the export market.
  - It is not expected that competing clean fuels for aviation will be available in the medium to long term.
- Direct Air Capture will be viable if the cost is below US$200 per ton CO_2 captured.
- Carbon Storage - CO_2 storage in the Zululand basin has been evaluated. The option to reverse the gas pipeline to Mozambique for storage of CO_2 in Mozambique NG basins once it is depleted was found to be impractical and was not economically viable.

Exxaro

- CO_2 reduction initiatives: 78 MW solar plant at Grootegeluk mine and alternative fuel for large haulage trucks to replace diesel fuel (technology still to be decided). Current diesel consumption is 55 million litres pa. They also have two wind farms in operation.
- **Exxaro plans do not include developing new coal mines in future due to uncertainty of future global coal demand.**

- Studies commissioned by Exxaro:
    - Carbon capture and storage using Blue Algae to capture CO_2 at power stations. Found to be very water intensive and CO_2 streams from coal power stations are dilute
    - Carbon Nano-tube technology was also investigated
- An underground coal gasification (UCG) pre-feasibility study was done in 2013; however, the project was not feasible because of commercial and regulatory considerations and technological challenges to control ignition and combustion underground.
- A fluidised bed reactor to utilise coal discards was investigated. Concluded that **environmental issues outweigh returns on investment to make this feasible**. The calorific value of discards is very low and variable and the waste has high sulphur content which will be costly to remove.
- Small nuclear reactors using Thorium has been investigated in the past. There is no plan to revisit the use of nuclear.

Road Freight Association – RFA

- There is an opportunity to increase efficiency by optimising operations, for example, reducing truck idling time while waiting to load coal which wastes fuel.
    - The percentage of reduction of fuel usage that can be achieved depends on the operations. Notwithstanding, it could be higher than 10% for certain applications.
- The primary objective of the transport sector is not to be the technology standard bearer; it will **follow technology** development and **adopt competitive technology** taking into account economic considerations.
- Businesses have different strategies for replacement cycles of trucks and it varies across operations; it is not reported to the RFA.
- LNG technology for trucks seems to be a viable option but the risk of **government implementing levies and taxes on LNG** is a concern. It is expected that LNG consumption will reach a threshold where taxes will be introduced. Government must provide clarity and give an undertaking regarding this
- The **technology ecosystem is important**; infrastructure such as for refuelling and charging needs to be in place before technology will gain traction.
- It is expected that infrastructure to support technologies will be implemented by the private sector based on supply and demand

Council for Geoscience – CGS

- The Council for Geoscience (CGS) is **piloting a Carbon Capture and Storage (CCS) project** by conducting research that aims to identify geological storage formations that would be appropriate for storing carbon dioxide. This work is funded by the South African government and the World Bank.
- The **pilot project aims to store 10,000 tons of CO_2**. The site is located in Leandra region in Mpumalanga close to the Sasol Secunda plants and consists of basalt geological structure which needs to be investigated as a suitable CO_2 storage environment.

- **Compressed CO_2 will initially be transported to the storage site by truck** and the option for moving CO_2 by pipeline will be considered at a later stage depending on the results of the pilot project.
    - The Sasol plant has the advantage that CO_2 is already concentrated in a process stream.
    - Kusile will be evaluated for potential CO_2 capture as well.
- Construction and **initial sequestration will begin in year 2 of the pilot project**. While there is pressure to complete the pilot project within 2 years, the project will have to run for a few years before it can be determined if it is suitable for commercialisation.
    - A timeline for commercialisation, capital cost for investment and expected cost of carbon capture cannot be given at this stage.
- A **full EIA** will be done according to Word Bank requirements and CGS policies, the status of ground water and air quality will be monitored throughout the project.
    - There is **currently no legislation in South Africa giving guidance on CO_2 sequestration**, this is a legal hurdle that needs to be overcome and a framework guiding sequestration will need to be developed.
- The CGS is currently **updating the 2010 atlas of potential CO_2 storage locations** with new data, the updated atlas will be available towards the end of 2022

Central Energy Fund – CEF

- CEF is involved in LNG import project at Coega and has issued Request for Proposal for a **gas aggregator partner** at Coega.
    - The LNG anchor offtake will be for natural gas power generation as required in the IRP 2019. The project is a joint agreement between CEF, Transnet, CDC and IPPs.
- Initiatives for LNG imports through Richards Bay are driven by Transnet.
- There is a **need for better alignment on the initiatives to import LNG at Coega and Richards Bay**. There is concern that South Africa may not have the resources to develop Richards Bay and Coega LNG projects simultaneously.
- CEF is concerned about the announcement of the Sapref refinery shutdown at the end of March 2022 and the potential impact on security of fuel supply.
- The PetroSA plant at Mossel bay is currently shut down due to lack of gas feedstock.
    - The new gas finds by TotalEnergies in Brulpadda may provide feedstock to PetroSA.

South African Petroleum Industry Association - SAPIA

- In 2019, 3 million tons of CO_2e was emitted by SA crude refineries. This reduced in 2020 due to shutdowns. Oil refinery GHG emissions are **less than 1% of SA total GHG emissions.**
- Internal combustion engines (ICE) will be around for the foreseeable future in South Africa considering the current car parc of around 12 million vehicles of which 8 million are passenger cars.
    - Around 500 000 passenger vehicles being sold per annum; this implies up to 25 years to turn-over the current car population. The average price of cars sold is less than R350 000 and this group makes up 80% of all cars sold.

  - Electric vehicles are too expensive for the general public and are not expected to make significant market penetration.

- SA should **target hybrid EVs in the near term** (< 10 years). **Cleaner fuels** will still be **required for hybrid cars**, which have modern efficient engine technology.
  - Hybrid cars are available at approximately R350 000 and thus will play an **important role in the transition to fossil fuel decarbonisation.**
  - A **strong demand for liquid fossil fuels** in the **next 20 years** is expected.
- A current rough estimates for **CF investment is 2.1 – 2.5 billion US$** (R37.5 billion at R15/US$) (**excluding Enref**)
- The **challenge** is making the **10 ppm sulphur specification for petrol** and meeting the other specifications for octane, benzene and olefins.
  - **Approximately 2/3 of the capex** required for CF2 is needed to **achieve the petrol CF2 specifications.** The investment cannot be fully recovered from market due to **price regulation** at the pump
- They believe refinery shutdowns **impact security of supply and the economy**.
  - An estimated **30,000 jobs will be lost if 3 refineries shut down** (refer economic impact report on SAPIA website).
- They caution **that Durban back of port infrastructure and NMPP** may **not have sufficient capacity** to handle the required fuel imports if the Durban and Natref refineries shutdown.
- The **legislative framework for mandatory blending of biofuels is prohibitive** and needs to be reviewed– industry is engaging government on the issues. Different legislations are not aligned, are conflicting or does not take a holistic view, for example:
  - Customs and excise taxes. (Duty at source)
  - Manufacturing licences required for biofuels blending
  - Fuel pricing, magisterial areas differentials, backhauling from ethanol plants to blending facilities etc.

South African Wind Energy Association - SAWEA

- General challenges for the industry include:
  - Access to land for renewable energy generation. Mostly private land is used. Government land is made available by Eskom and municipalities.
  - Electricity transmission and grid constraints in areas that are most suitable for wind farms such as in the Western Cape and Eastern Cape. It will take more than 5 years to build the required grid capacity upgrades.
  - There are Environmental Impact Assessment issues related to land and electricity distribution.
  - The NERSA licencing processes - Application processes must be aligned to make sure that licences are obtained as soon as possible.
  - The is uncertainty as to what the market will require and when.

- A study was done by the World Bank regarding off-shore wind farms in South Africa. The study indicated that it will take at least 15 years to implement off-shore wind farms.
- There are currently no local manufacturing of wind farm components.
  - The **Renewable Energy Industrialisation Master Plan** is looking at local production for components of wind farms.

CSIR

- CSIR have **done extensive modelling for various scenarios of electricity supply and demand and for various energy mixes based on IRP2019**. In all scenarios, coal power with CCS is more costly than other alternatives such as renewable power. **Coal plants with HELE technology such as ultra-supercritical plants do perform at higher efficiencies (40% plus), however, the additional capital and operational costs of carbon capture and storage makes them less competitive than renewable power**.
- The **cost of solar PV and wind has decreased significantly over the past 10 years** with average tariffs decreasing some 80-90%. This trend is expected to continue as capacity at scale is developed.
- **There is a role for natural gas in peaking load service (OCGT) to cover the variability of the renewable power.** They don’t recommend building baseload gas power (CCGT) because it risks lock-in of gas technology and the need for baseload power is not as critical today.
- The **footprint required by renewable power installations is relatively large**, however, studies have shown that SA is richly endowed with large expanses of land where solar and wind resources are abundant. Availability of **land is not considered a constraint.**
- **Electricity transmission and grid capacity is constrained**. System capacity upgrades must be designed and implemented to support the power development programme.
- **Similarly, gas to power projects require LNG import and gas pipeline infrastructure to support them**, as well as meet increased industrial demand for gas over the next 10 years (Sasol and industrial large scale gas users).
- **Nuclear power cost remains very high** and does not compete with other alternative power. If nuclear development costs can be decreased by 50% or more, for example, through smaller modular designs, they could become competitive.

Transnet

- Transnet together with the World Bank are busy evaluating feasible paths for the company to attain net zero carbon by 2050. They will be identifying specific technologies and strategies over the next 2 years.
- Their **main energy sources** are;
  - electricity (supplied by Eskom) and
  - diesel (supplied by the Oil Industry)
- Transnet has previously investigated LNG for traction, but it was stopped because the decision was to acquire electric locomotives.
  - The next purchasing cycle for locomotives will be in 5 to 10 years.

- Transnet is looking at importing LNG at Richards Bay and transportation of gas in pipelines.
    - TNPA has issued a Request for Information (RFI) for LNG imports in Richards Bay in Dec 2021. The information will be used to determine the way forward. The process is ongoing and comments on timelines for implementations cannot be given at this stage.

POLICIES AND REGULATIONS TO SUPPORT DEVELOPMENT OF NEW TECHNOLOGY AND INDUSTRIES

International Regulation and Policy Options that Governments use to Incentivise New Technology and Industries

Tax incentives and funding policies are used by governments to incentivise research and development of new technologies and industries. The development of technologies and industries that will reduce GHG emissions is a key focus area worldwide. Additional policies and regulations support the development environment and commercialisation of new technologies and to develop industries. Policies are developed specific to the countries' objectives.

The table below shows an overview of key policies and regulations types that are used by governments to incentivise development.

Policy and Regulation Options	Descriptions	Purpose
Financial Tax Incentives		
Tax Incentives for R&D	Tax credits, tax allowances, tax deferrals etc. For expenditure on R&D.	Promotes research and development for new technology and skills development.
Tax Incentives for Business Investment	Tax credits, tax allowances, tax deferrals etc. For investment establishing businesses in targeted sectors.	Reduce risk and encourage investment in targeted sectors.
Carbon taxes	Tax per ton CO_2 emitted	Encourage adoption of alternative cleaner technology and fuels.
Direct Funding		
Grants/Subsidies	Non repayable grants and cost-sharing grants for full or partial financing of new businesses.	Increase affordability of technology and address high capital cost barriers to reduce financial risk and provide funding and favourable financing options for developing new technologies and industries.
Investment Incentives	Business owners are able to claim back the portion of the approved project that the incentive addresses.	
Equity Funding	Government provides the business owner with finance to grow the business in exchange for a percentage ownership of the business.	
Financing Support	Loan guaranties, favourable loan terms, assistance in acquiring funding from funding institutions.	
Key Supporting Policies and Regulations		
Planning	Framework, plans and strategies for development of technologies and industries and align initiatives and policies.	Provide clarity on goals and how all aspects of development of new technology and industries will be achieved.
Targets	Targets to achieve the strategic goals, development of technology,	Create clear signals to suppliers, consumers and

	manufacturing capacity and commercialisation of products	investors on what is planned for the future.
Codes and Standards	Standards for safe construction, manufacturing, transport and storage of products. Product specifications.	Provides clarity enabling stakeholder to develop, operate and produce within prescribed parameters.
Demand and Markets	E.g. Commitment for offtake of products by government structures. Collaborations between suppliers and markets. Create export markets. Discourage consumption of alternative products. Long term production and supply agreements.	Development of stable markets for products promote technologies and reduce risk.
Infrastructure	Infrastructure enabling economic commercialisation of new technologies.	Infrastructure e.g. refueling stations, transport, transmission, exports, storage for raw materials and products.
Pricing and Tariffs	Administered product pricing and tariffs	Address volatility in the market and enable competitiveness
Collaboration	Collaboration with other governments and agencies and private entities to develop technology and industries and to open markets for products.	Reduce risk and create opportunities to develop technology, industries and markets
Knowledge sharing and skills development	Partnerships between government, industry, academia, and science councils, agencies.	Support capacity for technology research and development and skills required by the industries.

The table below shows tax incentives that are used by various governments to incentivise research and development. Tax credits, accelerated depreciation, grants and tax deduction is most commonly used.

Tax Incentives For Research And Development	South Africa	Australia	Brazil	China	France	Germany	Japan	Netherlands	UK	United States
Accelerated depreciation on R&D assets	✓	✓	✓		✓			✓	✓	✓
Cash grants	✓	✓			✓	✓		✓	✓	
Expedited government approval process										
Financial support			✓					✓		
Income tax withholding incentives			✓					✓		

Loans			✓		✓	✓		✓	✓	
Patent-related incentives			✓		✓			✓	✓	
Reduced social security contributions								✓		
Reduced tax rates				✓				✓	✓	
Tax credits		✓		✓	✓	✓	✓	✓	✓	✓
Tax deduction (including super deduction)	✓	✓	✓	✓				✓	✓	✓
Tax holiday					✓					

Source: Ernst & Young

The table below show examples of initiatives and funds that were introduced by governments to incentivise commercialise targeted cleaner technologies.

Initiative	Description
Section 45Q tax credit, United States	Section 45Q of the Internal Revenue Code offers a tax credit that varies from just under $12 up to $50 for each metric ton of carbon captured and sequestered
SDE++ scheme, Netherlands	The SDE++ provides subsidies for the use of techniques for the generation of renewable energy and other CO_2-reducing technique, 5 billion euro was available for 2021.
CCUS Infrastructure Fund. United Kingdom	The CCS Infrastructure Fund support capital expenditure on transport and storage networks and industrial carbon capture (ICC) projects
Innovation Fund, European Union	The Innovation Fund helps to scale up technological solutions necessary for the green transition in Europe.
Australia Government	Australia government has committed A$250-million in funding to a programme that will turbocharge the development of commercial-scale carbon capture, use and storage (CCUS) projects and hubs across Australia
Asia Energy Transition Initiative, Japan	Japan pledged $10bn in government funding for renewable and low-carbon projects in Asian nations aiming to support development and demonstration of clean energy technology, including CCUS, towards decarbonisation.

Current Policies and Funding to Incentivise Development of New Technologies and Industries in South Africa

The table below shows the tax incentives and grants that are currently available in South Africa, this include financial incentives for research and development and support of industrial projects that new technology and industries could benefit from.

Incentive	Description
Section 11D (Income Tax Act) , Super Deduction for R&D	Certain expenditures incurred on the R&D approved project, will be eligible for the 150% deduction at the time of filing the tax return.
Section 12C (1)(gA) (Income Tax Act), R&D assets accelerated depreciation	Capital expenditures incurred to develop, construct or purchase new and unused assets used in the conduct of qualifying R&D activities

	qualify for accelerated depreciation.
Support Program For Industrial Innovation (SPII), (DTIC), Cash grant for R&D	Cash grants for the development of innovative products and/or processes. Maximum ZAR5 million per project of the qualifying costs incurred during the technical development stage.
Technology and Human Resources for Industry (THRIP), (DTIC), Cost-sharing grants For R&D	Cash grants for research and development in science, engineering and applied research and development in science, engineering technology. The THRIP is focused specifically to increase the number of people with appropriate skills in the development and management of research based technology for industry.
Section 12R (Income Tax Act) : Special Economic Zone (SEZ), Reduced Corporate Tax	Reduced corporate tax rate and other incentives offered to companies carrying on a business in an SEZ designated by the Minister of Trade and Industry and approved by the Minister of Finance
Section 12L. (Income Tax Act), Energy Savings	Deduction per kilowatt hour (c/kWh) of energy savings. The incentive aims to promote the efficient use of energy as a means to safeguard the security of the energy supply and to help combat greenhouse gas emissions.
Section 12B. (Income Tax Act), Renewable Energy Capex Allowances	provides for a deduction of the lesser of the actual and arm's length costs of acquiring and installing any machinery, plant, implement, utensil or article used in the types of generation projects listed in section 12B(1)(h) (Generation Asset).
Section 12(U) (Income Tax Act) Capex Allowances	Section 12U provides for capital allowances for roads and fencing used in the generation of electricity greater than 5MW from the following sources: wind; solar; hydropower to produce more than 30MW; and biomass comprising organic wastes, landfill gas or plant material.
Carbon Tax	Tax on tons of greenhouse gas emissions emit. Inventive to take steps, such as switching fuels or adopting new technologies, to reduce their emissions to avoid paying the tax.

South Africa has set up a Green Fund to support transition to low carbon. There are also inter-governmental cooperation agreements as well as various international funds that are available to developing countries for projects that will lead to the reduction of GHG emissions.

Funding Option	Description
Green fund	The Government of South Africa through the Department of Environmental Affairs (DEA) has set up a Green Fund to support the transition to a low carbon, resource efficient and climate resilient development path delivering high impact economic, environmental and social benefits. The Development Bank of Southern Africa (DBSA) is the implementing agent of the Green Fund.
TIA: Technology development Fund	TIA is a South African national public entity that serves as the key institutional intervention to bridge the innovation chasm between research and development from higher education institutions, science councils, public entities, and private sector to support the development of technologies from proof concept, leading to product prototype and ultimately demonstration thereof in an operating environment.

German Federal Ministry of Economic Cooperation and Development (BMZ). Germany	About €40 million (~R700 million) in grant funding committed by the German Federal Ministry of Economic Cooperation and Development (BMZ) for the promotion of South Africa's green hydrogen economy. A separate commitment of €200 million (~R3.5 billion) in concessional loan finance for public and private sector green hydrogen projects has been made by the German development bank KfW.
Partnership to aid South Africa to move to low carbon economy.	The partnership between South Africa and the US, the UK, Germany, France, and the EU involves the disbursement of $8.5 billion over the next three to five years to help the country shift towards a low-carbon economy.
Green Climate Fund	Created by the United Nations Framework Convention on Climate Change (UNFCCC), the Fund aims to support a paradigm shift in the global response to climate change. It allocates its resources to low-emission and climate-resilient projects and programmes in developing countries
The International Finance Corporation (IFC)	The International Finance Corporation (IFC) provides financing of private-enterprise investment in developing countries around the world, through both loans and direct investments
The Climate Technology Centre and Network (CTCN)	The Climate Technology Centre and Network (CTCN) promotes the accelerated development and transfer of climate technologies at the request of developing countries for energy-efficient, low-carbon and climate-resilient development.
World Bank	The World Bank provides financing for projects towards reducing air pollution such as renewable energy and pilot projects for CCUS.
Global Environment Facility (GEF) Trust Fund	The GEF is the largest multilateral trust fund focused on enabling developing countries to invest in nature, and supports the implementation of major international environmental conventions including on biodiversity, climate change, chemicals, and desertification.

ENERGY EQUIVALENTS AND GENERAL GUIDELINES

Coal Power Generation	Value	Units	Comments
MWh	3600	MJ	
	3.412	mmBTU	
Gigajoule GJ	1,000	MJ	
Petajoule PJ	1,000,000	GJ	PJ = 10^{15} Joules
Subcritical Plant Efficiency – Sub C	38%		Emissions >880 gCO_2/kWh
Supercritical Plant Efficiency – SC	42%		emissions 800 to 880 gCO_2/kWh
Ultra-Supercritical Efficiency – USC	45%		emissions 740 to 800 gCO_2/kWh
Advanced Ultra-Supercritical Efficiency – AUSC	50%		emissions 670 to 740 gCO_2/kWh
Integrated Gasification Combined Cycle Efficiency - IGCC	50%		emissions 670 to 740 gCO_2/kWh

Gas Turbine Generators	Value	Units	Comments
MWh	3600	MJ	
	3.412	mmBTU	
Open Cycle Gas Turbines - OCGT			
Thermal efficiency	35%		Existing diesel OCGT in RSA. Emissions are 28% less than diesel i.e. 0.18 $kgCO_2$/kWh versus 0.25 $kgCO_2$/kWh
Utilisation	20%		Peaking
Combined Cycle Gas Turbines - CCGT			
Thermal efficiency	60%		New generators in RSA. Emissions 0.18 $kgCO_2$/kWh
Utilisation	40 to 70%		Mid-merit

Fossil Fuel Emissions	LHV, MJ/kg	Liq. Density, kg/m3	Emissions, kg CO_2/kg Fuel
Sub-bituminous coal	22.0		92.15
Heavy fuel oil	41.70	950.0	72.19
Natural gas / LNG	49.17	458.0	50.31
Brent crude oil	44.00	825.0	
Diesel	43.40	850.0	69.36

Source: engineeringtoolbox.com

Renewable Power Land Requirements	Land Requirement	Comments
Wind Power	25 ha/MW	Ha = 10,000 m^2
Solar PV	1.5 ha/MW	

Source: Utility-Scale Solar Photovoltaic Power Plants, Project Developers Guide, IFC World Bank, 2015

Source: https://sciencing.com/much-land-needed-wind-turbines-12304634.html

Green Energy	Units	Comments
Electrolyser power for green hydrogen	55kWh/kg H_2	
Water consumption for green hydrogen	9 to 18 kg water/kg hydrogen	Water must be demineralized

REFERENCES

Ali, H et al; 2021; Cost–Benefit Analysis of HELE and Subcritical Coal-Fired Electricity Generation Technologies in Southeast Asia; doi.org/10.3390/su13031591

Academy of Science of South Africa (ASSAf); 2017; The shale gas industry in South Africa: Toward a science action plan. ; dx.doi.org/10.17159/assaf.2017/0019

Adrien Hosking et al; 2021; Development of Hybrid Polymer Membranes for Direct Air Capture of Carbon Dioxide; netl.doe.gov/sites/default/files/netl-file/21DAC_Alam.pdf

Adzuieen Nordin et al; 2013; Analysis of carbon dioxide emission of gas fuelled cogeneration plant. 2013 IOP Conf; iopscience.iop.org/article/10.1088/1757-899X/50/1/012054/pdf

Aline Oliboni de Azambuja; 2016; Microbial community composition in Brazilian stored diesel fuel of varying sulphur content, using high-throughput sequencing; www.sciencedirect.com/science/article/pii/S0016236116310729

Anglo Coal Australia; 2008; Fact Sheet: Commitment to reducing greenhouse gas emissions.; www.anglocoal.com.au/wps/wcm/resources/file/eb2ff14f75d53f1/ANG%200849%20FS%20Greenhouse%20DM-04.pdf

ASHRAE SA Chapter; 2020; Getting to zero: a guide to developing net zero carbon buildings in South Africa; www.cityenergy.org.za/getting-to-zero-a-guide-to-developing-net-zero-carbon-buildings-in-south-africa/

Aspen Institute; 2019; Decarbonizing the electricity sector & beyond a report from the 2019 aspen winter energy roundtable; www.aspeninstitute.org/publications/2019-winter-summary-report/

BAPEPSA; 2021; A Biomass Action Plan for Electricity Production in South Africa; https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_SouthAfrica_final.pdf

Barry MacColl, Eskom; 2016; FFF IPP Conference: The role of Eskom in future coal based generation?; www.fossilfuel.co.za/conferences/2016/IPP/MacColl-Barry.pdf

BP; 2018; BP Advancing the Energy Transitions; www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/sustainability/group-reports/bp-advancing-the-energy-transition.pdf

BP; 2021; bp Statistical Review of World Energy 2021; www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf

Bruno Merven et al; 2021; Assessment of new coal generation capacity targets in South Africa’s 2019 Integrated Resource Plan for Electricity; cer.org.za/wp-content/uploads/2021/09/Annexure-A_ESRG_New-coal-plants-South-Africa.pdf

Center for Strategic and International Studies (CSIS); 2020; Climate Solutions Series. Decarbonizing the Electric Power Sector; www.csis.org/analysis/climate-solutions-series-decarbonizing-electric-power-sector

Centre of Environmental Rights; 2018; Myth of Clean Coal Fact Sheet; cer.org.za/wp-content/uploads/2018/11/Myth-of-Clean-Coal-Fact-Sheet_Final_November-2018.pdf

Chevron; 2021; Climate change resilience: Advancing a lower carbon future ; www.chevron.com/-/media/chevron/sustainability/documents/climate-change-resilience-report.pdf

CO_2 Capture Project ; 2008; Three basic methods to separate gases; www.co2captureproject.com

Congressional Research Service (CRS).; 2020; Carbon Capture Versus Direct Air Capture; crsreports.congress.gov/product/pdf/IF/IF11501/2

ConocoPhillips; 2020; Climate Change Framework for Energy Transition; www.conocophillips.com/sustainability/managing-climate-related-risks/strategy/

Council for Scientific and Industrial Research (CSIR); 2017; Forecasts for electricity demand in South Africa (2017 – 2050) using the csir sectoral regression model for the integrated resource plan of South Africa; www.energy.gov.za/IRP/irp-update-draft-report2018/CSIR-annual-elec-demand-forecasts-IRP-2015.pdf

Council for Scientific and Industrial Research (CSIR); 2020; Statistics of utility scale power generation in South Africa in 2020; researchspace.csir.co.za/dspace/handle/10204/11865

Council for Scientific and Industrial Research (CSIR); 2020; Technical Report, Systems analysis to support increasingly ambitious CO_2 emissions scenarios in the South African electricity system; researchspace.csir.co.za/dspace/handle/10204/11483

Council for Scientific and Industrial Research (CSIR); 2022; Impact of the increasing fuel prices on the economy and possible alternatives and/or considerations in addressing increases in fuel prices; pmg.org.za/committee-meeting/34564/

Council for Scientific and Industrial Research (CSIR; 2016; South African Coal Quality for Independent Power Producers; fffcarbon.co.za/

Council of Geoscience; 2010; Atlas on geological storage odf carbon dioxide in South Africa; cleanenergysolutions.org/resources/atlas-geological-storage-carbon-dioxide-south-africa

Dave Collins; 2016; COP21 outcomes and the implications for South Africa's energy future; fffcarbon.co.za/

Deborah Jelen; 2021; Direct air capture using novel structured adsorbents; netl.doe.gov/sites/default/files/netl-file/21DAC_Jelen.pdf

Deloitte; 2020; Survey of Global Investment and Innovation Incentives | South Africa; www2.deloitte.com/global/en/pages/tax/articles/global-investment-and-innovation-incentives-survey.html

Department of Environmental Affairs; 2014; South Africa's Greenhouse Gas (GHG) Mitigation Potential Analysis. ; www.environment.gov.za/sites/default/files/docs/appendixG_afolusector.pdf

Department of Mineral Resources and Energy (DMRE), EPRI; 2017; Power generation technology data for integrated resource plan of South Africa technical update; www.energy.gov.za/IRP/irp-update-draft-report2018/EPRI-Report-2017.pdf

Department of Mineral Resources and Energy (DMRE); 2016; South African coal sector report; www.energy.gov.za/files/media/explained/South-African-Coal-Sector-Report.pdf

Department of Mineral Resources and Energy (DMRE); 2018; South Africa's Renewable Energy Programmes Overview and comments from Head of IPP Office; www.ipp-projects.co.za/Home/About

Department of Mineral Resources and Energy (DMRE); 2019; Integrated Resource Plan (IRP2019); www.energy.gov.za/IRP/2019/IRP-2019.pdf

Department of Mineral Resources and Energy (DMRE); 2019; The South African energy sector report 2019; www.energy.gov.za/files/media/explained/2019-South-African-Energy-Sector-Report.pdf

Department of Mineral Resources and Energy (DMRE); 2021; South African Gas Master Plan: Base case Report version 01; www.energy.gov.za/files/media/explained/Gas_Master_Plan_Basecase_Report.pdf

Department of Public Enterprises (DPE); 2019; Roadmap for Eskom in a Reformed Electricity Supply Industry; www.gov.za/sites/default/files/gcis_document/201910/roadmap-eskom.pdf

Department of Science And Innovation; 2022; Hydrogen society roadmap for South Africa 2021; www.dst.gov.za/index.php/resource-center/strategies-and-reports/3574-hydrogen-society-roadmap-for-south-africa-2021

Department Science and Innovation; 2021; South African Hydrogen Valley Final Report 2021; www.dst.gov.za/images/2021/Hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf

Department of Forestry, Fisheries and the Environment (DFFE) ; 2014; Green House Gas Inventory for south Africa 2000 - 2010; www.environment.gov.za/sites/default/files/docs/greenhousegas_invetorysouthafrica.pdf

Department of Forestry, Fisheries and the Environment (DFFE) ; 2016; Towards the development of a GHG emissions baseline for the agriculture, forestry and other land use (AFOLU) sector in South Africa; www.dffe.gov.za/sites/default/files/docs/afolu_research_report.pdf

Department of Forestry, Fisheries and the Environment (DFFE) ; 2019; South Africa Low Emissions Development Strategy 2050; www.environment.gov.za/sites/default/files/strategic_plans/southafricas_lowemission_developmentstrategy_dec2018draft.pdf

Department of Forestry, Fisheries and the Environment (DFFE) ; 2021; Republic of South Africa CLIMATE CHANGE BILL; www.parliament.gov.za/bill/2300773

DNV GL – Maritime; 2020; marine fuel group technology & research, white paper 2020 ammonia as a marine fuel; www.dnv.com/Publications/ammonia-as-a-marine-fuel-191385

Dr. Christopher W. Jones; 2021; MIL-101(Cr)-Amine Sorbents Evaluation Under Realistic Direct Air Capture Conditions; netl.doe.gov/sites/default/files/netl-file/21CMOG_CDRR_Jones.pdf

Engineering and Mining Journal; 2021; Iron Ore Miner Fortescue Expands Fleet. Publication: Engineering and Mining Journal Page: 56; www.e-mj.com/departments/operating-strategies/iron-ore-miner-fortescue-expands-fleet-mobility/

ENI; 2020; Long-Term Strategic Plan to 2050 and Action Plan 2020-2023; www.eni.com/en-IT/media/press-release/2020/02/long-term-strategic-plan-to-2050-and-action-plan-2020-2023.html

Environmental Defence Fund (EDF); 2015; South Africa: An emissions trading case study; www.edf.org/sites/default/files/south-africa-case-study-may2015.pdf

Ernst & Young; 2021; Worldwide R&D Incentives Reference Guide 2021; www.ey.com/en_gl/tax-guides/worldwide-r-and-d-incentives-reference-guide

Eskom; 2020; Transmission Development Plan 2020-2029; www.eskom.co.za/eskom-divisions/tx/transmission-lines/transmission-development-plans/

ESKOM; 2021; Eskom integrated report 2021; www.eskom.co.za/investors/integrated-results/

ESKOM; 2021; Eskom sustainability report 2021; www.eskom.co.za/wp-content/uploads/2021/11/2021sustainabilityReport.pdf

Eskom; 2021; Medium term system adequacy outlook 2022 2026; www.eskom.co.za/wp-content/uploads/2022/01/Weekly_System_Status_Report_2022_w1.pdf

ESKOM; 2021; Portfolio Committee on Environment, Forestry and Fisheries. Eskom Status of compliance with Environmental laws;

European Commission; 2021; 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality; www.europeansources.info/record/fit-for-55-delivering-the-eus-2030-climate-target-on-the-way-to-climate-neutrality/#:~:text=Communication%20published%20by%20the%20European,gas%20(GHG)%20emissions%20by%20at

EU-South Africa (EU-SA); 2021; Powerfuels 2: Stimulating domestic hydrogen consumption opportunities in South Africa; www.euchamber.co.za/wp-content/uploads/2021/02/Powerfuels-Summary-Report-South-Africa-EU-SA_Partners-for-Growth-Final-28-Jan-2021.pdf

Exxaro Resources Limited; 2020; Integrated report 2020; www.exxaro.com/investors/integrated-reports

ExxonMobil; 2020; Updated 2021 Energy & Carbon Summary; corporate.exxonmobil.com/-/media/Global/Files/energy-and-carbon-summary/Energy-and-carbon-summary.pdf

Federal Ministry of Economic Affairs and Energy; 2021; The German National Hydrogen Strategy and Planned Funding Instruments for International Hydrogen Projects; www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6

Feig GT et al; 2017; South African carbon observations: CO_2 measurements for land, atmosphere and ocean. S AfrJ Sci. 2017;113(11/12), Art.#a0237; dx.doi.org/10.17159/sajs.2017/a0237

Florian Zerobin et al; 2020; Concentrated Carbon Dioxide (CO_2) from Diluted Sources through Continuous Temperature Swing Adsorption (TSA); Download Citations | ACS Publications

Fossil Fuel Foundation, Peter Terbrugge ; 2017; Comments on the NPC Discussion Paper on Energy; fffcarbon.co.z

Fossil Fuel Foundation; 2017; FFF submission to the Department of Energy re. IRP 2016. The value of the continued use of coal in the energy plan for South Africa; fffcarbon.co.za/wp-content/uploads/2017/06/FFF-response-to-IRP2016_Rev-5-003.pdf

Gattuso J-P et al; 2021; The Potential for Ocean-Based Climate Action: Negative Emissions Technologies and Beyond.; www.researchgate.net/publication/348250708_The_Potential_for_Ocean-Based_Climate_Action_Negative_Emissions_Technologies_and_Beyond

Global CCS Institute; 2015; Fact sheet capturing CO_2; www.globalccsinstitute.com/archive/hub/publications/191018/fact-sheet-capturing-co2.pdf

Global CCS Institute; 2020; Global status of CCS 2020; www.globalccsinstitute.com/resources/global-status-report/

Green Hydrogen Systems; 2022; Produce your own hydrogen from renewable energy sources at the lowest cost possible; www.greenhydrogen.dk

GreenCape; 2018; Energy Services: Market Intelligence Report 2018; www.greencape.co.za/assets/Uploads/GreenCape-Energy-Services-2018-MIR-25052019.pdf

Guati-Rojo, A et al; 2021; Public Attitudes and Concerns about Ammonia as an Energy Vector.; www.mdpi.com/1996-1073/14/21/7296

H. Alissa Park; 2021; Next Generation Fiber Encapsulated Nanoscale Hybrid Materials for Direct Air Capture with Selective Water Rejection; netl.doe.gov/sites/default/files/netl-file/21DAC_Park.pdf

Hitachi; 2010; Technology options for clean coal power generation with CO_2 capture ; www.globalccsinstitute.com/archive/hub/publications/159728/technology-options-clean-coal-power-generation-co2-capture.pdf

Holz, Christian et al; 2021; New Coal Power Generation in South Africa in Light of South Africa's Climate Fair Share. Climate Equity Reference Project Working Paper Series. WP007. Version 1.0. Zenodo. [doi: 10.5281/zenodo.2595499]; doi.org/10.5281/zenodo.2595499

IDDRI & Climate Strategies. Burton, J. et al.; 2018; Coal transition in South Africa - Understanding the implications of a 2°C-compatible coal phase-out for South Africa. ; www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/Rapport/20180609_ReportCoal_SouthAfrica.pdf

IEA Bioenergy; 2018; South Africa – 2018 update Bioenergy policies and status of implementation; www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_SouthAfrica_final.pdf

IEA Clean Coal Centre (CCC); 2020; Annual review the global resource on the clean use of coal; www.sustainable-carbon.org/

IEA Clean Coal Centre (CCC); 2020; CARBON PRICES AND THEIR IMPACT ON COAL POWER; www.sustainable-carbon.org/report/carbon-prices-and-their-impact-on-coal-power-ccc-308/

IEA Clean Coal Centre (CCC); 2021; Increasing efficiency of pulverised coal -fired power plants, ccc/310; www.sustainable-carbon.org/library/reports/

IGUA-SA; 2021; Annual report of the Industrial Gas Users Association 2021; www.igua-sa.org/reports/

IHS Markit ; 2021; Climate and Sustainable Finance. How Chile aims to be among the largest

exporters of green hydrogen in the world; ihsmarkit.com/research-analysis/big-ambitions-how-chile-aims-to-be-among-the-largest-exporters.html#:~:text=On%203%20November%2C%20Chile's%20Ministry,largest%20hydrogen%20exporters%20by%202040.

IHS Markit ; 2021; Climate and Sustainable Finance; ihsmarkit.com/industry/Climate-Sustainability.html

Imasiku, K. et al; 2021; Review of Green Hydrogen Economy in Southern Africa.; doi.org/10.3390/su132313240

Intergovernmental Panel on Climate Change (IPPC); 2022; Climate Change 2022. Impact Adaption and Vulnerability. Summary for Policymalers; www.ipcc.ch/report/ar6/wg2/

International Energy Agency (IEA); 2008; Clean Coal Technologies Accelerating Commercial and Policy Drivers for Deployment; www.iea.org/reports/clean-coal-technologies

International Energy Agency (IEA); 2012; Technology Roadmap High-Efficiency, Low-Emissions Coal-Fired Power Generation; www.iea.org/reports/technology-roadmap-high-efficiency-low-emissions-coal-fired-power-generation

International Energy Agency (IEA); 2013; HELE coal-fired power generation roadmap; iea.blob.core.windows.net/assets/4bfcc54d-d130-413c-9511-e0c2eb85328f/HELE_Foldout_A3_2ndProofs.pdf

International Energy Agency (IEA); 2018; Global Energy and CO_2 Status Report 2018 Energy Demand; iea.blob.core.windows.net/assets/23f9eb39-7493-4722-aced-61433cbffe10/Global_Energy_and_CO2_Status_Report_2018.pdf

International Energy Agency (IEA); 2019; Global Energy & CO_2 Status Report; www.iea.org/reports/global-energy-co2-status-report-2019#:~:text=As%20a%20result%20of%20higher%20energy%20consumption%2C%20global%20energy%2Drelated,energy%2Drelated%20carbon%20dioxide%20emissions.

International Energy Agency (IEA); 2019; World Energy Investment 2019; www.iea.org/reports/world-energy-investment-2020

International Energy Agency (IEA); 2020; The role of CCUS in low carbon power system; www.iea.org

International Energy Agency (IEA); 2021; Driving Down Methane Leaks from the Oil and Gas Industry A regulatory roadmap and toolkit; www.iea.org/reports/driving-down-methane-leaks-from-the-oil-and-gas-industry

International Energy Agency (IEA); 2021; Financing Clean Energy Transitions in EMDEs; www.iea.org/reports/financing-clean-energy-transitions-in-emerging-and-developing-economies

International Energy Agency (IEA); 2021; The Role of Critical Minerals in Clean Energy Transitions; www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

International Renewable Energy Agency; 2018; Renewable energy policies in a time of transition; www.irena.org/publications/2018/apr/renewable-energy-policies-in-a-time-of-transition

International Renewable Energy Agency; 2020; Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal; irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

International Renewable Energy Agency; 2021; A pathway to decarbonise the shipping sector by 2050, International Renewable Energy Agency, ISBN 978-92-9260-330-4; www.irena.org/publications/2021/Oct/A-Pathway-to-Decarbonise-the-Shipping-Sector-by-2050#:~:text=Urgent%20action%20is%20needed%20to,transacted%20via%20ocean%20going%20vessels.

International Renewable Energy Agency; 2021; Planning and Prospects for Renewable Power: Eastern and Southern Africa; www.irena.org/publications/2021/Apr/Planning-and-prospects-for-renewable-power-Eastern-and-Southern-Africa

International Renewable Energy Agency; 2021; Reaching Zero with Renewables: Biojet fuels; irena.org/publications/2021/Jul/Reaching-Zero-with-Renewables-Biojet-Fuels

Investec; 2021; Energy RSA Report 2021; www.investec.com/en_za/focus/economy/sa-clean-energy-lost-in-transmission.html

Jeff Kudronowicz, Anguil; ; Air Pollution Abatement Technologies for the Oil and Natural Gas Processing Industries.; anguil.com/

Konrad-Adenauer-Stiftung; 2020; Carbon Pricing in Sub-Saharan Africa; www.kas.de/documents/282730/282779/Carbone+Pricing+in+sub-Saharan+Africa+anglais.pdf/afbff20e-0b1a-61e8-24d6-38ae056c0c81?t=1594785554783

Kurt Zenz Housea et al; 2010; Economic and energetic analysis of capturing CO_2 from ambient air; www.pnas.org/content/pnas/108/51/20428.full.pdf

Lehtveer M and Emanuelsson A; 2021; BECCS and DACCS as Negative Emission Providers in an Intermittent Electricity System: Why Levelized Cost of Carbon May Be a Misleading Measure for Policy Decisions. ; www.frontiersin.org/articles/10.3389/fclim.2021.647276/full

Maria Elena Diego et al; 2017; Making gas-CCS a commercial reality: The challenges of scaling up; www.researchgate.net/publication/318392771_Making_gas-CCS_a_commercial_reality_The_challenges_of_scaling_up/fulltext/596c146a458515e9afb1cef7/Making-gas-CCS-a-commercial-reality-The-challenges-of-scaling-up.pdf

McKinsey & Company; 2021; Global Energy Perspective 2021; www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2021

Meridian Economics; 2021; What does South Africa's updated nationally determined contribution imply for its coal fleet?; meridianeconomics.co.za/wp-content/uploads/2021/09/Briefing-Note-No.-2021_10_2021-09-28_Implications-of-the-updated-SA-NDC-for-the-power-sector-Final.pdf

Moshe Mohutsiwa; 2015; Estimation of capital costs for establishing coal mines in South Africa; wiredspace.wits.ac.za/jspui/bitstream/10539/18378/2/Moshe_Mohutsiwa_Estimation%20of%20Capital%20Costs%20for%20Establishing%20Coal%20Mines%20in%20South%20Africa.pdf

Naledzi Environmental Consultants; 2018; Background information bid. application for postponement of the minimum emission standards (mes) for 14 of Eskom's coal and liquid fuel-fired power stations; cer.org.za/wp-content/uploads/2018/08/English-Background-Information-Document-August-2018.pdf

National Energy Technology Laboratory (NETL); 2021; Carbon Capture Program CDR Annual Meeting; netl.doe.gov/sites/default/files/netl-file/21CMOG_CDRR_Hancu.pdf

National Treasury; 2019; Reviewing the design, implementation and impact of South Africa's Research and Development Tax Incentive; www.treasury.gov.za/comm_media/press/2021/TaxPolicyDiscussion/2021121501%20Discussion%20Document%20-%20Research%20and%20Development%20Tax%20Incentive.pdf

NBI; 2021; 2021–2023 A very important time for climate what you need to know about ramping up climate ambition; www.nbi.org.za/wp-content/uploads/2021/12/A-Guide-to-Climate-Change-for-South-African-CEOs.pdf

NBI; 2021; Chapter 3: The role of gas in South Africa's path to net-zero; www.nbi.org.za/reports/the-role-of-gas-in-south-africas-path-to-net-zero/

NBI; 2021; Chapter 1: decarbonising South Africa's power system; www.nbi.org.za/wp-content/uploads/2021/08/NBI-Transition-Chapter-Decarbonising-SA-power-11-Aug-2021.pdf

NBI; 2021; Chapter 2: Decarbonising south Africa's petrochemicals and chemicals sector; www.nbi.org.za/decarbonising-south-africas-mining-as-well-as-petrochemicals-and-chemicals-sectors/

NBI; 2021; Chapter 2: Decarbonising South Africa's power system; www.nbi.org.za/reports/decarbonising-south-africas-power-system/

NBI; 2021; Chapter 4: Decarbonising the South African mining sector; www.nbi.org.za/reports/decarbonising-the-south-african-mining-sector/

Nel Hydrogen Electrolysers; 2022; Nel Hydrogen Electrolysers; nelhydrogen.com

Nel Hydrogen Electrolysers; 2022; On-Site Hydrogen Solutions for Generator Cooling; nelhydrogen.com

Organisation for Economic Co-operation and Development (OECD); 2005; 0; www.oecd.org/env/cc/34878689.pdf

Osman K et al; 2014; Review of carbon dioxide capture and storage with relevance to the South African power sector.S Afr J Sci. 2014;110(5/6),S Afr J Sci. 2014; sajs.co.za/article/view/4169

Parsons Brinckerhoff, World Bank; 2013; Techno-Economic Review of CCS Implementation in South Africa; openknowledge.worldbank.org/handle/10986/29164

Peter Jansohna et al; 2011; Technologies for Gas Turbine Power Generation with CO_2 Mitigation; infoscience.epfl.ch/record/220200/files/1-s2.0-S1876610211002669-main.pdf

REN21; 2018; Advancing the global renewable energy transition; www.ren21.net/gsr_2018_highlights_en

REN21; 2018; Renewables 2018 global status report; www.ren21.net/gsr-2018/

REN21; 2021; RENEWABLES 2021 GLOBAL STATUS REPORT; www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

Roger Aines; 2020; Options for Removing CO_2 from California's Air; www.icef.go.jp/pdf/2020/program/concurrent_session/RogerAines_P.pdf

Royal Dutch SHELL PLC; 2021; Shell Energy Transition Strategy 2021; www.shell.com/investors/shareholder-meetings/_jcr_content/par/expandablelist_copy/expandablesection_11.stream/1618407326759/7c3d5b317351891d2383b3e9f1e511997e516639/shell-energy-transition-strategy-2021.pdf

Sanedi; 2011; South African Coal Roadmap. Overview of the South African Coal Value Chain; fffcarbon.co.za/initiatives/2013/SACRM-Value-Chain-Overview.pdf

Sanedi; 2013; South African Coal Roadmap. Outlook for the Coal Value Chain : Scenarios to 2040; fffcarbon.co.za/initiatives/2013/SACRM-Technical-Report.pdf

Sanedi; 2013; South African Coal Roadmap. TECHNICAL REPORT: SACRM SCENARIOS TO 2040; fffcarbon.co.za/initiatives/2013/SACRM-Technical-Report.pdf

Sanedi; 2013; The South African Coal Roadmap; www.fossilfuel.co.za/initiatives/2013/SACRM-Roadmap.pdf

Sanedi; 2017; 2017-12-15 Hybridisation infographic ;

Sanedi; 2017; Appraisal of Implementation of Fossil Fuel and Renewable Energy Hybrid Technologies in South Africa; www.sanedi.org.za/img/wp-content/uploads/2018-01-15%20Hybrid%20Technologies%20in%20South%20Africa%20full%20report.pdf

Sanedi; 2018; PROSPECTUS Addressing climate change through CCS technology: The South African Centre for Carbon Capture and Storage Programme.;

SAPIA; 2021; The economic contribution of the downstream oil industry to South Africa in 2019; www.sapia.org.za/portals/0/MediaStatements/SAPIA_EIA_Exec%20Summary.pdf

Sasol; 2021; Sasol limited climate change report for the year ended 30 June 2021 ; www.sasol.com/sites/default/files/financial_reports/Sasol%20Climate%20Change%20Report_2021_22Sep21.pdf

Sasol; 2021; Sasol Parliamentary Portfolio Committee on Environment, Forestry and Fisheries Sasol briefing on air quality compliance roadmaps & greenhouse gas reduction strategy;

Siemens Energy; 2021; Siemens Energy tailor made high efficiency Siemens Energy tailor made high efficiency steam turbines; www.siemens-energy.com/global/en/offerings/power-generation/steam-turbines.html

Siemens Energy; 2021; Turning biomass into value power generation equipment for biomass-fuelled plants; assets.siemens-energy.com/siemens/assets/api/uuid:129bf11b-5986-415b-aabd-707c608a0c7d/broschure-biomasse-en-se.pdf

Siemens; 2016; 'Green' Ammonia is the key to meeting the twin challenges of the 21st century; www.siemens-energy.com/uk/en/offerings-uk/green-ammonia.html

Sisa Njikelana; 2016; Viability of power generation from coal in Africa - a political perspective; fffcarbon.co.za/publications/

SLR Consulting; 2021; The challenges of permitting green hydrogen and ammonia projects in South Africa; https://cdn.slrconsulting.com/uploads/2021-03/Briefing%20Note%20-%20Green%20Hydrogen%20and%20Ammonia%20in%20South%20Africa.pdf

SLR Consulting; 2022; The challenges of permitting green hydrogen and ammonia projects in South Africa; www.slrconsulting.com/en/news-and-insights/insights/challenges-permitting-green-hydrogen-and-ammonia-projects-south-africa

South African Centre for Carbon Capture and Storage, AD Surridge; 2016; Carbon Capture and Storage in South Africa - Cop 22; cop22.co2geonet.com/media/6833/2-tony_surridge_ccs-developments-in-south-africa.pdf

Southern African Institute of Mining and Metallurgy (SAIMM); 2021; The Journal of the Southern African Institute of Mining and Metallurgy. Volume 121 No.11 November 2021; www.saimm.co.za/

SRK Consulting; 2021; Specialist Climate Change Assessment. Gas-to-Power Plant in Zone 10 (South); docs.srk.co.za/sites/default/files/images-20181122/South_Africa/Public_Documents/CDC_Coega_3000_MW_gas_to_power_project_EIA/Appendices/Zone_10_North/24_Appendix_K3_Climate_Change_Specialist_Report_Zone_10N.pdf

Stockholm Environment Institute (ESI), Energy Research Centre, University of Cape Town; 2019; The end of coal? Planning a "just transition" in South Africa; www.sei.org/publications/the-end-of-coal-planning-a-just-transition-in-south-africa/

Sustainable Energy Africa (SEA); 2020; State of Energy in South African Cities; www.sustainable.org.za/resource.php?id=84

TC Meyer et al; 2016; Critical environmental considerations for IPP coal power generators -reflections on environmental auditing at SA coal fired power stations; fffcarbon.co.za/

The Department of Public Works and Infrastructure ("DPWI"); 2021; National Infrastructure Plan 2050 ("nip 2050") for comments; www.governmentpublications.lib.uct.ac.za/news/draft-national-infrastructure-plan-2050

The Department of Trade, Industry and Competition (dtic); 2016; Draft Post-2015 National Energy Efficiency Strategy; www.gov.za/documents/post-2015-national-energy-efficiency-strategy-comments-invited-24-dec-2016-0000

The Department of Trade, Industry and Competition (dtic); 2021; Auto Green Paper on the Advancement of New Energy Vehicle in South Africa; www.gov.za/sites/default/files/gcis_document/202105/44606gen308.pdf

The Goldman Sachs Group, Inc.; 2020; Carbonomics. Innovation, Deflation and Affordable De-carbonization; www.goldmansachs.com/insights/pages/carbonomics-innovation-deflation-and-affordable-de-carbonization.html

The International Centre for Sustainable Carbon (ICSC); 2019; Emissions standards South Africa; www.sustainable-carbon.org/library/emission-standards/

The International Centre for Sustainable Carbon (ICSC); 2021; A review of cost estimates for carbon capture and storage in the power sector by Toby Lockwood, ICSC/317; www.sustainable-carbon.org/report/a-review-of-cost-estimates-for-carbon-capture-and-storage-in-the-power-sector/

The International Centre for Sustainable Carbon (ICSC); 2021; Advances in non-energy products from coal, CCC/311; www.sustainable-carbon.org/report/advances-in-non-energy-products-from-coal-ccc-311/

The International Centre for Sustainable Carbon (ICSC); 2021; Blended firing of coal and lignite, ICSC/316; www.sustainable-carbon.org/report/blended-firing-of-coal-and-lignite/

The International Centre for Sustainable Carbon (ICSC); 2021; Fossil fuel-based energy storage, ICSC/314; www.sustainable-carbon.org/webinar/fossil-fuel-based-energy-storage-technologies/

The International Centre for Sustainable Carbon (ICSC); 2021; Hydrogen production from coal; www.sustainable-carbon.org/report/hydrogen-production-from-coal-icsc-313/

The International Centre for Sustainable Carbon (ICSC); 2022; Global thermal coal supply fundamentals; www.sustainable-carbon.org/report/global-thermal-coal-supply-fundamentals/

The International Centre for Sustainable Carbon (ICSC); 2022; The role of low emission coal technologies in a net zero Asian future; www.sustainable-carbon.org/webinar/the-role-of-low-emissions-coal-technologies-in-a-net-zero-asian-future/

The Minerals Council; 2020; Facts and figures pocketbook; www.mineralscouncil.org.za/downloads/send/3-fact-sheets/1761-facts-and-figures-2020#:~:text=A%20Facts%20and%20Figures%20Pocketbook,has%20on%20our%20everyday%20lives.

The Royal Society; 2017; The potential and limitations of using carbon dioxide; royalsociety.org/low-carbon-energy-programme

The Royal Society; 2020; Ammonia: zero-carbon fertiliser, fuel and energy store. POLICY BRIEFING; royalsociety.org/-/media/policy/projects/green-ammonia/green-ammonia-policy-briefing.pdf

The South African National Energy Agency (SANEA); 2020; South African Energy Risk Report 2020; southafricanenergyassociation.site-ym.com/page/RiskReport

Theo Fischer et al; 2016; Emission limits of and waste disposal considerations for plant firing coal and plant co-firing with biomass or waste materials ; www.fossilfuel.co.za/conferences/2016/IPP/Fischer-Theo.pdf

Thomas Garner; 2016; Is Electricity from coal still viable? Fossil Fuel Foundation; fffcarbon.co.za/publications/

ThyssenKrupp; 2021; Large-scale water electrolysis for green hydrogen production; ucpcdn.thyssenkrupp.com/_legacy/UCPthyssenkruppBAISUhdeChlorineEngineers/assets.files/products/water_electrolysis/tk_19_0820_hydrogen_broschuere_2019_03.pdf

Total; 2020; 2020 Strategy and Outlook; totalenergies.com/sites/g/files/nytnzq121/files/documents/2020-09/strategy-and-outlook-2020.pdf

Trade & Industrial Policy Strategies (TIPS); 2021; The coal value chain in South Africa; www.tips.org.za/research-archive/trade-and-industry/item/4161-the-coal-value-chain-in-south-africa

UNECE; 2021; Coordinated Operations of Flexible Coal and Renewable Energy Power Plants: Challenges and Opportunities; unece.org/sustainable-energy/publications/coordinated-operations-flexible-coal-and-renewable-energy-power

United Nations Environment Programme (UNEP); 2021; Emissions Gap Report 2021; www.unep.org/emissions-gap-report-2021

University of the Witwatersrand, Prof Rosemary Falcon; 2012; Clean coal technologies in a low carbon economy: South African scenarios opportunities for reducing greenhouse gas emissions assaf conference; www.assaf.org.za/files/Conference%20Presentations/Low%20Carbon%20Cities/Section%201.pdf

University of the Witwatersrand, Prof Rosemary Falcon; 2016; Coal resources of South Africa and their unique qualities; fffcarbon.co.za/conferences/2016/IPP/Falcon-Rosemary.pdf

US TRADE AND DEVELOPMENT AGENCY; 2017; South Africa Energy Storage Technology and Market Assessment; www.crses.sun.ac.za/files/research/publications/technical-reports/USTDA_Public+Version+1.pdf

Wang X and Song C; 2020; Carbon Capture From Flue Gas and the Atmosphere: A Perspective.; www.frontiersin.org/articles/10.3389/fenrg.2020.560849/full

World Coal Association; 2021; Clean Coal Technology in ASEAN Balancing Equity, Security & Sustainability; www.worldcoal.org/clean-coal-technologies-in-the-asean/

WSP; 2021; Shell and BP South Africa Petroleum Refineries (SAPREF) atmospheric impact report increased capacity of the north flare; www.wsp.com/404

Yousuf Haffejee; 2016; Successful Coal IPP's for Africa : What is Required; fffcarbon.co.za/conferences/2016/IPP/Haffejee-Yousuf.pdf

Yushan Yan; 2021; Electrochemically Driven Carbon Dioxide Separation; netl.doe.gov/sites/default/files/netl-file/21DAC_Setzler.pdf

Ready for a brighter future

www.sanedi.org.za

Block C,
Upper Grayston Office Park,
152 Ann Crescent,
Strathavon , Sandton, 2146

+27 011 038 4300

information@sanedi.org.za