GREEN HYDROGEN SOUTH AFRICA

International PtX Hub

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

IKI INTERNATIONAL CLIMATE INITIATIVE

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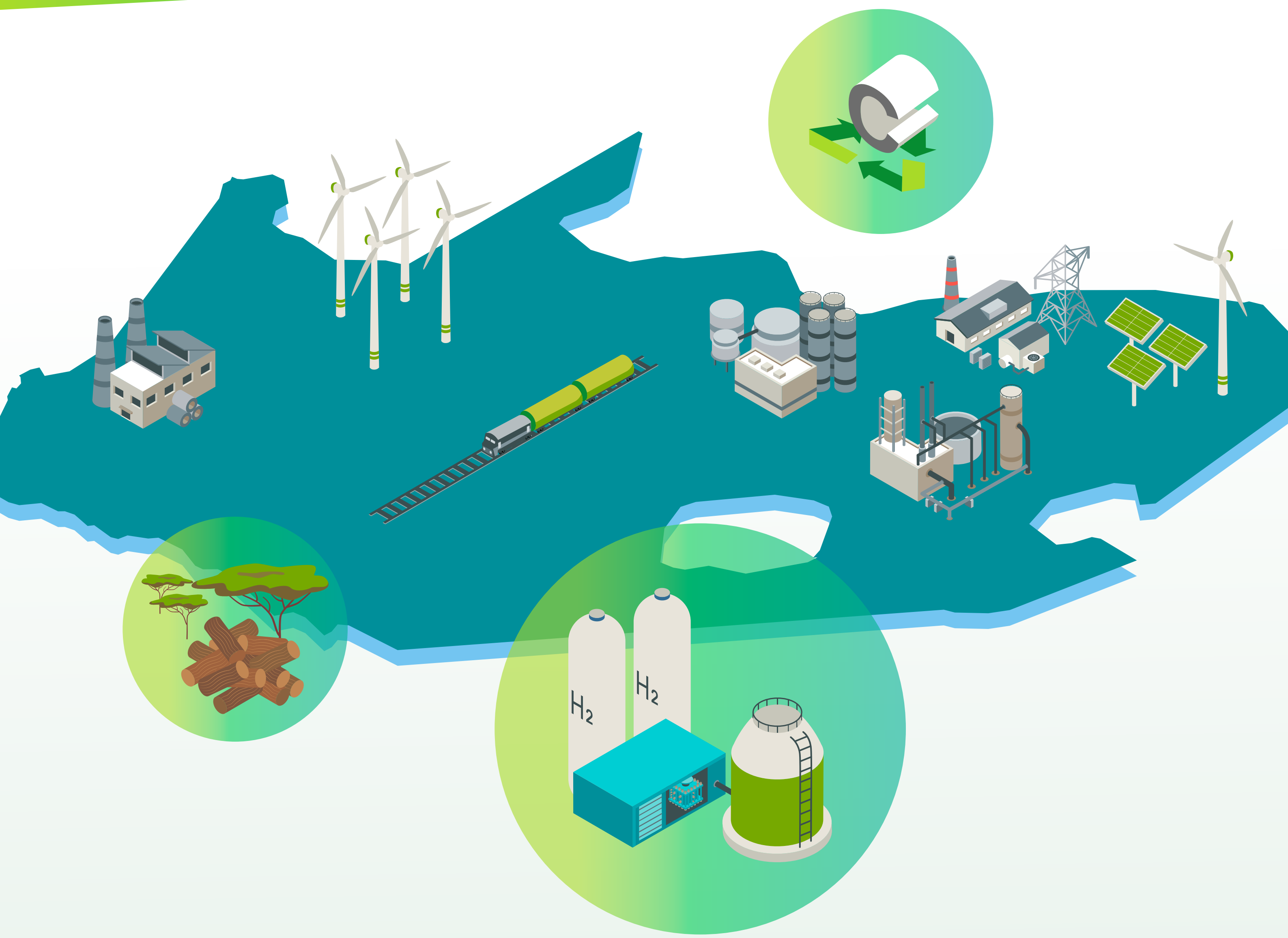
CARBON SOURCES FOR THE PRODUCTION OF POWER-TO-X AND SYNTHETIC FUELS IN SOUTH AFRICA

Executive Summary



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This is the executive summary of a comprehensive study of the same title. The entire study is available from February 2024 on ptx-hub.org

Pretoria, February 2024

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Overall framework

The scope of the present study is to primarily **investigate South Africa's potential for producing Power-to-X (PtX) products,** in order to determine whether the country can afford exporting these products instead of only using them domestically for achieving its own climate change mitigation goals and for being aligned with the global defossilisation and decarbonisation trends. The report discusses the existing carbon dioxide (CO_2) point sources in South Africa and assesses the technical possibilities of Carbon Capture (CC) technologies for extracting CO_2 from these sources.

The **overall methodological approach** of the study follows a demand and supply analysis:

- **Demand for CO_2 as a feedstock for PtX product,** is quantified through estimation of the domestic demand for PtX products in South Africa, based on relevant national planning documents, and also potential demand by foreign markets (EU, ICAO, IMO), focusing on set targets and sustainability requirements;

- **Supply of CO_2 as a feedstock for PtX product,** is determined on the basis of the estimation of the available CO_2 that could be potentially captured, considering mostly the industrial point sources in the country. The potential expected quantities of **CO_2 from the power, petrochemical, cement and steel sectors in South Africa** are analysed and estimated, considering the announced plans for the development of the sectors towards 2030 and 2050.

Considering the above, **exports can be approached as the difference between the potentially captured CO_2 from the industrial point sources and the domestic demand for CO_2 as a feedstock**. The sustainability dimension as a key factor determining the eligibility of the captured CO_2 in the exporting countries is also touched upon, although the study primarily aims at providing a more theoretical analysis that will set the basis for future targeted investigation.

South Africa's carbon supply potential

South Africa is one of the largest greenhouse gas (GHG) emitters on the African continent. The country's power and industrial sectors are the primary sources of its GHG emissions, with coal-fired power plants and heavy industries, such as iron & steel, cement and petrochemicals, being the major emitters.

The evolution of South Africa's power sector emissions can be estimated through a combination of factors such as current emission levels, future energy demand projections, and policy and regulatory frameworks. The government's Integrated Resource Plan of 2019, which outlines the country's energy mix and electricity generation capacity, provides a basis for **estimating future emissions from the power sector, considering the expected fuel mix by 2030 and 2050 and a mean emissions factor**. Subsequently, carbon capture is assumed to take place via a post combustion capture process using MDEA (methyldiethanolamine) as solvent.

Besides power, **process emissions of South Africa's core industries in the 2030 and 2050 horizon are estimated on the basis of relevant analysis and projections** reported in the literature for the industrial emissions of the entire African continent (McKinsey, Africa's green manufacturing crossroads report, 2021). The analysis is based on the International Energy Agency's (IEA) decarbonisation scenarios framework. First, it includes a base case, where African countries comply with their current National Determined Contribution (NDC) commitments and industry does not make any specific decarbonisation efforts beyond the set NDC requirements. Second, the framework involves a global NDC-guided case, that aligns Africa's NDC with the global average and the industry undertakes mainly relatively inexpensive brownfield improvements (e.g., use of biofuels). Only the unavoidable portion of the industrial process emissions, is considered to be available for the carbon capture process, which refers to the emissions that are inherent in certain industrial processes for which mitigation is not currently feasible.

Table 1 provides an **overview of the estimated potential for captured CO_2 from the analysed sectors in South Africa**, considering applicable technologies and assuming that carbon capture is applied to unavoidable industrial emissions. Reported quantities should be considered at the theoretical maximum ones and the exact determination of the techno-economical feasible captured CO_2 utilisation is subject to further detailed studies.

In terms of sustainability criteria, sectors with highest share of unavoidable emissions should be prioritised for carbon capture. Starting from the cement sector which has the highest share of unavoidable emissions (most sustainable) and moving up to the power sector which has the lowest share (least sustainable). The estimated amount of captured CO_2 per point source is presented in the following graphs for the years 2030, 2040 and 2050. With respect to the readiness for implementing CC in each sector, it should be mentioned that alternative processes/technologies for steelmaking are already available and can be implemented in the 2030's, while the petrochemical sector would need more time for its transition (based on the publicly available Sasol's sustainability plan). Further, according to the country's NDC, defossilisation of the power sector will not take place before 2050.

The following two figures (Figure 1 and Figure 2) present the lowest and highest amounts of captured CO_2 respectively, as derived from the base case and global NDC-guided scenarios. The maximum amounts of captured CO_2 ranges between 210-220 $MtCO_2$ for 2030, 140-170 $MtCO_2$ for 2040 and 170-206 $MtCO_2$ for 2050, which would allow, assuming that renewable hydrogen will be available at scale, to sustainably produce at least 81 million litres of synthetic kerosene in 2030 and 65 million litres in 2050.

Table 1: Overview of captured CO_2 from each sector, considering applicable technologies and assuming that CC is applied to unavoidable emissions

Sector	Process emissions share (unavoidable emissions)	2030 $MtCO_2$	2040 $MtCO_2$	2050 $MtCO_2$
Mineral (cement/lime)	65%	6,0-6,9	3,8-9,6	3,3-13,7
Petrochemical (CTL/petr. refining)	50%	29,9-38,7	11,4-36,0	7,1-34,6
Iron and steel	12%	1,1-1,3	0,9-1,4	0,5-1,6
Power	0%	170,9	126,2	155,4

Potential for captured CO_2 ordered according to sustainability criteria – Global NDC ambitions scenario

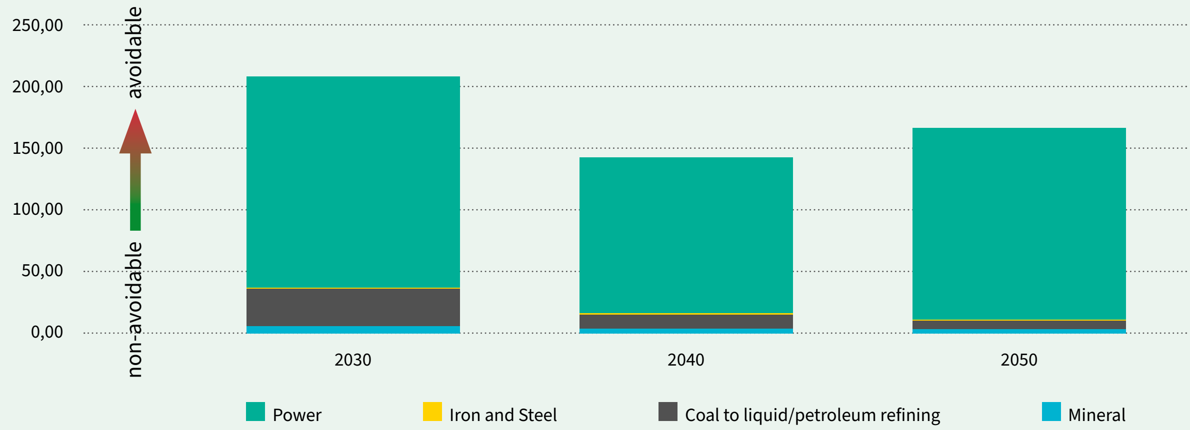

Figure 1: Own illustration

Potential for captured CO_2 ordered according to sustainability criteria – Existing African NDC scenario

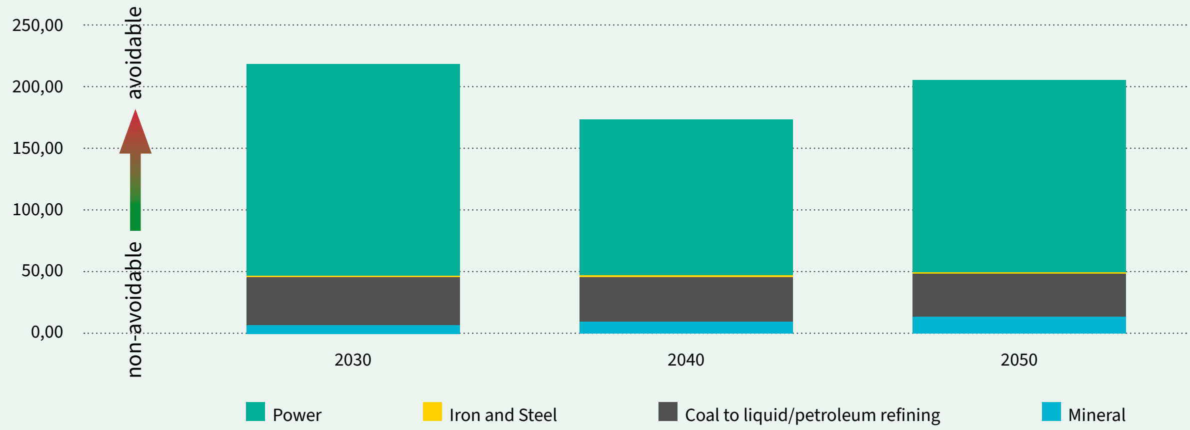

Figure 2: Own illustration

South Africa's carbon domestic demand

The potential carbon domestic demand, with respect to utilising emitted CO_2 for the production of synthetic fuels or other derivatives, is approached through the **analysis of the published scenarios for the evolution of the liquid fuel demand for transport applications up to 2050** (National Business Institute (NBI) publication series 'Just Transition and Climate Pathways Study for South Africa' – Chapter 2: Decarbonising South Africa's Petrochemicals and Chemicals Sector). The scenarios assume liquid fossil fuels will still play a major role in the mix, but the gradual penetration of hydrogen, Sustainable Aviation Fuel (SAF) and electricity (i.e. for Electric vehicles (EVs)) is also foreseen. Based on these scenarios, **three scenarios for the degree of CO_2 exploitation that could be aimed for have been interpolated**, namely:

- **Max CO_2 Exploitation:** all the projected liquid fossil fuel is substituted by green synthetic fuel. SAF production as per NBI scenario.
- **Medium CO_2 Exploitation:** half of the projected liquid fossil fuel is substituted by green synthetic fuel. SAF production as per NBI scenario.
- **Min CO_2 Exploitation:** no liquid fossil fuel is substituted. SAF production as per NBI scenario.

The next step of the analysis is to **translate the energy demand for fossil fuels into CO_2 demand for the production of PtX of equivalent energy**. To that end, we assumed that the fossil fuel in the developed scenarios is replaced by synthetic fuels, produced by the Reverse Water Gas Shift Fischer Tropsch (RWGS FT) process, and SAF is produced by direct methanol synthesis, followed by e-methanol-to-kerosene conversion. The respective estimates are shown in Table 2.

Table 2: CO_2 demand estimations for the different scenarios considered

Matrix of liquid fuel demand and green synthetic fuel exploitation scenarios, including respective CO_2 demand				Max Exploitation: All liquid fuel demand covered by green fuels		Medium Exploitation Half of liquid fuel demand covered by green fuels		Min Exploitation Only SAF projected demand is met	
	Year	Liquid fossil fuels (PJ)	SAF (PJ)	CO_2 (Mt) for e-diesel	CO_2 (Mt) for SAF	CO_2 (Mt) for e-diesel	CO_2 (Mt) for SAF	CO_2 (Mt) for e-diesel	CO_2 (Mt) for SAF
Reference Technology Scenario	2030	791	1	67.7	0.1	33.9	0.1	-	0.1
	2040	668	30	57.2	2.2	28.6	2.2	-	2.2
	2050	500	80	42.8	5.9	21.4	5.9	-	5.9
Sustainable Development Scenario	2030	709	5	60.7	0.4	30.4	0.4	-	0.4
	2040	554	35	47.4	2.6	23.7	2.6	-	2.6
	2050	388	73	33.2	5.4	16.6	5.4	-	5.4
Global net-zero Scenario	2030	689	5	59.0	0.4	29.5	0.4	-	0.4
	2040	368	33	31.5	2.4	15.8	2.4	-	2.4
	2050	124	81	10.6	6.0	5.3	6.0	-	6.0

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Estimated carbon exports potential

Overall, and following the methodology employed in this work, Table 3 provides an overview of:

- The estimated captured CO_2 from the point sources examined in the present work (i.e. power sector, iron and steel, cement and petrochemical industries), following the two scenarios considered (base case and global-guided NDC case): Results are presented considering the quantities coming from the power sector, as well as considering only CO_2 from process emissions (i.e. only the unavoidable emissions);
- The estimated quantities of CO_2 needed for the production of synthetic fuels to cover domestic needs in South Africa;
- The estimated exports potential, determined by subtracting the domestic CO_2 demand from the overall produced CO_2: Results are presented considering the quantities coming from the power sector, as well as considering only CO_2 from process emissions (i.e. only the unavoidable emissions)

It is noted that the reported values represent the theoretical upper limit of captured carbon – practical and market considerations in operating plants can reduce the expected captured carbon to as low as 20-60% of the theoretical values.

Table 3: Overview of estimated captured CO_2 from point sources, estimated CO_2 quantities of CO_2 to cover domestic needs, and estimated available CO_2 for exports

CO_2 quantities ($MtCO_2$)	2030	2040	2050
Captured CO_2 – incl. power sector	207.9-217.8	142.3-173.1	166.3-205.3
Captured CO_2 – without power sector	37.0-46.9	16.1-46.9	10.9-49.9
Domestic CO_2 demand	29.9-67.8	18.2-59.4	11.3-48.7
CO_2 available for export – incl. power sector	137.5-187.9	79.4-155	107.8-194
CO_2 available for export – without power sector	0-17.0	0-28.7	0-38.6

Based on the results, it can be concluded that if South Africa were to substitute all projected fossil fuel consumption with locally produced synthetic fuel, **there would be potentially enough captured CO_2 from its point sources to meet that 'domestic' demand**. Further, there is also **significant CO_2 surplus that could be utilised for exports. However, sustainability considerations would limit the available quantities that can in principle be eligible for exports to international markets**, since unavoidable emissions are a relatively small portion of the total emissions, which are dominated by coal power production. For the EU market, CO_2 from the power sector would only be eligible until 2036, according to the Renewable Energy Directive (RED), while CO_2 from other sectors, such as petrochemicals, will be eligible until 2041. It is noted that sustainability criteria should be met in any case. Thus, defining the amortisation period of the above-mentioned point sources constitutes one of the key next steps for determining in an accurate quantitative manner the eligible CO_2 for the various export markets, according to the relevant policies. In the case CO_2 from the power sector is not considered, the estimated export potential for CO_2 is drastically reduced, and depending on the defossilisation scenarios for domestic demand and degree of achievement of the global climate ambition, captured CO_2 from industrial processes might not even been sufficient to cover the expected domestic demand of transport liquid fuels.

Figure 3 and Figure 4 schematically present the results of the present evaluation of the potential of South Africa for available CO_2 for exports up to 2050, both when CO_2 captured from the power sector is accounted for and when it is not. For each case, a range is presented, considering different scenarios with respect to the degree of defossilisation of the liquid transport fuels sector in South Africa. The presented potential for available CO_2 for exports from South Africa does not consider specific sustainability requirements from the receiving markets. Such a consideration would limit the available quantities and would even set them to zero after a certain period of time, as for example is the case of Europe with the previsions of RED.

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Potential for available CO_2 for exports, including CO_2 captured from the power sector ($MtCO_2$)

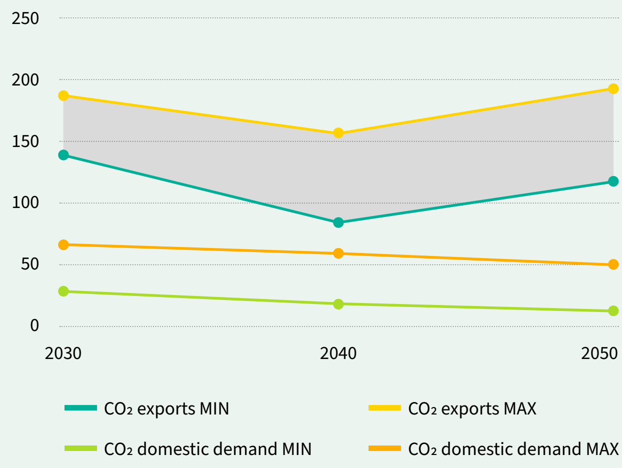

Figure 3: Own illustration

Potential for available CO_2 for exports, excluding CO_2 captured from the power sector ($MtCO_2$)

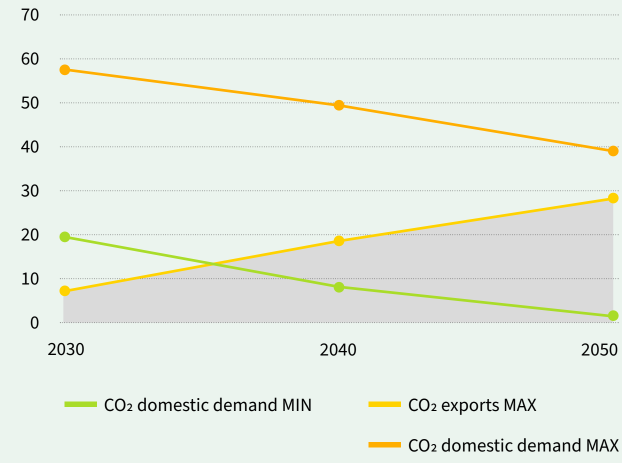

Figure 4: Own illustration

Recommendations and Future Work

PtX fuels (and products) can provide a crucial solution that can replace fossil fuel consumption in the hard to abate sectors, mainly in industry and transport (including heavy-duty vehicles, shipping and aviation). Both hydrogen and carbon are needed for the synthesis process of a PtX product, and the way these two elements can be secured largely determine the technical, economic and sustainability potential for the finally produced synthetic fuel. The particular characteristics of South Africa's energy system, as well as its key geopolitical position in the southern part of Africa, well located for the global trade routes and with significant national trade history, have an important influence on the development of the PtX value chain. Below, **key recommendations to unlock the PtX products potential of South Africa are provided**:

- **Recognise synthetic and PtX fuels as a key component of the energy mix for 2030 and 2050:** this is an important prerequisite to set the foundations for the production and use of PtX fuels and allow for the development of the required value chain. Benefits (environmental, economic, energy security, technological, social) deriving from the creation of the PtX value chain both as a whole and at each individual stage.

- **Create a long-term national energy strategy taking PtX fuels into account:** a strategy will essentially provide a clear signal for the development of the relevant market, by identifying specific targets for the introduction of PtX fuels in the energy mix, on the basis of a least cost approach within a frame of decarbonization of the national economy and ensuring security of energy supply.

- **Align the national regulatory frame with the relevant international best practices:** Alongside the specific regulatory framework for PtX, any possible need to amend the regulatory framework in other energy sectors, notably electricity and renewables, should be considered. The aim is to establish a framework for regulation, design, and support that enables the coordination of different segments of the energy market to enable the development and use of the necessary PtX infrastructure.

- **Promote technologies and demonstrate feasibility:** performance of feasibility studies on identified CCU cases to allow for an accurate determination of the realistic potential in the key industrial sectors is needed, also considering the related environmental issues and the public acceptance of such projects.

Key next steps towards the determination of the 'marketable' exports potential of PtX products produced in South Africa would include the following:

- Consideration of biogenic carbon sources and quantification of their potential as carbon feed in the PtX process;

- Consideration of PtX products other than fuels, such as chemicals to be used as feedstock in the relevant industry;

- Determination of the real potential for implementation of carbon capture in the industrial point sources in South Africa.