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Diverting CO_2 Emissions from the Atmosphere through Capture and Geologic Sequestration: The Journey So Far!

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Abstract

Carbon Dioxide (CO_2) emissions accumulating in the earth's atmosphere as a result of the use of fossil fuels for energy generation are causing an imbalance in the Earth's incoming and outgoing radiation. This has led to rising surface air and sub-surface ocean temperatures with impending devastating consequences. Most of the damage observed so far is irreversible and will persist for up to 1000 years even after emissions stop. It is now two decades since March 1992 when about 250 scientists and engineers gathered in Amsterdam for the First International Conference on Carbon Dioxide Reduction (ICCDR-1). The Earth Summit of Rio de Janeiro (1992) also lent impetus to the quest for CO_2 emissions reduction through the commitment of various governments to tackle the climate change issue. Of the portfolio of options available, a key means of reducing anthropogenic greenhouse gas emissions is to capture carbon dioxide from large stationary sources, compressed either in supercritical form or sub-cooled liquid form, for underground storage. In this paper, we review the feasibility and development of knowledge and technology for CO_2 capture and storage (CCS) as well as present current status of global CCS development. In addition, we explore possible characterization of depleted oil and gas fields in the Niger Delta for CO_2 sequestration and propose that it is time Nigeria effectively starts a CCS programme especially as a Clean Development Mechanism(CDM) project. Besides earning carbon credits, Nigeria will be attracting increased flow of investment in a capital intensive sector, stimulating transfer of the most innovative technologies available in the power/oil and gas sectors as well as developing infrastructure.

Keywords: Carbon dioxide capture and storage(CCS), geologic sequestration, atmosphere, clean development mechanism(CDM).

1. Introduction

Mankind has used energy in various forms and in varying ways from his emergence as a hunter-gatherer. While the discovery and use of fire and animal power meant better living conditions, coal ushered in the industrial revolution of the 18th and 19th centuries and the remarkable recovery of the post World War II economy was brought about and largely conditioned by the discovery and use of oil. Thus the fossil fuel era resulted in a period where man's appetite for energy grew faster than his appetite for food (Figure 1).

The combustion of fossil fuels involves the oxidation of hydrocarbons and CO_2 and H_2O are necessary and essential products. While amounts of CO_2 emitted annually resulting from human activities vary compared to the large natural cycles that exchange CO_2 between the atmosphere, oceans and terrestrial biosphere, there is no doubt that current emissions exceed the capacity of the natural systems to absorb. The unfortunate accumulation of the emission in the atmosphere that is now causing global warming and forcing climate change is the net result. There is a consensus (Herzog, 2001) that both post and future anthropogenic CO_2 emissions will continue to contribute to global warming and sea level rise with grave implications globally such as- accelerated climate change

- mass extinctions
- ecosystems breakdown and
- large scale discontinuities.

Developing countries are particularly at risk, as their infrastructures are most vulnerable to extreme events and there is expectation that climate change will worsen their food security, water availability and health in addition to accelerating biodiversity losses (Stern, 2006).

Amid the dire warning of severe weather perturbation, carbon dioxide capture and storage (CCS) is presently considered one of the most promising approaches to mitigate global climate change.

Natural analogues for geologic storage of CO_2 have been studied for effective understanding of the trapping mechanism while mass balance analysis of CO_2 injection during Enhanced Oil Recovery (EOR) programmes in some mature oil and gas fields have shown the feasibility of carbon dioxide capture and storage. This paper takes a look at the feasibility and development of knowledge and technology for CO_2 capture and storage(CCS) as well as the present status of global CCS with application to depleted oil and gas fields in the Niger Delta for CO_2 sequestration.

2. Carbon dioxide emission

Carbon dioxide is emitted principally from the burning of fossil fuels both in large combustion units such as those of electric generation and in smaller, distributed sources such as automobile engines and furnaces used in residential and commercial buildings. Carbon dioxide emission also results from some industrial and resource extraction processes as well as from the burning of forests during land clearance (Table 1). Although the emission rates for fossil fuel combustion varies with fuel type (Table 2), global emissions are estimated at 6.4 $x10^9$ metric tons of carbon each year, with another $0.2x10^9$ tons Carbon released during the calcining of limestone to make cement. This large and growing anthropogenic release of carbon to the atmosphere is a relatively recent phenomenon, having risen from a sum of $1.6x10^9$ tons of Carbon in 1950 (at the start of the century it was only $0.5x10^9$ tons) (Marland and Boden 2007). Figure 2 shows rising concentration of CO_2 in the atmosphere from 275ppmv in pre-industrial times to 378ppmv by 2008 leading to global temperature rise of $0.74+ 0.18^oC$ over the last century (1900-1999) whereas global temperature has not varied by more than 1 or 2^0C during the past hundred centuries (O'Cunningham et.al., 2005). International awareness and concern preceeding the Earth Summit of 1992, led to the United Nations Framework Convention on Climate Change (UNFCCC) which ultimate objective (Article 2) is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system". It is noted that cumulative emissions of hundreds or even thousands of gigatons of CO_2 would need to be prevented during this century to stabilize the CO_2 concentrations at 450 to 750ppmv (IPCC 2008). A portfolio of options for reducing greenhouse gas emission that would facilitate the achievement of the stabilization goals include:

- Reducing energy demand by increasing efficiency of conversion and/or utilization devices.
- De-carbonizing energy supplies either by switching to less carbon intensive fuels (eg, coal to natural gas) and/or increasing the use of renewable energy sources and/or nuclear energy (each of which on balance emits little or no CO_2).
- Sequestering CO_2 through the enhancement of natural sinks by biological fixation
- Reducing non-Co_2 greenhouse gases
- CO_2 capture and storage in geologic formations (CCS).

Although each of these options can be effective, to a large extent, it is CCS that can contribute significantly to the least-cost route of reducing and stabilizing CO_2 emission in the atmosphere. It has been estimated that without CCS in the technological mix, the cost of climate stabilization would rise by seventy percent. (IEA, 2008).

3. Carbon dioxide capture and storage

Carbon dioxide capture and storage is a process through which $C0_2$ can be diverted from the atmosphere. It is a waste management strategy which does not reduce the production of CO_2 but provides a depository to keep it from harming the earth.

CCS is a system of technologies that integrates three stages:

- Capture CO_2 out of the flue gases either from the stack of a power plant or the blast furnaces top gas in iron making.
- Transport the CO_2 by pipeline or ship to carefully selected storage site
- Safely keep it in the storage site for thousands of years.

Each of the stages of CCS is technically available and has been used commercially for many years.

3.1 : Carbon dioxide Capture

The most promising CO_2 capture technologies are post combustion and pre-combustion processes. In the more conventional post-combustion approach, CO_2 is captured from the gas emitted from burning coal or natural gas to produce energy. On the other hand, the pre-combustion method is used when hydrogen and CO_2 are stripped from natural gas. The pre-combustion route opens up opportunity for poly-generation in which besides electricity and CO_2 additional products are obtained. The CO_2 that is currently emitted to the atmosphere through both the pre-combustion and post-combustion processes could be captured and compressed for transportation to suitable storage sites. A third capture technique is Oxyfuel combustion. Similar to post-combustion, the fuel is burnt in pure oxygen which results in a much purer CO_2 stream from when the fuel is burnt in air.

Figure 3 is a schematic diagram of the main capture processes and systems. All require a step involving the separation of carbon dioxide (CO_2) hydrogen (H_2) and oxygen (O_2) from the bulk gas stream (flue gas, synthesis gas or raw natural gas). The separation steps can be accomplished by means of physical or chemical solvent, membranes, and solid sorbents or by cryogenic separation. The choice of a specific capture technique is determined largely by the process condition under which it must operate. Current post-combustion and pre-combustion systems for power plants capture 85-95% of the CO_2 produced (IPCC 2008).

The technology for carbon dioxide capture is already in use in several industrial applications. Pre-combustion technologies are employed for large-scale production of hydrogen (which is used mainly for ammonia and fertilizer manufacture and for petroleum refining operations). The separation of CO_2 from raw natural gas (which typically contains significant amounts of CO_2) is also practised on a large scale using technologies similar to those used for post-combustion capture (Philibert, 2007).

Oxyfuel combustion for CO_2 capture is currently in the demonstration phase (Table 3) while research to achieve higher levels of system integration, increased efficiency and reduced cost for all types of capture systems is being vigorously pursued.

3.2: Carbon dioxide Transport

Except where a plant is located directly above a geological storage site, the captured CO_2 must be transported from point of capture to a storage site. Pipelines today operate as a mature technology and are the most common method of transporting CO_2. Gaseous CO_2 is typically compressed to a pressure above 8mPa in order to avoid 2-phase flow regimes and increasing the density of CO_2 thereby making it easier and less costly to transport (Torp, 2011). CO_2 can also be transported as a liquid in ships that carry CO_2 insulated tanks at a temperature well below ambient and at much lower pressures.

Pipelines transporting CO_2 have been in operation in the United States of America since late 1970s. According to Han et. al., (2010) over 2300km of pipelines transport more than 40million tons of CO_2 per year from natural and anthropogenic sources.

3.3: Carbon dioxide Storage

The final stage in the CCS process is long term storage of CO_2. Carefully chosen CO_2 sequestration sites have specific attributes that ensure that the injected CO_2 remains trapped for millions of years in well defined zones ensuring that it does not leak or damage other sub-surface assets such as hydrocarbon reservoir or fresh water aquifers. Geological sinks for CO_2 include deep saline formations, depleted oil and gas reservoirs and unminable coal seams that are dispersed in sedimentary basins world wide. Generally, the geological storage sites should have; (i) adequate capacity and injectivity, (ii) a satisfactory sealing cap rock or confining unit and (iii) a sufficiently stable geological environment to avoid compromising the integrity of the storage site.

The needed trapping is associated with fluid/fluid or fluid/solid interactions in porous media such as dissolution, physical adsorption or some homogenous and heterogeneous reactions. Han et. al., (2010) demonstrated the four major trapping mechanisms to include:

(i) Fundamental confinement of mobile CO_2 phase under low permeability cap rock or stratigraphic trapping.
(ii) Converting CO_2 to mineral precipitates or mineral trapping.
(iii) Dissolution in in-situ fluid or solubility trapping.
(iv) Trapping by surface tension and correspondingly remaining in porous media as an immobile CO_2 phase or residual trapping.

Figure 4 is a schematic of the contribution of the various trapping mechanisms over time.

4. CCS PROSPECTS & CHALLENGES

4.1: Prospects

4.1.(i): Information and knowledge from natural CO_2 deposits: Oil and gas deposits are good analogues of CO_2 storage, however a more similar set of analogues are natural CO_2 deposits (Pearce et al 1996). Natural CO_2 deposits originating from volcanic activities and other processes occur around the world. Some deposits are stored in secure and impermeable traps (the 200 million tons of CO_2 in the Pisgah Anticline in Mississippi has remained in place for 65 million years with no sign of leakages (Studlick et. al., 1990.) A few others are known to be unstable and leaking but have been useful for studying the health, safety and environmental effects of CO_2 leakage (Solomon, 2006). Stevens et. al. (2001) discuss three such major research programmes.

(a) NASCENT- The Natural Analogues for the Storage of CO_2 in the Geological Environment coordinated by the British Geological Survey with industry, academic and European National Geological Survey with participants focusing on evaluating European Natural CO_2 Deposits. Fields have been identified in France, Germany, Greece, Hungary and Italy.

(b) NACS- The National Analogs for Geologic CO_2 Sequestration effort is evaluating large commercial CO_2 fields in USA. These fields located in sparsely populated areas are providing insight into the timing of CO_2 migration and storage, geochemical and mineralogical effects of CO_2 as well as the operation safety and cost of handling and distribution.

(c) GEODISC- The Australian Petroleum Cooperative Research Centre (APCRC) is evaluating the technological, environmental and commercial feasibility of geological sequestration of CO_2 in Australia. One of the ten projects within the program is the study of several high-CO_2 natural gas fields to better understand CO_2 generation, migration and entrapment.

4.1.(ii) Information and knowledge from EOR operations: Information and experience gained from injection of CO_2 from a large number of enhanced oil recovery (EOR) projects indicate that it is feasible to store CO_2 in geologic formations as a CO_2 mitigation option (Solomon, 2006).

A case study of SACROC Northern platform- a 35year CO_2 injection site (Han et. al., 2010) in the Persian Basin of western Texas shows that, of the 93 million metric tons of CO_2 injected, about 38 million metric tons were produced from 1982 to 2005. A simple mass balance suggests that the SACROC unit has accumulated approximately 55 million metric tons of CO_2. Table 4 shows some current CO_2 storage projects. There has also been a dramatic increase in the commitment of governments and industry for full-scale CCS demonstrations (Table 5). Reports have identified 73 large-scale carbon dioxide capture and storage projects around the world including 15 that are currently operational or in construction capturing 35.4million tonnes per annum (Mtpa) of carbon dioxide. A further 58 projects are in the planning stages of development with additional potential capture capacity of more than 115(Mtpa) (GCCSI 2012).

4.2: Challenges

1. The technology for CCS seems clear-cut. However, there are several challenges for the full implementation of the strategy. Energy efficiency of power plants with CO_2 capture diminishes significantly. Hence the application of CO_2 capture results in a higher consumption of fossil fuels. This leads to rising system costs for energy which invariably becomes an economic burden on climate protection. CCS stands in contrast to laboured advancements on energy efficiency and the promotion of renewable energies along with reduction of costs. It is problematic that capturing CO_2 is generally energy intensive, increasing net energy use as opposed to reducing it. This fact alone limits the potential for CCS technology to contribute to sustainable strategy to preventing climate change. A more comprehensive approach to climate change prevention should focus on massive increase in energy efficiency as well as renewable energy resources.
2. Although many studies have demonstrated the ability of natural underground geological formations to provide adequate CO_2 storage for long periods, the possibility of severe leakage arising from destabilizing earth movements can not be ruled out. The lake Nyos leakage of 1986 is still fresh in the geoscientific world. Perhaps this is the reason why despite the vast array of knowledge and information, the world is still cautious on the full-scale implementation of CCS. Added to this, is that outside the scientific world, most of the general public lack the knowledge and understanding of CO_2 and CCS. This public unfamiliarity has led to CCS being often perceived negatively as dangerous and risky in several ways (Itaoka et. al., 2012) such as safety; potential for contamination of and damage to natural environment (ie, ground water, plants and animals) owing to the potential leakage at storage sites; and cost.
3. There is also the lack of legal and regulatory framework for CO_2 storage in geologic formations. A few countries have begun work on the development of relevant legislation as existing laws from oil and gas, mining and industrial sectors in fossil fuel-based economics offer no regulatory mechanism for CO_2 storage. Besides, it appears very unlikely that operators will proceed with commercial implementation of CCS without substantial inducement and financial incentives from government.

5. CCS IN NIGERIA

Although not a developed nation and neither classed among Annex I nor II countries, Nigeria is a major polluter (45^{th} in world ranking and 4^{th} in Africa after South America, Egypt and Algerian) contributing over 100 million tons of CO_2 annually to the greenhouse gases in the atmosphere. This high emission is largely from gas flaring in the petroleum sector and fossil fuel consumption by her large and increasing urban and rural population as well as cement manufacture, land use change and forestry. Oladipo (2008, 2010) has shown that all sectors of Nigeria's socio-economic development including national ecosystems are vulnerable to climate change. With a shoreline 800km in length, a 0.2m sea level rise would flood about 3400km^2 of Nigeria's coastland. A 1.0m sea level rise will be catastrophic, inundating over 18,400km^2 and actually displacing 80% of Niger Delta population (Okon 2008).

Nigeria, like other developing countries is not required under the current global climate change negotiation to take on emission reduction commitment. Nevertheless it has to adapt to the expected impacts. This explains why most attention on climate change is geared towards adaptation efforts. Nigeria is also actively embarking on a number of Clean Development Mechanism (CDM) projects from which she is deriving environmental and financial benefit. Six such projects currently exist, while twelve others are awaiting UNFCCC endorsement.

Galadima and Garba (2008) have looked at the fundamental science and potential implementation risks in CCS in Nigeria. Technology and financial involvement, they argue, are too enormous for the country now, except the oil industry operators are actively involved. On the other hand, Anastassia et al. (2009) tie CO_2 storage in Nigeria to CO_2-EOR programme. The additional oil recovered while serving as sufficient inducement to industry operators could effectively off-set implementation costs.

This article proposes that it is time Nigeria effectively starts a CCS programme especially as a CDM project. Apart from earning carbon credits, Nigeria will be attracting increased flow of investment in a capital intensive sector, stimulating transfer of the most innovative technologies available in the power /oil and gas sectors as well as developing infrastructure.

The Niger Delta region is a prolific petroleum province (13^{th} in world ranking in terms of basin size). However, the Niger Delta is not a single gigantic field but is composed of thousands of individual reservoirs most of which are sandstone pockets trapped within oil-rich shales. Growth faults and antithetic faults play an essential role in trap configuration.

Of the 500 fields so far discovered (both on-shore and off-shore) in the area, 1481 wells are producing from156 of these fields. The rest are at various stages of appraisal and development or have been abandoned for various reasons (Akpanika and Udoh 2008). These abandoned fields could form the starting point for characterization studies for CO_2 storage in the area. Such studies will include geology, hydrogeology, geochemistry and geo-mechanics (structural geology and deformation response to stress changes). Documentation of the characteristics of any particular storage site will have to rely on data obtained directly from the reservoir such as:

- Core and fluids produced from wells at/or near the study site
- Pressure transient tests conducted to test seal efficiency.
- Indirect remote sensing measurements such as seismic reflection data, and
- Regional hydrodynamic pressure gradients.

Thus sites defined will not only be available to CO_2 from Nigeria, but also from Annex 1 countries transported by ocean tankers.

6. Conclusion

Carbon dioxide (CO_2), the greenhouse gas making the largest contribution to atmospheric emissions from human activities, is released from burning fossil fuels or biomass. As much as $6.6x10^9$ metric tons of Carbon is released into the atmosphere each year. The concentration of CO_2 in the atmosphere which has thus increased from 275ppmv in pre-industrial times to current values of 378ppmv is causing global temperatures to rise by as much as $0.74^0C \pm 0.18^0C$. An increase in temperature of more than 2^0C will have dramatic impacts on life on earth. Steps should therefore be taken that aim at stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with climate systems.

Several technological options for reducing net CO_2 emissions exist. However carbon dioxide capture and storage (CCS) which involves diverting whatever CO_2 produced from the atmosphere for storage in geological formations, is a good option because it can be implemented on a large scale, across borders with potential capacity for deep emission reductions.

The technology for the 3-step capture, transport and storage processes are to a large extent mature although public perception of risks involved and lack of widespread demonstration scheme has hindered its large scale implementation. As governments, particularly the Annex I and II countries and industry begin to invest massively in CCS, it is believed that it will become the preferred process to save planet earth from imminent disaster associated with rising global temperatures and climate change.

Nigeria, like most developing countries, is vulnerable to the impact of climate change. Apart from embarking on adaptive measures for mitigation of impact, steps should be taken to earn large carbon Emission Reduction (CER) credits through Clean Development Mechanism (CDM) projects. A CCS programme is also proposed which will begin with studies for the characterization of the several abandoned or depleted oil and gas fields in the Niger Delta Region.

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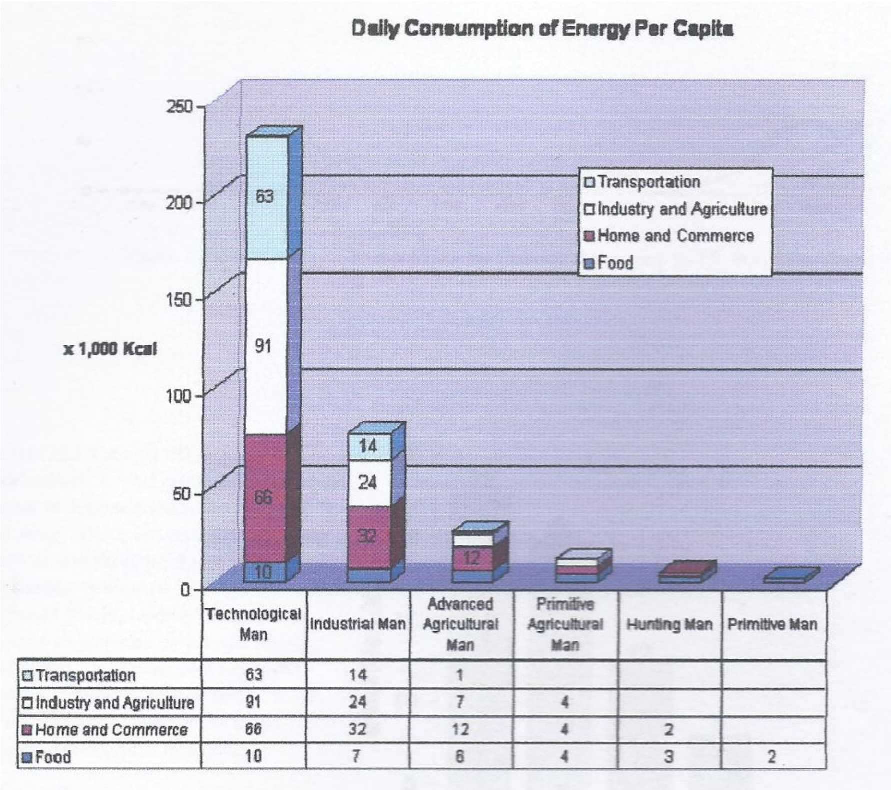

Figure 1: Estimated daily consumption of energy per capita at different historical points.
Source: Cook (1971)

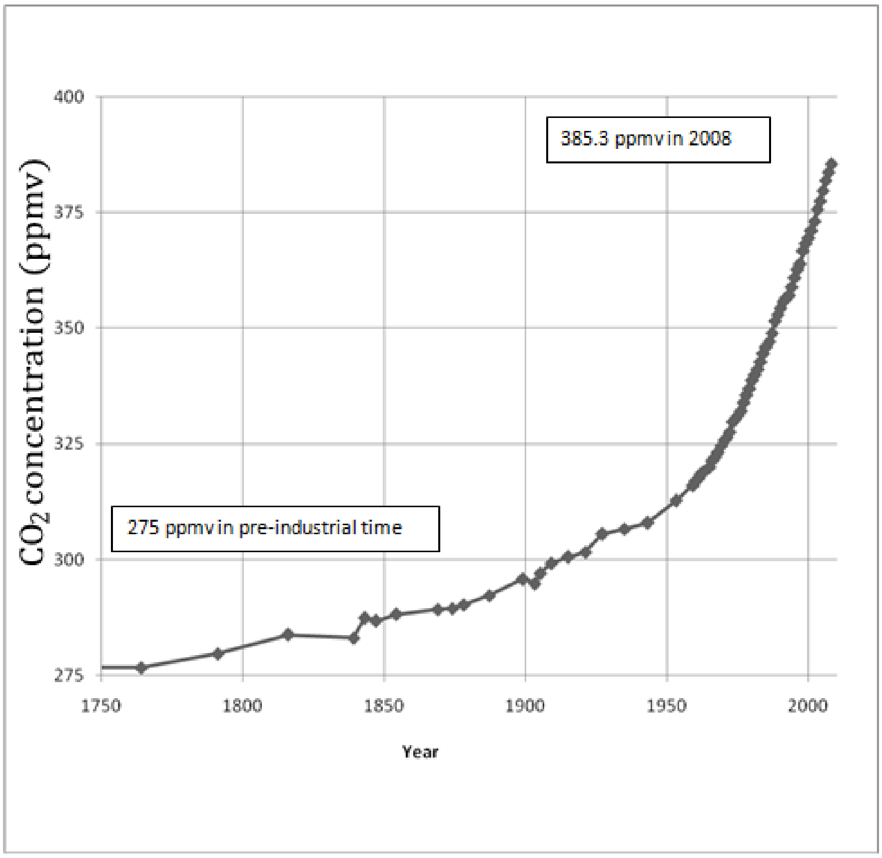

Figure 2: Rising atmospheric carbon dioxide concentration.
Source: http://cdiac.ornl.gov

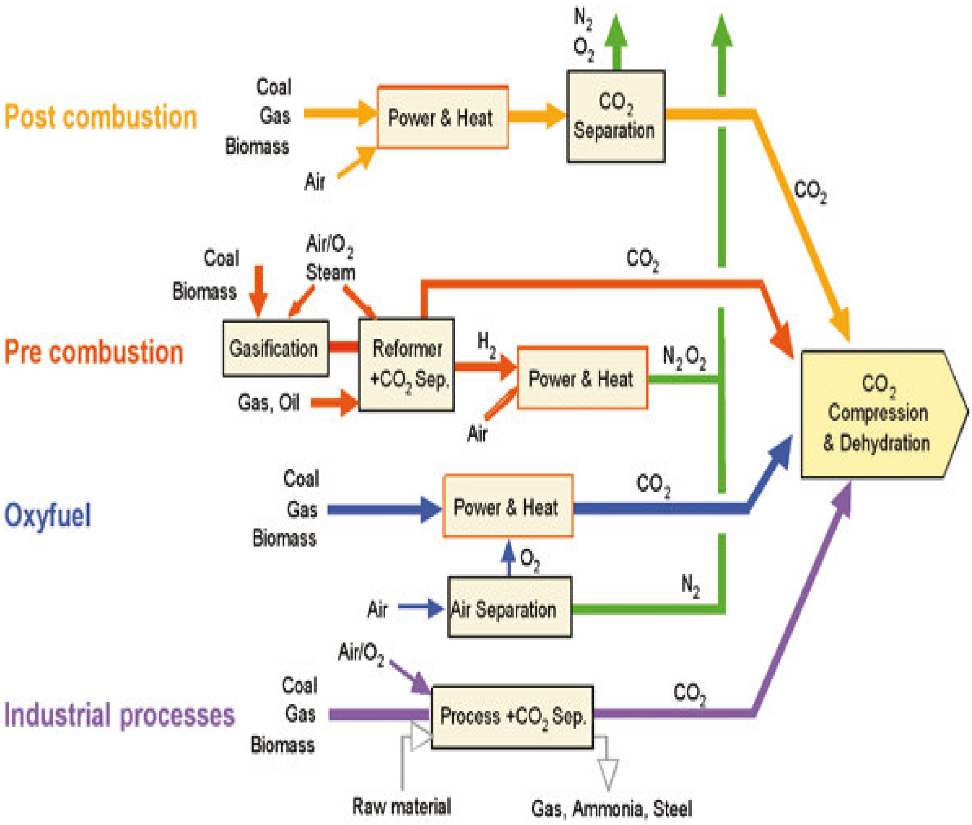

Figure 3: Carbon dioxide main capture processes and systems
Source: IPCC (2008)

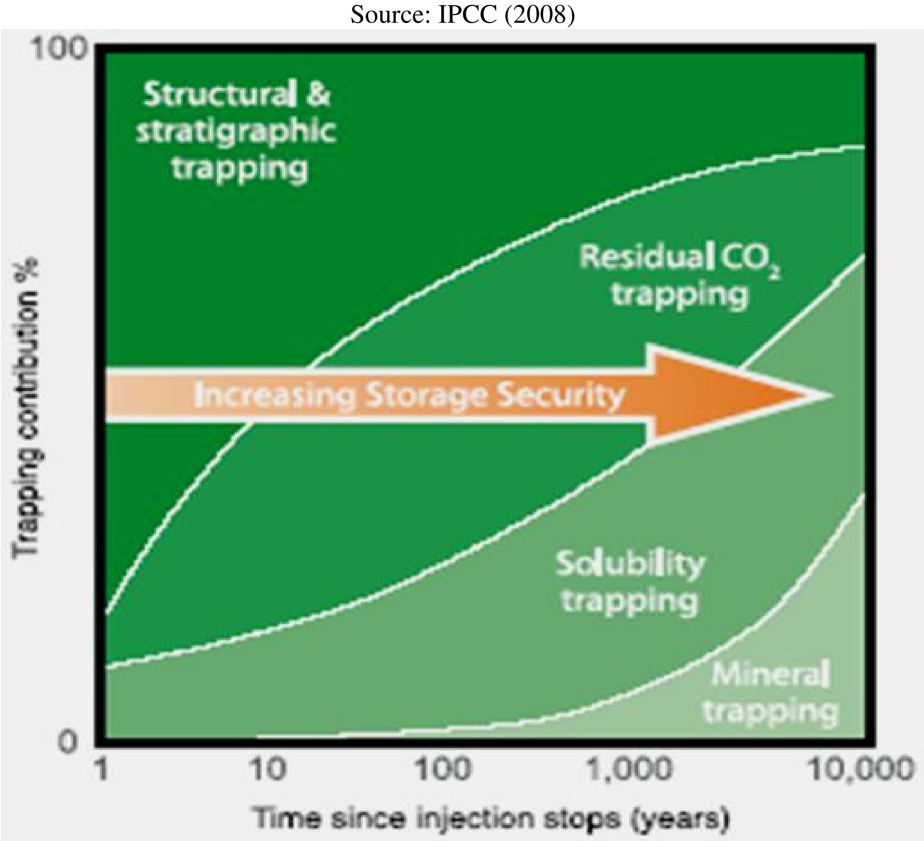

Figure 4: Contribution of trapping mechanisms over time.
Source: Herzog (2001)

Table 1: Profile by process or industrial activity of worldwide large stationary CO2 sources with emissions of more than 0.1 $MtCO_2$ per year

Process	Number of sources	Emission ($MtCO_2$ yr^{-1})
Fossil fuels		
Power	4,942	10,539
Cement production	1,175	932
Refineries	638	798
Iron and steel industry	269	646
Petrochemical industry	470	379
Oil and gas processing	N/A	50
Other sources	90	33
Biomass		
Bioethanol and bioenergy	303	91
Total	**7,887**	**13,466**

Source: IPCC (2008)

Table 2: Emission rates of various fossil fuels.

FUEL	CO_2 EMISSION RATE
Natural Gas	13.78
Petroleum	19.94
Hard Coal	24.15
Lignite and Brown Coal	25.22

Source: Marland and Boden (2001).

Table 3: State of Maturity of CCS Components.

CCS component	CCS technology	Research phase [a]	Demonstration phase [b]	Economically feasible under specific conditions [c]	Mature market [d]
Capture	Post-combustion			X	
	Pre-combustion			X	
	Oxyfuel combustion		X		
	Industrial separation (natural gas processing, ammonia production)				X
Transportation	Pipeline				X
	Shipping			X	
Geological storage	Enhanced Oil Recovery (EOR)				X[e]
	Gas or oil fields			X	
	Saline formations			X	
	Enhanced Coal Bed Methane Recovery (ECBM)[f]		X		

a. **Research phase** means that the basic science is understood, but the technology is currently in the stage of conceptual design or testing at the laboratory or bench scale, and has not been demonstrated in a pilot plant.
b. **Demonstration phase** means that the technology has been built and operated at the scale of a pilot plant, but further development is required before the technology is ready for the design and construction of a full-scale system.
c. **Economically feasible under specific conditions** means that the technology is well understood and used in selected commercial applications, for instance if there is a favourable tax regime or a niche market, or processing on in the order of O.I $MtCO_2$ yr^1, with few (less than 5) replications of the technology.
d. **Mature market** means that the technology is now in operation with multiple replications of the technology worldwide.
e. **CO_2 injection for EOR** is a mature market technology, but when used for CO_2 storage, it is only economically feasible under specific conditions.
f. **ECBM** is the use of CO_2 to enhance the recovery of the present in unminable coal beds through the preferential adsorption of CO_2 on coal. Unminable coal beds are unlikely to ever be mined, because they are too

deep or too thin. If subsequently mined, the stored CO_2 would be released.

Table 4: Current CO_2 Storage Projects

S/N	PROJECT	OPERATOR	START DATE	CO_2 SOURCE	FORMATION AND STORAGE CAPACITY	REMARKS
1	Sleipner/ North Sea	Statoil (Norway's State owned Oil & Gas Company).	1996	Extracted from natural gas offshore Sleipner gas field.	Utsira Saline Formation. 1000m below sea bed near the natural gas field. Estimated to have a capacity for 200 million tons of CO_2	1 million tons of CO_2 injected per year since start.
2	Weyburn-Midale/ Canada	Great Plain Synfuel Plants.	2000	Coal gasification plant that produces synthetic natural gas and various chemicals.	Captured CO_2 transported by pipeline 320km across international borders to Sakatchawan, Canada.	2.8million tons per year injected into depleting oil fields for EOR.
3	In Salah/ Algeria	Sonatrach (Algerian national oil & gas Company with BP & Statoil as partners).	2004	Extracted from natural gas.	Krechba Geologic Formation 1800km below ground near national gas extraction suite capacity 17million tones.	700,000 tones injected per year. CO_2 is piped 160km from capture to storage.
4	Snohvit/ Europe	Statoil	2008	Extracted from natural gas.	Tubasen Sandstone formation 2600m under the seabed below the formation where the natural gas is produced.	1 million tons per year.

Source: IEA (2008)

Table 5: Commitment of Governments and Industry to full-scale CCS demonstration.

S/N	LOCATION	PROJECT
1	Australia	Launched the Global CCS Institute (GCCSI) in April 2009 to foster international collaboration, particularly around near-term, large-scale demonstration projects.
2	Brazil Petrobas	Investing in two to four large-scale demonstration projects as part of its sustainability and climate change plan.
3	Canada	CAD 3.5 billion allocated. Large-scale CCS project demonstration.
4	China	A constitution of companies embarking on Green Gen Project law received approval and support from the Government.
5	European Union	EUR 1 billion financial stimulus for CSS demonstration. Complements an earlier (2009) EU decision to set aside EUR 300 million allowance revenues for CCS funding.
6	France	EUR 1billion funding for small scale demonstration projects package for research and development; these projects will be expanded after their performance is assessed.
7	Italy's ENEL	The nation's electricity company is developing one pilot plant.
8	Norway	Continuing its leadership by developing Mongstad and Karsto projects.
9	South Africa	Launched CCS centre in September, 2009. Plans to rapidly build capacity with the aim of having at least one full-scale project operational by 2020.
10	The United Arab Emirates	3 large-scale CCS projects under development building on the regions expertise in enhanced oil recovery.
11	United Kingdom	Large-scale demonstration competition • one major project to be operational by 2014 • to require any new coal-fired power plant over 30 MW capacity to demonstrate CCS on a proportion to its capacity.
12	United States	Proving USD 3.4 billion in new funding for CCS projects.

Source: IEA (2011)

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