

The Potential for Sequestration of Carbon Dioxide in South Africa

Carbon Capture and Storage in South Africa

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Abstract

CSIR was commissioned by DME to compile a report on the potential for sequestration of carbon dioxide in South Africa in 2004. This report was the first attempt to obtain a picture of this potential. In the paper the main findings of the 2004 report are summarized. In the introduction the background for the study is presented as well as the main goals of the project. The sources and quantities as well as the composition of the carbon dioxide containing waste streams were compiled. The potential for biological, geological, chemical and marine storage was determined and it was found that the biological storage potential is limited, the chemical storage potential is largely unknown, the geological storage potential may be large, but further study is required. The marine storage potential is probably very large, but the environmental impact may be serious.

1. General introduction

Internationally and nationally the potential for the sequestration of carbon dioxide is increasingly receiving attention (Carbon Capture and Storage, CCS), (IPCC,2005) due to the growing levels of carbon dioxide and other greenhouses gases in the atmosphere. South Africa has acceded to the Kyoto Protocol as a non-Annex I country, which e.g. means that South Africa currently has no obligations regarding the reduction of greenhouse gas emissions. (Kyoto, 1997) However the current protocol will expire in 2013 and there is significant pressure from developed countries on non-Annex I countries to also develop policies to reduce greenhouse gas emissions as part of a follow-up Kyoto protocol (Stern, 2006). One policy option is to undertake a CCS program and therefore DME contracted CSIR to undertake a preliminary study on the potential for CCS in South Africa.(In this paper the outcomes of the study are reported. The detailed report is available at the DME web page. (Engelbrecht *et al*, 2004) The overall goals of the study were:

- To generate a knowledge base of the biological and geological potential for sequestration of CO₂ in South Africa.

- To publish such information for general use.

2. Scope of the study

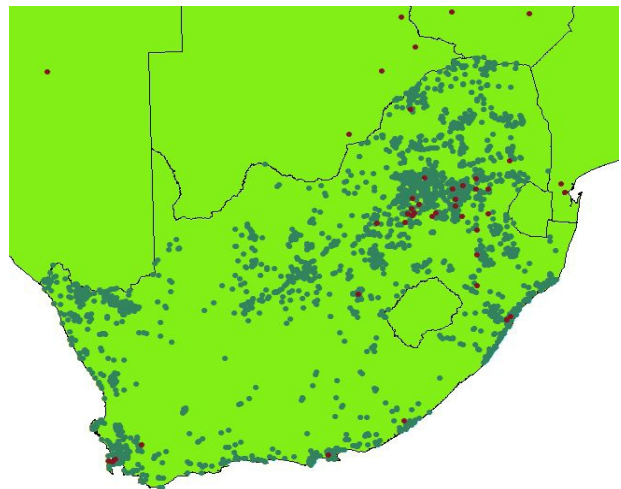
The study had the following components:

- To identify and quantify major CO₂ point sources and locations and to estimate the gas compositions associated with the different point sources.
- Report on total biological sequestration potential in South Africa.
- Report on the suitability of geological sequestration potential relevant to the large point sources of CO₂.
- Report on chemical sequestration potential.
- Report on the marine sequestration potential.
- Present conclusions of the study

3. Results of the study

3.1 Sources and quantities of CO₂

The sources of carbon dioxide released in South Africa are presented on Map 1.



Map 1. Carbon dioxide emissions from mines (grey) and power stations (red)

Sequestrable emissions are from point sources and it is potentially possible to capture the emitted CO₂. Non-sequestrable emissions are spread over a large area and it is not viable to capture the CO₂.

Table 1. Year 2000 CO₂ emissions by industry sector (Scholes, Van der merwe 1998).

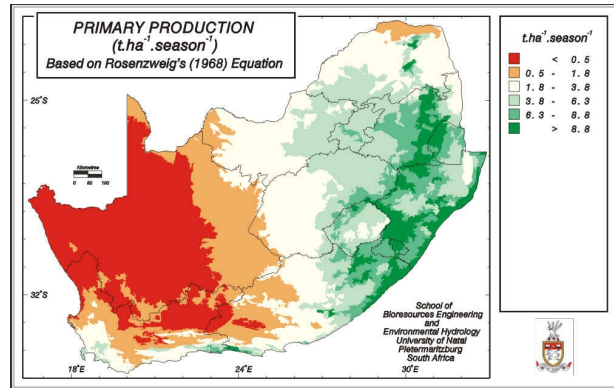
	Mt	%
Sequestrable		
Electricity production	161	65
Industrial processes	28	11
Other energy	30	12
Manufacturing	30	12
Total	249	100
Non sequestrable		
Waste	10	6
Agriculture	48	27
Fugitive	42	24
Transport	40	22
Heat production	37	21
Total	178	100
Total	427	

From Table 1 it can be seen that the major emitter of CO₂ (64.63%) is the electricity generating industry and that a total of 249 Mt can be captured annually.

The combined CO₂ emissions from Eskom and Sasol (Sasol, 2000) are 218 Mt/a. This represents 87.5 % of the total sequestrable South African CO₂ emissions of 249 Mt/a. These emissions are mainly present in the form of flue gas with a CO₂ concentration of 10 -15 % (186Mt/a) (Uys 'et al',1996). The remainder of the CO₂ (32Mt/a) is emitted in a concentrated form (90-98%) and is also available under pressure (20 Bar).

3.2 Biological Sequestration

Biological sequestration is the medium to long-term storage of carbon, derived from the atmosphere (Christie, Scholes, 1995), in living and dead plant parts and soil organic matter. (Du Toit, 1992). This report confines itself to biological sequestration in terrestrial ecosystems within the territory of South Africa. The carbon sequestration contribution by the living and dead bodies of animals is negligible, and microbial biomass and its by-products are included in soil organic matter (SOM).



Map 2. Approximate distribution of Net Primary Productivity in South Africa. (Schulze, 1977)

Map 2 shows that the NPP in most parts of South Africa is relatively small, which implies that the carbon sequestration potential is also small. Most of the land area in South Africa is under productive use, growing crops, timber, or forage for herbivores. The harvest of biomass and its export or import from the study area may also be sufficiently large to require a correction in the sequestration estimate. Where the harvested product is long-lived, such as timber used in mine-props or construction, it becomes itself a sequestered pool. Actions that increase this pool could be legitimately claimed as sequestration, but the quantities are relatively small.

Table 2. Maximum potential biological sequestration in South Africa.

Biome	deltaC gC/m ²	Period y	Area Mha	Total TgC (Mt)	Rate TgC/y (Mt/y)
Savannas	7000	30	40	2800	93
Karoo	1000	30	38	380	13
Thicket	8000	30	2.5	200	7
Low tillage farming	2400	30	10.6	254	8
Grassland to plantation forest	to 8000	30	1.8	144	5
Total				3778	126

In Table 2 the maximum potential biological sequestration potential is presented, but a more realistic assessment of what is achievable, given economic realities and other constraints, is about a tenth to a hundredth of these values, i.e. 1 to 12 TgC/y. These rates can be sustained for about 30 years.

The sum of the potential is about equal to South Africa's annual carbon emissions from fossil fuel

consumption. Thus for biological carbon sequestration to 'solve' the emission problem, we would have to use *all* the land of South Africa, for this purpose alone, and even then we would only be able to do so for 30 years.

In Table 3 all techniques for biological sequestration are listed, duration, land requirements and costs are estimated.

Table 3. Upper realistic potentials for biological sequestration of CO₂. (Scholes *et al.* 2000)

Technique	Rate ¹ million tons CO ₂ /y	Duration ² years	Extent ³ ha	Cost ⁴ R/ton
Options involving an increase in carbon stocks on the land				
Afforestation	3.9	20	330000	-46.60
Reduced tillage	0.4	20	5% of cropland s	9.70
Savanna thickening	7.9	20	40% of savannas	0.81
Options involving a reduction of emissions of non-CO ₂ GHG emissions				
Reduced cane burning	0.3	unlimited	40% of cane	24.50
Reduction in veld fires	0.7	unlimited	~80% of SA	-77.00
Reduction of emissions from enteric fermentation	6.9	unlimited	~70% of SA	-5.00
Manure management	1.7	unlimited	feedlots	49.00

3.3 Geological Sequestration

Geological sequestration is a form of direct sequestration where CO₂ is stored in underground formations, such as depleted oil and gas reservoirs, non-minable coal seams and saline reservoirs. These formations have the capacity, structure, seals, porosity and other properties (i.e. dissolving of CO₂ in groundwater), that make them amenable to decades or centuries worth of CO₂ storage. (Danae, Voormeij and Simandl, 2002) Such methods should be environmentally effective, socially acceptable and economically feasible and will have their own weaknesses and strength

3.3.1 Oil and gas reservoirs

South Africa has only fairly recently become an oil and gas producing nation and all these facilities are based offshore and concentrated in the Mosselbay area. Consequently there would be only limited capacity and availability of reservoirs into which CO₂ could be injected but the technique would become relevant as the existing oil and gas fields become more mature and production declines. (Bradshaw, 2002) Based on this background there is long-term potential to

sequester CO₂ in this manner. The site of the potential storage capacity will be related to the original reservoir. Production figures are in the order of 1.4 billion m³/y. We would suggest that the practicalities of replacing the extracted gas with CO₂ would discount this figure by 50% with a resulting figure of 0.7 billion m³/y (approx 1 million ton of CO₂ /y*) being the potential amount for sequestration.

*The extracted gas is calculated at normal pressure and the sequestered CO₂ is calculated at 80 bar pressure.

3.3.2 Deep saline formations (Law *et al.*, 2001)

The potential storage capacity of the Vryheid Formation, assuming an average thickness of 350m over an area of 1km² and at 2% of its effective volume, is in the order of 7 million m³ assuming that all the available pore-space could be utilized. Assuming a strike length of approximately 350km, a depth of burial between 800-3000m, giving a down dip length of approximately 75km at 3% dip, a maximum area of 26,500 km² is calculated. This equates to 183,750 million m³ (approx 183,750 million ton at the expected pressure) of storage capacity, which would be sufficient to store all South Africa's CO₂ emissions for 500 years at current usage. Bearing in mind the poor permeability attributed to these sediments a significantly lower figure is likely to be realistic.

This figure should be discounted by an order of magnitude to 18 370 million m³ to allow for poor storage capacity, geological and other constraints. Furthermore the capacity of the arenaceous sediments in the Beaufort Group i.e. the Katberg Formation (1000m in thickness) based on a strike length of 200km and a down dip length of 40km thickness (at 3% dip), a maximum area of 8,000 km² and a volume of 8,000 km³ is available. Assuming 2% of its effective volume is used, this equates to 16,000 million m³. This figure should be discounted by an order of magnitude to 1,600 million m³ (approximately 1600 million ton of CO₂ at 80 bar pressure) to allow for poor storage capacity as well as geological and other constraints.

3.3.3 Chemical capture

Chemical capture of CO₂ has been postulated as being a permanent, but more expensive, way of capturing the carbon. (Lackner, 2003) The technique requires the neutralization of carbonic acid to form carbonates or bicarbonates and replicates but accelerates the natural weathering processes that are exothermic and

thermodynamically favored and result in stable products that are common in nature.

The considered options are as follows:

- Injection of CO₂ into alkaline strata that would gradually dissolve the pore water and leach the mineral base from the rock forming carbonates or bicarbonates with no long-term leakage concerns.
- Neutralisation of carbonic acid with carbonates to form an aqueous bicarbonate solution to be injected underground or disposed of at sea, thus eliminating problems associated with acidic carbonic acid.
- Formation of insoluble carbonates that could be stored and confined. This could be theoretically achieved by the reaction of CO₂ with serpentine or olivine rocks rich in magnesium silicates but the process is unproven. Typical source rocks for this process could be found in the dumps of mines processing the platinum group metals, kimberlites or old asbestos mines, all of which are common in South Africa and potentially near areas of large point sources. Figures regarding the neutralising material indicate that the ratio rock material/ CO₂ is 2.5

3.4 Marine sequestration

The worldwide burning of fossil fuel results in the release of 6.3 Gt C/year (23.1 Gt CO₂ /year) into the atmosphere. The net terrestrial uptake is 1.4 Gt C/year and the net oceanic uptake is 1.7 Gt C/year resulting in a net atmospheric increase of 3.2 Gt C/year. (Ocean, 2002) As the mixing of the different water layers in the oceans is relatively slow, equilibrium between the atmosphere and the different ocean layers is absent. Therefore it is technically possible to speed up CO₂ transfer to the deeper ocean water layers. All CO₂ contained in fossil fuels could easily be absorbed by these deep ocean water layers assuming perfect mixing, due to the large quantity of deep sea water and the current amount of dissolved CO₂, (38000 Gt C) in these layers. If 3.2 Gt C/y, which represents less than 0.1% of the deep sea water content, would be stored annually in the ocean, no further atmospheric increase would occur. Over time, deep sea water levels return to the surface mainly in the Pacific and Indian Ocean, thereby releasing some of the stored CO₂. The time scale of this process is several hundred or thousands of years. The duration is dependent on the site where the CO₂ is transferred to the deeper water layers. (Jones, Young, 2002)

3.4.1 Technologies

The technologies for the sequestration of carbon dioxide into oceans can be grouped into two categories:

- The use of a delivery system for the sequestration of concentrated CO₂ streams. Waste CO₂ from incineration processes can be concentrated and transported under pressure (as a compressed medium above its critical point, 72.8 bar at 31°C it has a high density) in pipelines towards the sea. Here it can either be directly injected in the deep sea water levels, at least 1500 m deep, or it can be loaded on a ship and dispersed into the sea from the ship at designated sites, again at a depth of at least 1500 m. 1500 m is sufficiently deep to prevent the return of the CO₂ to the surface and to prevent effects on the surface eco-system. The pressure at this depth is so high that the density of CO₂ exceeds the density of water and the CO₂ would sink to the bottom of the ocean. (Murray 'et al', 1995)
- The use of fertilisers in nutrient-poor oceanic environments to help increase the uptake of CO₂. Phyto plankton requires nutrients in the following ratio 106C:16N:1P:0.001Fe. Therefore, if phyto plankton growth is limited by the absence of iron, as happens in so-called "High Nutrient Low Chlorophyl" (HNLC) oceanic regions, then the addition of 1 atom of Fe can catalyse the uptake of 100 000 atoms of carbon. (Adhiya, Chisholm, 2001) If this carbon then gets sequestered in the ocean, significant removal of atmospheric carbon would become possible with only a small amount of iron fertiliser. Oceanic experiments (IRONEX, SOIREE, IESENEX) have been carried out with the following main results:
 1. Iron indeed limits primary production
 2. Phyto plankton biomass can be increased over the short term (weeks) by the addition of iron.
 3. There is no evidence of increased carbon sequestration following fertilisation in the time frame of these experiments.
 4. The composition of the phyto plankton community changes dramatically upon the addition of iron, with diatom biomass increasing preferentially.
 5. Dimethyl sulphide (which nucleates cloud formation) emission is increased by iron fertilisation.

In terms of sequestration, point 3 is crucial as the main purpose of the experiments was to quantify the amount of sequestered carbon.

As South Africa is situated relatively close to the Southern Ocean and as there are large quantities of iron available as well as good ports, South Africa might be preferred for Ocean fertilisation projects provided that a large positive sequestration of carbon can be proven and the ecological effects are shown to be acceptable.

3.4.2 Environmental effects

Fertilisation of oceans takes place in the upper layers of the sea where biodiversity is large. The following points are almost certain to occur when iron is added as a nutrient:

1. Changes in phyto plankton species composition resulting in changes in the food-web (i.e. fish, birds, whales).
2. Decreased biodiversity compared to the "natural" state with rare species becoming dominant.
3. Dependence of diatom growth rate not only upon availability of Si and other nutrients in certain ratios but also on a favourable light/mixing regime.

Other points are less certain, but could have a large impact, such as a possible 30 to 70% reduction in tropical marine primary production or hypoxia/anoxia in the deep ocean due to the decomposition of dissolved organic carbon at these depths. However there are also opposing views which expect an export of carbon to the deep ocean upon fertilisation and at the same time the authors expect an increase in fish production (Markels, 1999).

4. Conclusions and recommendations

In the report a preliminary assessment was made for the first time in South Africa regarding the potential for CO₂ sequestration. The following preliminary conclusions and recommendations can be made:

- The highly concentrated CO₂ streams currently produced by Sasol are well suited for CO₂ sequestration without much further processing.
- The potential for biological sequestration in South Africa is limited compared with many other countries as the low rainfall in most of the country accounts for a small net primary production.

- The potential for CO₂ sequestration in exhausted gas fields at Mosselbay also needs more study because it may enhance gas recovery.
- It appears that the porosity and permeability of geological formations is rather low by international standards, but the potential for CO₂ sequestration is large and therefore further study is required.
- Deep Ocean sequestration of CO₂ is potentially possible, however environmental consequences are poorly understood. It is recommended that South Africa stay informed regarding international developments.
- The consequences of ocean fertilisation are not known at present and it is recommended that South Africa stay informed regarding international developments.

Table 4 gives an overview of the sequestration potential for the different sinks including data regarding leakage to atmosphere.

Table 4. Sequestration potential for different sinks.

Potential sink	Tonnage (million ton/year)	Duration (years)	Comments
Afforestation	3.9	20	An effort is required to store CO ₂ in "perpetuity"
Reduced tillage	0.4	20	
Savanne thickening	7.9	20	
Gas reservoirs	1	Very long*	There may be enhanced gas recovery
Mines	10 or more	Site specific	More study is required
Vryheid formation total	18,375 million	Very long	Relatively poor porosity and permeability, more study is required
Katberg formation total	1,600 million	Very long	
Coalbed methane	Small	Long**	It may enhance methane recovery
Chemical capture	1 – 5	Indefinite	Large volume of "reactive material" required
Deep ocean	Nearly unlimited	Several hundred years	Deep ocean ecosystems poorly understood
Ocean fertilisation	Not known	Not known	Study required, but not by South Africa

5.

6. Acknowledgment and contributions by the authors

DME is acknowledged for the financial contribution to the project.

A Engelbrecht contributed on carbon dioxide emissions and concentrations.

B Scholes contributed on biological sequestration.

A Golding contributed on geological and chemical sequestration.

S Hietkamp contributed on oceanic sequestration and was responsible for the overall project coordination.

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