American Journal of Science and Technology
2014; 1(4): 145-150

American Association for Science and Technology

Keywords
Carbon Dioxide,
Sequestration,
Enhanced Coal-bed Methane Recovery,
Carbon Capture and Storage,
Clean Development Mechanism,
Nigeria

Received: March 05, 2014
Revised: March 19, 2014
Accepted: March 20, 2014

Potentials, prospects and challenges of geologic CO_2 sequestration for enhanced coal-bed methane recovery in Nigeria

Falode O. A., Alawode A. J.

Department of Petroleum Engineering, University of Ibadan, Ibadan, Nigeria

Email address
falodelias@yahoo.com (Falode O. A.)

Citation
Falode O. A., Alawode A. J.: Potentials, Prospects and Challenges of Geologic CO_2 Sequestration for Enhanced Coal-bed Methane Recovery in Nigeria. *American Journal of Science and Technology.* Vol. 1, No. 4, 2014, pp. 145-150.

Abstract

The need for improved hydrocarbon supply has necessitated the development of unconventional hydrocarbon resources such as tight gas, gas hydrate and coal-bed methane (CBM). Conventional CBM production involves hydraulic fracturing to connect the wellbore to the coal natural fracture system via induced fracture followed by pumping off large volumes of formation water to cause reservoir pressure depletion and allow methane to desorb from coal i.e. degassing the coal seams. CBM is simple but inefficient due to reported total recovery of generally less than 50% of the gas-in-place. In recent years, enhanced coalbed methane (ECBM) recovery techniques, based on injection of liquefied carbon dioxide (CO_2), have been proposed for the recovery of larger fraction of methane in place. ECBM has been reported to have higher yields, of the order of magnitude of 90% total recovery. Injecting CO_2 in unmineable coal seams leads not only to methane recovery but also to CO_2 sequestration. Coal was discovered in Nigeria in 1909 and coal mining began with a drift mine at Ogbete, Enugu in 1915; coal production attained its climax within the period of 1958 and 1959. Since then, there had been a continual instability in the amount of coal produced in successive years; also some mines were abandoned because the coal-beds are deep and unmineable. The characteristics of these unmineable coalbeds rule out economically profitable mining but can be developed to produce methane (CH_4). It, therefore, became imperative for Nigeria to develop her deep unmineable coalbed to meet expanding demand of methane in the different world markets and contribute to reduction in greenhouse gas (GHG) emission that causes global warming and climate change. This, of course, is in line with the current ongoing reforms at making the oil and gas sector in Nigeria more vibrant and attractive to investment. The reforms give strict attention to the Nigerian Gas Master Plan and provide an excellent background for Carbon Capture and Storage (CCS) projects under the Clean Development Mechanism (CDM). Implementation of CO_2-ECBM project in Nigeria would help to build confidence in CCS technology. Hence, this paper reviews CCS techniques and global CCS and CO_2-ECBM recovery projects, and assesses the potential and prospects of CO_2-ECBM recovery in Nigeria. The technical, financial and legal challenges of CO_2-ECBM in Nigeria are also discussed.

1. Introduction

The need for improved hydrocarbon supply has necessitated the development of unconventional hydrocarbon resources such as tight gas, gas hydrate and coal-bed methane (CBM). Also, the use of carbon dioxide (CO_2) for enhanced oil recovery (EOR), conventional natural gas, gas hydrate methane and coalbed methane is in various stages of common practice and development globally because of the commercial viability. Storing carbon dioxide underground has shown considerable promise (UNEP, 2006).

'Burying or interring global warming', as it is called, has to some extent mitigated the effect of fossil fuel production on the environment. As a result, geological sequestration has opened up opportunities for reducing carbon dioxide emissions to a level that is becoming globally acceptable (Sengul *et al*, 2007).

Coal is the most abundant mineral fuel in the world. The quantity of methane gas stored in this coal is evaluated to be within 84 to 360 Tm^3 (i.e. 2,976-12,640 tcf); this is many times greater than the world's proven gas reserves in conventional gas fields (Smith and Whiteley, 2009). Coal was discovered near Udi in central eastern Nigeria in 1909 and coal mining started with a drift mine at Ogbete, Enugu in 1915. In 1950, the Nigerian Coal Corporation (NCC) was established by the Federal Government of Nigeria, headquartered in Enugu and given the mandate of exploring, developing and mining the coal reserves in Nigeria. NCC has operated two underground mines, Okpara and Onyeama, and two surface mines, Orukpa and Okaba, located on the eastern edge of Anambra Coal Basin. Between 1950 and 1959, coal production in the Enugu mines increased annually from 583,487 tonnes to a peak value of 905,397 tonnes. However, since 1959, when coal production attained its climax, there had been a continual instability in the amount of coal produced in successive years; also some mines were abandoned because coal-bed are deep and unmineable. These unmineable coalbed can be developed to produce methane (CH_4) through CO_2-Enhanced Coalbed Methane (CO_2-ECBM) Recovery projects.

During the formation of coal seams by compaction of plants, gases including methane are generated and accumulated into the coal cleats or adsorbed into the coal micro-pores. The conventional way of recovering such coal bed methane is normally by means of hydraulic fracturing to connect the wellbore to the coal natural fracture system via induced fracture followed by pumping off large volumes of formation water to cause reservoir pressure depletion and allow methane to desorb from coal i.e. degassing the reservoir.

CBM recovery process is simple but inefficient due to reported total recovery of generally less than 50% of the gas-in-place. A more attractive process with higher yields, of the order of magnitude of 90%, is the process called Enhanced Coal Bed Methane recovery (ECBM), whereby liquefied carbon dioxide is pumped into the coal seam to displace methane due to higher CO_2 adsorptivity. CO_2 is preferentially adsorbed, displacing the sorbed methane present at the internal surface of coal layers. Injecting CO_2 in unmineable coal seams leads not only to methane recovery but also to CO_2 sequestration.

Bergen *et al*, (2000) showed that CO_2 replaces one molecule of methane in a molecular proportion of 2:1 and 5:1 at about 700 m depth and 1,500 m depth respectively but that increasing temperature and pressure limit the coal methane content and reduces the coal seam permeability respectively beyond 2,000 m depth. Research at Delft University of Technology on coal samples corroborated the viability of CO_2-methane molecular replacement proportion of 2:1 at about 700 m depth of thick coalbed (Lako, 2002).

In the study titled 'Potential for CO_2 Sequestration and Enhanced Coalbed Methane Production in the Netherlands' (Novem, 2001), several sources of CO_2 were itemized as power plants (including Integrated Gasification Combined Cycle - IGCC - power plant, gas fired steam plant and gas fired combined cycle), industrial cogeneration plants (including gas and steam turbines), waste incineration plants, and chemical industry (including ammonia plants, hydrogen plants and ethylene oxide plants).

Carbon Capture and Storage (CCS) projects conform to the near-future demand in the economic and environmental context of the Kyoto agreement. This, of course, is in line with the current ongoing reforms at making the oil and gas sector in Nigeria more vibrant and attractive to investors. The reforms give strict attention to Nigerian Gas Master Plan and provide an excellent background for Carbon Capture and Storage (CCS) projects under the Clean Development Mechanism (CDM). According to United Nations Framework Convention on Climate Change - UNFCCC (2009), CDM is an arrangement under the Kyoto Protocol allowing industrialized countries that have a greenhouse gas reduction commitment to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. It allows net global greenhouse gas emissions to be reduced at a much lower global cost.

Companies have already started to identify investment opportunities in applying CDM in Nigeria. Of recent, an agreement was reached between Abu Dhabi and Nigeria to identify and develop carbon emissions reduction projects in the oil and gas sector in Nigeria under the Clean Development Mechanism (Eye of Dubai, 2009). Additional support for the commencement of these projects in West Africa would be provided by the recognition of CCS under the Kyoto Protocol.

It is, therefore, high time for Nigeria to develop her deep unmineable coalbed to meet expanding demand of methane in the different world markets and contribute to reduction in greenhouse gas (GHG) emission that causes global warming and climate change.

Hence, this paper reviews CCS techniques and global CO_2-ECBM recovery projects, and assesses the potentials, prospects and challenges of CO_2-ECBM recovery in Nigeria.

2. Methodology

2.1. Review of Carbon Capture Techniques

Carbon dioxide emitted from industrial plants and processes contributes significantly to global warming; it should therefore be prevented from entering the atmosphere. CCS may be applied where CO_2 is produced in large amounts, i.e. at CO_2-intensive industries such as iron, cement, chemicals and pulp production, refineries, oil and gas processing, since one third of CO_2 emissions is generated in that manner (IEA, 2008). Different methods have been developed to sequester CO_2 from getting to the atmosphere. Recent techniques include pre-combustion capture, post-combustion capture and oxy-fuel combustion.

Pre-combustion capture is a coal fired integrated gasification combined cycle (IGCC) process, where fossil fuel is de-carbonized to produce hydrogen. In this technology, the remainder of the coal is volatized by heat produced from partial reaction of fuel with oxygen and steam. After further processing in a shift reactor, a mixture of hydrogen and CO_2 is produced. The CO_2 is captured, while hydrogen is used to generate electricity and heat (Anastassia *et al*, 2009). This process can also be used in natural gas-based plants.

Post-combustion capture is usually employed in coal- and gas-fired power plants. The CO_2 is captured from flue gases produced from the combustion of fuel in air. The separation is effected by chemical absorption using different organic solvents such as mono-ethanolamine (MEA), or ammonia (IPCC, 2005).

In oxy-fuel systems, oxygen instead of air is used for fuel combustion with a recirculation of about 70 % flue gas stream to dilute the oxygen. Water vapour and CO_2 are the major constituents of the flue gas produced (IPCC, 2005 and IEA, 2008). Oxy-fuel combustion is still in demonstration phase, but post-combustion and pre-combustion systems are economically feasible under specific conditions (IPCC, 2005).

2.2. Review of Carbon Transport Techniques

After compression to a supercritical liquid, CO_2 is transported by pipeline, tankers and ships, and injected in deep coal seams containing methane. Though pipelines and tankers are the conventional ways of transporting CO_2, pipelines are the most employed method. This is evident in the long time use of pipeline for transporting CO_2 to injection wells in Enhanced Oil Recovery (EOR) projects. CO_2 transport by shipping may be more commercially advantageous if CO_2 is transported over large distances. Intermediate storage facilities, harbour fees, fuel costs, cost for liquefaction, and loading and unloading activities make up the cost of CO_2 ship transport (IEA GHG, 2004; IPCC, 2005).

2.3. Review of Carbon Storage Techniques

The transported supercritical CO_2 are injected in an area with favourable geological characteristics (Lako, 2002). The major carbon capture storage methods are ocean storage, mineral carbonation and geologic storage.

Ocean Storage: Liquid CO_2 could be stored in the deep ocean by injecting it at depths below 3,000 m where it will be denser than water, as proposed by some researchers, and thus would be gravitationally stable (Smith and Whiteley, 2009).

Mineral Carbonation: Mineral carbonation involves CO_2 removal from flue gases and the fixation of CO_2 using alkaline and alkaline-earth oxides, such as magnesium oxide (MgO) and calcium oxide (CaO). Chemical reaction produces stable carbonates – magnesium carbonate ($MgCO_3$) and calcium carbonate ($CaCO_3$ – limestone), which can be disposed of in silicate mines or reused for construction (Smith and Whiteley, 2009).

Geological Storage: Several methods of geological storage of CO_2 include sequestration in gas hydrate reservoirs for enhanced methane recovery, storage in depleted gas or oil reservoirs, aquifers, oceans, coalbed methane reservoirs, or tight gas reservoir.

In order to achieve large storage capacities underground, CO_2 needs to be stored above its supercritical pressure, the pressure at which the gas liquefies. The supercritical pressure of CO_2 is about 74 times atmospheric pressure at 31^oC and therefore typically needs to be stored at depths of 800 meters or more below the surface (Smith and Whiteley, 2009). Three main mechanisms, for CO_2 storage in the subsurface and with water present as one of the fluid phases in the reservoir, are physical trapping, chemical trapping, and hydrodynamic trapping (IPCC, 2005).

Physical trapping can take two main forms, i.e. static trapping where upwards movement of CO_2 is blocked by cap rock, an impermeable layer of shale or clay rock, and residual-gas trapping caused by capillary forces in a porous structure. Chemical trapping occurs by dissolution or by ionic trapping; CO_2 reacts chemically with minerals in the geological formation (mineral trapping) or adsorbs on the mineral surface (adsorption trapping). In hydrodynamic trapping, the CO_2 migrates upward at a very low velocity and is being trapped in intermediate layers. Large quantities of CO_2 could be stored using this mechanism because the migration to the surface would take millions of years (IPCC, 2005).

2.4. Review of Global CCS and ECBM Recovery Projects

Geological storage of CO_2 is ongoing in three large industrial projects in the world: the CO_2-EOR Weyburn project in Saskatchewan, Canada; the offshore Sleipner natural gas processing project in the North Sea, Norway; and the In Salah natural gas project in central Algeria. These projects demonstrate that CO_2 can be economically and safely stored in geological formations (Anastassia *et al.*, 2009)

Australia's most comprehensive post-combustion CO_2 capture research facility, the CO_2 CRC H3 Capture Project, was commissioned at International Power's Hazelwood Power Station in Victoria's Latrobe Valley. The project was launched by Victorian Energy and Resources Minister Peter Batchelor in 2009. Although there are a number of completed and ongoing pilot projects and field trials in Canada (Alberta-ECBM project), Japan (Hokkaido project), Poland (RECOPOL project), and China (Qinshui Basin), there has only been one commercial scale ECBM project in the world to date (San Juan Basin in the U.S.A.) (Smith and Whiteley, 2009).

Reduction of CO_2 emission by means of CO_2 storage in coal seams in the Silesian Coal Basin of Poland, known as RECOPOL project, was an EU co-funded combined research and demonstration project that investigates the possibility of permanent subsurface storage of CO_2 in coal beds. The project commenced in November 2001 and development of the pilot site began in summer 2003. The development involves CO_2 injection into coal seams at a depth of 1050-1090 m, several hundreds of meters below the deepest mine workings of the Silesia mine. An existing coalbed methane well was rehabilitated back into production. A new injection well was drilled 150 m from the production well (Smith and Whiteley, 2009). A baseline production was established in the first half of June 2004 and first injection tests took place in the first week of July. CO_2 break-through occurred in late 2004 and the trial was completed in 2005. A total of 203 tonnes of CO_2 was brought in by trucks and injected (originally 1000 tonnes had been planned). CO_2 was successfully injected into the coal bed but CO_2 induced swelling was significant and the injectivity was lower than expected. Long term trapping of the CO_2 could not be demonstrated and enhanced methane production was lower than predicted.

According to Smith and Whiteley, (2009), other ongoing projects include:

- Fenn Big Valley, Alberta, Alberta Research Council, 1997 – ongoing (CO_2 and N_2)
- Red Deer, Alberta, Suncor (CO_2), from 2002
- Coal-Seq Project, Burlington Resources and BP, 1989 – ongoing (CO_2 and N_2)
- Simon Field, San Juan Basin, Colorado, BP Amoco, 1993-2002 (N_2)
- Qinshui Project, China, ARC and China, 2002 – ongoing (CO_2)
- Japan CO_2 Sequestration in Coal Seams Project (JCOP), Japan, 2003 –ongoing.

2.5. Assessment of Africa's Potentials for CCS and CO_2-ECBM Recovery

United States and Canada, Siberia, the Middle East, and North and West Africa are reported to have highly prospective geological basins for CO_2 storage within existing oil and gas regions (IEA, 2008). Appropriate formations for CO_2 storage can occur in both onshore and offshore sedimentary basins.

In Africa, the CO_2 storage capacity in aquifers varies from 6 to 220 Gt and in oil and gas fields from 30 to 280 Gt (Hendriks *et al.,* 2004). North and West Africa have the highest potential for CO_2 storage in oil and gas fields. All areas except for East Africa also have considerable storage space in aquifers (15-60 Gt each). Only South Africa has ECBM potential from 8 Gt to 40 Gt (Hendriks *et al.,* 2004; IEA, 2008).

3. Discussion

3.1. Assessment of CCS and CO_2-ECBM Recovery Prospects in Nigeria

The approval of a CCS project methodology under the CDM is an important step to help developing countries to start mitigating their greenhouse gas emissions (IEA, 2008). This is because at present the CDM is the only mechanism that has the potential to provide incentives for development of CCS in Africa.

Attracting an increased flow of investments and capital-intensive projects, encouraging technology transfer of the most innovative technologies used in petroleum and power sectors, promoting natural gas market and developing infrastructure are the major advantages of CDM to Nigeria.

Typical parameters characterizing the prospects of CBM and CO_2-ECBM of coal basins are area, recoverable gas in place, seam depth, cumulative seam thickness, permeability, gas content, well cost, and gas production potential (Lako, 2002).

The characteristics of Nigeria's unmineable coalbed rule out economically profitable mining but can be developed to produce methane (CH_4).

3.2. Assessment of Technical Challenges of CCS and CO_2-ECBM Recovery in Nigeria

The main challenges facing the implementation of Carbon Capture and Storage methods including CO_2-ECBM recovery projects are identified to include long implementation time, inefficient technology, gas leakage from geological storage, and high capture and storage costs (Galadima and Garba, 2008). Others are evaluating the reservoir characteristics of existing hydrocarbon fields and establishing the CO_2 transport facilities. CO_2 related problems on facilities especially severe corrosion on pipelines, well tubing and pumping equipment (Lopez *et al.*, 2003; Crolet *et al.*, 1991) have always been a noticeable challenge to oil industry and its great impact on project economics is well known.

3.3. Assessment of Financial and Legal Challenges of CCS and CO_2-ECBM Recovery in Nigeria

Four major non-technical challenges for successful implementation of CCS are itemized as: financing demonstration projects; setting a long term, stable price for CO_2; establishing legal and regulatory frameworks; and increasing public awareness and acceptance (IEA, 2005). ECBM recovery cost comprises of those of CO_2 supply and sequestration, production wells, injection wells, coal-bed methane gas gathering, treatment and compression, as well as the cost of cleaning and discharge of formation water (Lako, 2002).

Finance for CCS project may be available through the African Development Bank (AfDB). However, the bank was about to develop the capacity to implement climate change projects. It is currently establishing a unit that could handle issues of CDM (Bakker *et al.,* 2007).

There is a lack of a legal and regulatory framework for CO_2 storage in geological formations. A few countries have begun to work on the development of relevant legislation. Existing laws from oil and gas, mining and industrial sectors do not provide effective regulatory mechanisms for CO_2 storage (Clifton Associates, 2004; IPCC, 2005).

4. Conclusions

This paper reviews Carbon Capture and Storage (CCS) techniques, and global CO_2-ECBM recovery projects, and assesses the potentials, prospects and challenges of CO_2-ECBM recovery in Nigeria.

The approval of a CCS methodology under the CDM would help developing countries to start mitigating their greenhouse gas emissions (GHG) and pave the way for development of effective legal and regulatory framework to regulate CCS in the country coupled with revenue generation to offset costs of CCS. Attracting an increased flow of investments and capital-intensive projects, encouraging transfer of the most innovative technology needed, promoting natural gas market and developing infrastructure are the major advantages of CDM to Nigeria.

High capture and storage costs and CO_2 related corrosion of facilities are among the challenges facing the implementation of CCS and CO_2-ECBM recovery in Nigeria. Four major non-technical challenges for successful implementation of CCS are itemized as: financing demonstration projects; setting a long term, stable price for CO_2; establishing legal and regulatory frameworks; and increasing public awareness and acceptance.

Recommendations

Since CO_2 capture at the power plants in Nigeria presents a number of technical and financial difficulties, the CO_2 may be sourced from Europe by Nigeria's LNG ships on their way back home after delivering LNG to the European market. The transport of CO_2 by ship from overseas is a technically and economically viable solution.

Also, for CCS and CO_2-ECBM recovery projects to be commercially viable, a logical, long-term and stable price of CO_2 should be set. The problem of CO_2 related corrosion of facilities should be effectively tackled.

For the successful implementation of CCS projects, more work is needed to establish procedures for site selection, injection, abandonment and monitoring. Also, the community near the CCS and CO_2-ECBM recovery projects should be sensitized to the prospects and challenges of CO_2 storage and its inherent risks.

More research and demonstration projects, as well as development of legal and regulatory framework and incentives from the government are necessary for successful implementation of CCS technologies.

References

[1] Anastassia M., Fredrick O. and Malcolm W., (2009), "The Future of Carbon Capture and Storage (CCS) in Nigeria", Science World Journal, Vol.4, No. 3, pp. 1-6. www.scienceworldjournal.org ISSN 1597-6343.

[2] Anna Smith and Stewart Whiteley, (2009), "Carbon Capture and Storage: Options, Current Projects and Costs", 16th African Oil Week, Cape Town, South Africa

[3] Bakker S. J., de Coninck A.; H. C., Ba L. and Zhou P. P., (2007), "Advancing CCS and CDM in Africa", Outcomes of Two Workshops in Africa, Energy Research Centre of the Netherlands. ECN-E--07- 079, October 2007.

[4] Bergen F. van, Pagnier H.J.M., David P. and Kross B.M., (2000), "Inventory of the Potential for Enhanced Coalbed Methane Production with Carbon Dioxide Disposal", TNO, Utrecht, The Netherlands, www.ergweb.com/methane/pdf/ban_bergin.pdf.

[5] Clifton Associates, (2004), "The Long Term Storage of CO2", A Regulatory Requirements Project, Final Report, Clifton Associates Ltd. Regina, Saskatchewan, Canada, March 25, 2004.

[6] Crolet J.L. and Bonis M.R., (1991), "Prediction of the Risks of CO2 Corrosion in Oil and Gas Wells", SPE Paper 20835, SPEPE, November 1991.

[7] Eye of Dubai, (2009), "Masdar to Pursue Carbon Reduction Projects in Nigeria", January 21, 2009.

[8] http://www.eyeofdubai.com/v1/news/newsdetail-27634.htm. Accessed 3 March, 2009.

[9] Galadima A. and Garba Z. N., (2008), “Carbon Capture and Storage (CCS) in Nigeria: Fundamental Science and Potential Implementation Risks”, Science World Journal, Vol. 3, No. 2, pp. 95-99.

[10] Hendriks C., Graus W. and van Bergen F., (2004), “Global Carbon Dioxide Storage Potential and Costs”, ECOFYS Report EEP-02001, 2004.

[11] IEA GHG, (2004), “Prospect for CO2 Capture and Storage, Energy Technology Analysis”, International Energy Agency, 2004.

[12] IEA, (2008), “CO2 Capture and Storage: A Key Carbon Abatement Option”, OECD/IEA 2008.

[13] IPCC, (2005), “IPCC Special Report on Carbon Dioxide Capture and Storage” prepared by Working Group III of the IPCC, Metz B., Davidson, Deconninck H.C., Loos M. and L.A. Meyer (Eds), Cambridge: Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 442.

[14] Lako P, (2002), “Option for CO2 Sequestration and Enhanced Fuel Supply”, Monograph in the Framework of the VLEEM Project ECN-C--01-113.

[15] Lopez D.A. et al, (2003), “The Influence of Microstructure and Chemical Composition of Carbon and Low Alloy Steels in CO2 Corrosion: A State-of-the-Art Appraisal”, Published by Elsevier, 16 July 2003.

[16] Novem, (2001), “Potential for CO2 Sequestration and Enhanced Coalbed Methane Production in the Netherlands”, Utrecht, March 2001.

[17] Sengul M., Pillay A.E., Francis C.G. and Elkadi M., (2007), “Climate Change and Carbon Dioxide (CO2) Sequestration: African Perspective”, International Journal of Environmental Studies, Vol. 64, No. 5.

[18] UNEP, (2006), “Africa Environment Outlook 2: Our Environment Our Wealth”, UNEP Job No. DEW/0801/NA, United Nations Environment Programme, pp. 48–74.

[19] United Nations Framework Convention on Climate Change (UNFCCC) http://cdm.unfccc.int/index.html. Accessed 3 March, 2009.