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Benefits and Challenges of Implementing Carbon Capture and Sequestration Technology in Nigeria

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ABSTRACT
This paper reviews the state of carbon dioxide (CO_2) emissions, the potential benefits and challenges of implementing Carbon Capture and Sequestration (CCS) technology in Nigeria as a means of mitigating the threat posed in emitting CO_2. In 2010 Nigeria was ranked 44th by the International Energy Agency (IEA) for emitting about 80.51 million metric tons of CO_2 annually. In this paper, the three different stages that constitute carbon capture and sequestration are discussed individually, and then the potential for their integration into a commercial scale CCS process is considered. CCS technology shows promising possibility for application in plants that emit large amounts of CO_2 and also considered are some technological improvements to capture CO_2 from air, as the technology can be applied for removing CO_2 directly from the atmosphere and thus reducing the effect of emissions from vehicles and other moving sources. The development and deployment of CCS in Nigeria will be very significant in ensuring that we are able to meet increasing energy demand and keep the lights on whilst minimizing the environmental damage. The market for CCS in Nigeria is likely to be measured in $billions with the potential of creating over 100,000 jobs.

Keywords – *carbon dioxide, capture, CO_2 emissions, sequestration, transportation.*

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I. INTRODUCTION

About 80% of the world's energy supply is derived from fossil fuels. Roughly 6 billion metric tons of coal is used yearly, producing 18 billion tons of carbon dioxide (CO_2) which accounts for 40% of carbon emissions. It has been scientifically proven that CO_2 emissions from these fuels have caused a change in the climate and pose a risk of devastating effects in the future [1]. The world relies a great deal on fossil fuels as a source of energy thus it is imperative that the capture and storage of CO_2 from power plants be pursued [1]. The capture and storage of carbon has the potential to reduce CO_2 emissions to the atmosphere and meet future targets, as it is applicable to the power and industrial sectors. In 2010, Nigeria was ranked 44th by the International Energy Agency (IEA) for emitting about 80.51 million metric tons of CO_2 annually [2]. However, this figure is expected to go higher significantly in the near future with the recent industrial advancements and as the country continues its pursuit of generating more power to stabilize electricity supply. The major contributors to CO_2 emissions in Nigeria are reported as gas fuels, liquid fuels, solid fuels, gas flaring, cement production and bunker fuels [2]. CO_2 from most of these sources can be captured and stored in depleted oil and gas fields prevalently abundant in the Niger Delta region of the country and can be used for Enhanced Oil Recovery (EOR) purposes. Thus improving Nigeria's oil and gas production rate over the years and contributing to the economic development of the country. Apart from depleted oil and gas fields, captured CO_2 in Nigeria can also be stored in saline formations, unminable coal beds and oceans. Carbon Capture and Sequestration (CCS) is a three step process in which CO_2 is captured at its emission source, compressed, and transported to, and stored in, deep geological formations. In the UK, the CCS industry is working towards developing a cost competitive system by the 2020s by providing funding for research and development programs [3]. Other measures aimed towards reducing carbon footprint such as electric cars, will require more electricity thus making CCS an unavoidable option if electricity demand is to be met with a reasonable carbon footprint. Around 90% of carbon emissions from the power sector as well as industrial processes can be captured by CCS. Carbon is captured by three basic approaches: pre-combustion capture, oxy-fuel combustion systems and post combustion capture. There are currently four operational commercial-scale CCS plants globally [3]. Carbon dioxide is transported predominantly in pipelines at high pressures. This increases the efficiency of transportation and reduces the size of pipelines required. Typical issues regarding the transport of carbon dioxide are maintaining single-phase flow, pipeline corrosion and distance from source to storage. Onshore and offshore underground geological formations such as depleted oil and gas fields or deep saline aquifers are usually used for storage.

Chu Steven [1] reported typical geological storage density of CO_2 as approximately 0.6 kg/m^3. Therefore, about 53km^3/year will be required for underground storage for up to 80 million metric tons of CO_2 in Nigeria. The cost of a CCS technology project varies depending on the source of the carbon dioxide to be captured, the distance to the storage site and the characteristics of the site. The capture stage incurs the greatest cost in the process, approximately a third of the project cost. Attaching CCS to coal-fired power plants is currently cost competitive with other forms of low-carbon energy in terms of tonne of CO_2 emission abated. Cost of capture can be lowered by capturing CO_2 from industrial processes where it has already been separated as part of the process.

II. POTENTIAL BENEFITS OF CCS APPLICATION IN NIGERIA

Carbon Capture and Storage (CCS) is a vital tool in the global fight against climate change (greenhouse gas emissions). With its important application to the capture and storage of carbon dioxide emissions from power stations and industries, CCS has a crucial role to play in tackling greenhouse gas emissions whilst maintaining security of supply [4]. The International Energy Agency (IEA) has estimated that to halve global emissions by 2050 (widely believed to be required to limit the temperature rise to 2ºC), CCS will need to contribute one fifth of the required emissions reductions, both in the power sector as well as the industrial sector4. In addition, the IEA have found that attempting to halve global emissions by 2050 without CCS, would increase costs by more than 70% per year [4].

To meet global 2050 goals, the IEA has projected that we will need 100 CCS projects around the world by 2020 and more than 3000 by 2050 [4]. This is a significant scale-up from current ambitions and there are very major benefits arising from the deployment of CCS in addition to climate mitigation. In Nigeria, CCS can contribute immensely to the economy through enhanced oil and gas recovery. When considering the capital investment in capture, transport and storage that will be needed to build these projected CCS projects, a picture emerges of a global market for CCS worth more than $5 trillion by 2050 (similar to the oil industry). In Nigeria alone, CCS project worth up to $10 billion per year by 2030 could create up to 100,000 jobs. Although it must be said that CCS projects are large, capital intensive projects, they provide extremely good value for money both in terms of cost per tonne of CO_2 saved and per unit of clean electricity. For example, the costs of early demonstration projects has been estimated at $75-105 per tonne of CO_2 with costs reducing to around $50-60 per tonne of CO_2 by 2030 [4].

There are also significant social benefits from the deployment of CCS. The supply chain for CCS will create a large variety of jobs for those communities living near a capture plant, pipeline or storage facility. Jobs will be required in core engineering and manufacturing sectors, as well as pipeline design, management and operation and a host of skills related to CO_2 storage, including exploration and site characterization, injection well construction and management. Many energy intensive manufacturing industries will in future be seen to be unsustainable without CCS [4]. So the application of CCS will protect jobs and prosperity related to these industries. Developing networks of CCS pipeline networks will enable local prosperity through the longevity of regional industries. The development and deployment of CCS will be very significant in ensuring that we are able to meet increasing energy demand and keep the lights on whilst minimizing the environmental damage [4]. The market for CCS is likely to be measured in the $billions with the creation of a large variety of specialist jobs.

III. CURRENT STATE OF CCS TECHNOLOGY

The first paragraph under each heading or subheading should be flush left, and subsequent paragraphs should have a five-space indentation. A colon is inserted before an equation is presented, but there is no punctuation following the equation. All equations are numbered and referred to in the text solely by a number enclosed in a round bracket (i.e., (3) reads as "equation 3"). Ensure that any miscellaneous numbering system you use in your paper cannot be confused with a reference [4] or an equation (3) designation. The market for CCS is likely to be measured in the $billions with the creation of a large variety of specialist jobs.

3.1 The Process

Carbon capture and sequestration consists of three main stages: capture, transportation, and storage. In this section, different technologies for performing each of these steps are discussed in order to present the current state of the CCS process development globally.

3.2 Carbon Capture

In order to store carbon dioxide in the appropriate depleted geological formations beneath the earth crust, it is imperative to consider the issued involved in the actual removal or capture of the CO_2 from a process plant. This is achieved through a process called carbon capture. Carbon capture is the first step in the carbon capture and sequestration chain. In most cases, these process plants are coal or gas power plants, or processes that emit a lot of CO_2, such as cement manufacturing or steel production.

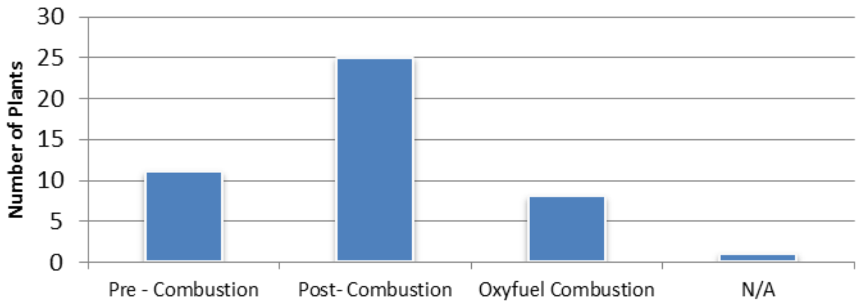

Fig. 1: Number of Plants, Planned Or Active, that Use each Kind of Capture Technology [5]

The capture of CO_2 can be achieved through a number of technologies. The major processes that will be considered in this study are:

- pre-combustion
- post-combustion
- oxyfuel combustion.

Fig. 1 shows how many plants use or are being built to use each technology. In the post-combustion process, CO_2 is absorbed from the exhaust of a combustion process by absorption into a suitable solvent. The absorbed CO_2 is separated from the solvent and compressed for transportation and storage while the solvent is recycled back for further absorption. Figueroa et al [6] report that post-combustion carbon capture technology is the most appealing carbon capture technology for a short term fix to the emissions of greenhouse gases (GHGs). This is because it can easily be retrofitted to existing coal and gas power plants. It is also the most widely used carbon capture technology at the moment [7]. The current state-of-the-art technology in post-combustion capture is amine-based scrubbing. Amine scrubbing can be considered the most viable technology for addressing the challenge of capturing CO_2 from coal power plants without the need of closing them down [8].

Since 1930, the separation of CO_2 from natural gas and hydrogen has been achieved with the aid of amine scrubbing [9]. The process involves the absorption of CO_2 from flue gas near ambient temperature into an aqueous solution of amine with low volatility. This is followed by the regeneration of amine by stripping it with water vapour at 100 to 120 °C, and the condensation of water from stripper vapour which leaves CO_2 that can be compressed to 100 to 150 bar for geological sequestration [9]. Currently, amine scrubbing takes place in packed columns, but efforts are being made to replace packed columns with membrane contactors. Membrane contactors are generally considered to be more efficient than packed column designs because they provide higher interfacial area per unit volume [8].

Pre-combustion involves gasification which serves as the fuel conversion process via partial oxidation to form a mixture of CO_2 and hydrogen (syngas) followed by a water-gas shift reaction before combustion [7]. This technology is particularly promising because it produces hydrogen gas which can be used as fuel for fuel cell vehicles. The major challenge with the pre-combustion process is the separation of syngas under conditions of high temperatures and high pressures [10].

Oxyfuel combustion involves the use of high purity oxygen (approximately 95%) instead of air in the combustion of fuel (such as gas, oil, or coal). This leads to the production of a flue gas mixture of CO_2/H_2O thereby producing a more concentrated CO_2 product stream (90- 99%) after the water in the mixture has been condensed. The advantage of this process is that there is usually no the need for subsequent separation to capture the CO_2 [5], [7], [10].

3.2.1 Emerging Capture Technologies

Capture from the Atmosphere

Capturing CO_2 from air involves capturing CO_2 directly from ambient air. Air capture technology was proposed by Klaus Lackner, a professor in the Department of Earth and Environmental Engineering at Columbia University. He proposed an air capture technology where solid sorbents are used in form of an anionic exchange membrane [11].

Capture by Biomass and Soil

Carbon capture by means of biomass and soil is a viable way to ameliorate the capture of CO_2 and also conserve the crops, forests, grasses, and soil. For instance, the decrease of annual subsidies for biofuels will increase the amount of carbon dioxide captured by crops, forests, and grasses [11].

3.2.2 Capture Challenges

A number of challenges are associated with carbon capture. The most significant challenges are cost and environmental issues. Other challenges include the need for materials and solvents that can improve the economy of the carbon capture process.

From recent statistics, it can be said that carbon capture accounts for the greatest cost of a typical CCS project [12]. This is one of the reasons why organizations such as the US Department of Energy (DOE) have focused their efforts in the development of CO_2 capture technologies [12]. Despite the promise of CO_2 capture technologies, their implementation on a national scale still seems infeasible. This infeasibility can be attributed to the consumption of large amounts of parasitic power by carbon capture technologies and the associated increase in electricity costs. Hence, the development of cost effective and innovative CO_2 capture technologies cannot be over-emphasized. The mitigation of the cost of CO_2 capture technology can be achieved by embarking on urgent research and development to design cost-effective and highly efficient carbon capture materials, technologies, and innovative power plants, and power cycles [13].

The environmental impact of carbon capture technologies have often been overlooked, but studies by Veltmanet al [14] show that carbon capture technologies such as amine-based scrubbing cause a 10-fold increase in toxic impact in freshwater ecosystems. The increase observed was attributed to the volatilization of solvent which in this case was monoethanolamine (MEA). Carbon capture technologies also face some technical challenges. One significant technical challenge is the low thermodynamic driving force due to the low concentration of CO_2 in air which is usually an issue in post-combustion carbon capture and air-capture technologies. It is also a significant factor in the development of cost-effective CO_2 capture technologies [6], [10].

3.2.3 Capture Implementation

Existing process plants can either be built as “carbon capture ready” in which case the process plant is designed in such a way that a CO_2 capture process can be integrated in to the whole process through retrofitting [15]. Alternatively, new process plants especially coal and gas power plants, cement manufacturing plants, and steel manufacturing processes can be built with the CO_2 process already integrated into the process [16].

3.3 CO_2 Transportation

After carbon dioxide has been captured from the emission source, it can be transported to a storage site by using pipelines, ships, rail and road tankers, or any combination of these [17]. Pipelines can be implemented for both onshore and offshore carbon dioxide transportation. For offshore transportation both pipelines and ships are competitive alternatives for CO_2 transportation. Pipeline transportation provides a constant and steady supply of CO_2, with no need for intermediate storage. However, this requires the development of new large scale infrastructures which increase the capital cost of implementing the technology. The transportation cost of CO_2 by pipelines and ships depends on the volume of CO_2 and the distance. Local conditions also need to be considered when planning to construct the pipelines for onshore transportation. The cost can be 50% higher for the areas with rivers, mountains or frozen ground on the route in comparison to flat areas [18].

Other possible options for transportation are rail and road tankers. CO_2 is transported in insulated steel containers in liquid state, with operating pressure between 18.5 and 21 bar, with temperature of -200°C. This type of transportation is considered to be safe with only few accidents reported during loading and unloading [19]. However, its usage is considered to be uneconomical for transportation of large volumes of CO_2 compared to ships and pipelines [18]. For long distances the combination of pipelines and ships should be implemented, whereas for shorter distances the usage of tankers and pipelines is considered to be reasonable [19].

3.3.1 Transportation Challenges

For transportation by pipelines, CO_2 needs to be compressed and cooled into the liquid phase, as it is inefficient to transport gaseous CO_2 due to the low density. Another disadvantage of transportation of gaseous CO_2 is a relatively high pressure drop that can occur along the pipeline [20]. It is important to maintain single-phase flow in CO_2 pipelines to avoid pressure drops along the transportation route. In a two-phase liquid-vapour flow, both liquid and gas phases present simultaneously that can result in operational and material problems with compressors and other transport equipment, which increase the chance of pipeline failure [18]. Supercritical state is the desired phase of CO_2 for transportation by pipelines [21]. To achieve this condition, CO_2 should be at pressures above 73.8 bar and temperatures higher than -60 °C, which gives a good margin to avoid two-phase flow [17].

Transport pipelines may be exposed to changing the temperatures due to weather or pipeline conditions. However, at pressures very close to the critical point, even a small change in temperature yields a very large change in the density of CO_2, which could result in a change of phase and fluid velocity, causing a slug flow [21]. Another challenge is corrosion of pipeline. Although, dry CO_2 (moisture-free) is not corrosive for carbon steels, the presence of moisture and acid gases can result in corrosion of pipelines. In this case, the pipeline construction should be made of a corrosive-resistant alloy. If it is not possible to get dried CO_2, stainless steel can be used to prevent the corrosion. However, both options will result in significantly increasing the pipeline cost [18]. The cost of CO_2 transporting can become a significant part of the overall CCS costs if the emission sources are located further than a few hundred kilometres from the storage sites. Thus, for successful integration of CO_2 transportation into the CCS, optimized pipeline transport network should be developed [22].

3.3.2 Transportation Implementation

For safe operation, the following design factors should be taken into consideration for transportation of CO_2 via pipelines: over-pressure protection and leak detection (odorants). Also, for CO_2 transportation through populated areas, the detailed route selection must be developed [23] and appropriate safety caution signs must be indicated for intruders to keep away from tempering with the CO_2 transportation pipelines.

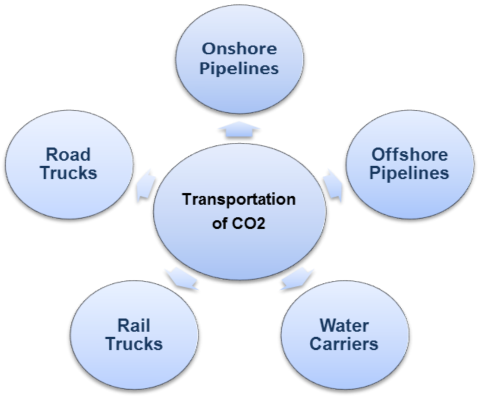

Fig. 2: Available Options for CO_2 Transportation

The CO_2 captured from the emission source contains different types and amounts of impurities. These impurities can change the physical properties of CO_2 such as critical pressure resulting in changing the hydraulic parameters of CO_2 and operating regime of the pipelines. Hence, CO_2 behaviour in presence of different impurities should be investigated. Fig. 2 shows the different options for CO_2 transportation, and based on the conditions of the captured CO_2, any combination of them can be used. There are currently no established standards for permitted levels of impurities in CO_2. Thus, for further development of the CO_2 pipeline infrastructure such standards and regulating framework need to be developed [21].

3.4 Carbon Storage

Storage is the third and last stage in the carbon capture and sequestration process. It consists of the injection of carbon dioxide into suitable geological sites, onshore or offshore. CO_2 must lie safely and permanently in these sites. While the real global underground storage capacity is uncertain, it is believed to be around 2000G-tonnes of CO_2 [23].These geological sites usually consist of a dense and highly porous rock reservoir, with a dome or anticline shape, covered by an impermeable cap rock or seal to prevent CO_2 migration into overlying water aquifers, other formations, or the atmosphere. This cap rock mechanism is the same mechanism that kept oil and natural gas under the ground for millions of years, so it is believed to be able to securely store CO_2. Recognised suitable sites are [24]:

- Saline formations
- Depleted oil and gas fields
- Unminable coal beds
- Oceans

Saline formations consist of rocks saturated with water too salty for human, agricultural or industrial uses. These formations need to be sufficiently porous and permeable to allow the injection of a large carbon dioxide volume in supercritical conditions. These are less mapped than depleted oil and gas fields and will have to be explored more intensely before they are used for storage. The Global CCS Institute believes they are very large and in the future will comprise a large part of the world's underground CO_2 storage [18], [24].

Depleted oil and gas fields have stored oil and gas for millions of years. However, these sites are penetrated with many wells of variable quality and integrity, which may present leakage paths for the stored CO_2. However, if in good condition, these could also be used to transport the gas underground. Even though their capacity is smaller than that of deep saline formations, they represent an early opportunity for CO_2 storage because they are well known, mapped, and explored. It is possible to start the CO_2 injection while the oil field is still operative. This procedure is called Enhanced Oil Recovery, EOR, and it consists of pumping a gas, in this case CO_2, into the oil field, decreasing the oil density to facilitate its extraction.

Captured CO_2 could be injected into the ocean at great depth, isolated from the atmosphere, for centuries. Carbon dioxide can be transported via pipeline or ship to be released on the sea floor, feeding a CO_2 lake. The main problem of this technology is the lack of field testing.

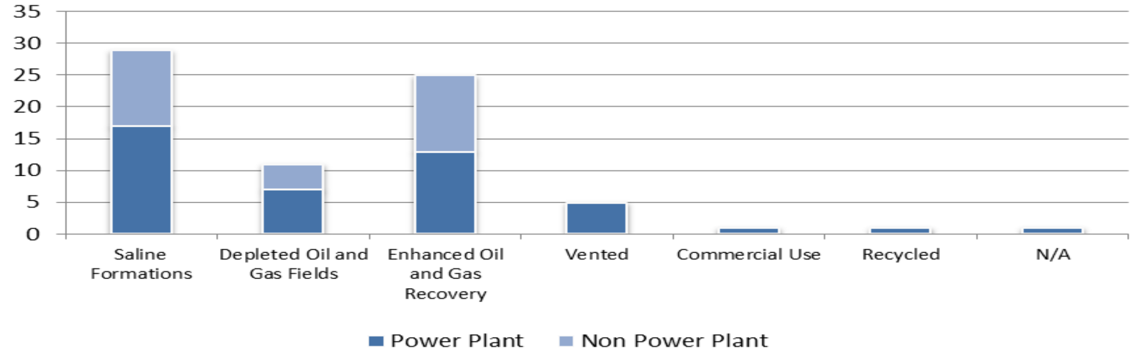

Fig. 3: Current Distribution of Carbon Dioxide Sequestration [24]

There are studies assessing the possibility of storage in basalt, oil shale, salt cavern, geothermal reservoirs and lignite seams, but these all seem to have smaller capacity. These technologies could be used for specific, niche situations. At the moment, however, these options are not common. Fig. 3 shows the sequestration sites of most active and planned CCS plants.

3.4.1 Storage Challenges

CCS has many detractors sustaining that it unsafe because it could cause earthquakes, leakages in groundwater that could create environmental problems and contaminate the aquifer, or eventual massive leakages in the atmosphere that could abate the CCS efficiency.

3.5 Integration of Capture, Transportation and Storage

As expressed earlier, CO_2 can be captured at low pressures using any of the established technologies (Pre-combustion, Post-combustion, Oxyfuel, Industrial processes, etc.). This pressure may vary between 1 and 20 bar depending on the capture technology. CO_2 must then be compressed to a pressure between 80 and 150 bar above its critical pressure in order to be transported and delivered to a storage reservoir. CO_2 is afterwards transported from the power plant to the vicinity of onshore or offshore reservoir(s) through a dedicated pipeline and then via a satellite line to a reservoir or it is transported from the power plant via a short connector pipeline to an onshore or offshore trunk line and then via a satellite line to a reservoir [25]. Fig. 4 summarizes the CCS integration process.

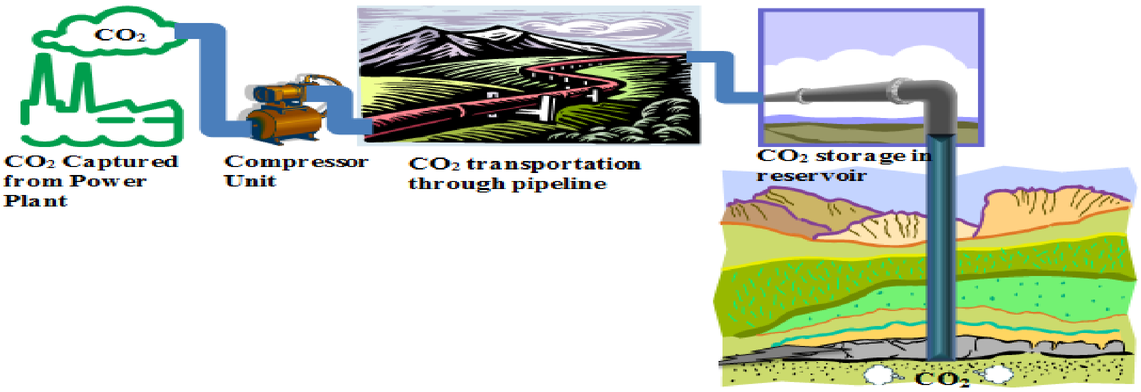

Fig. 4: Diagram of the Carbon Capture and Sequestration Chain

IV. THE FUTURE IMPLEMENTATION OF CCS IN NIGERIA

In the future, applying CCS technology in Nigeria has the goal of achieving secure sequestration in geologic formations and a large number of potential geologic sinks have been identified in the coastal region of the country. Due to higher petroleum prices in the near future, there may be increased interest in using CO_2 flooding as a means to enhance oil recovery (EOR). Higher gas prices would also lead to growing interest in using CO_2 for enhanced coal bed methane production (ECBM) [24]. However, the economic viability of these activities is dependent on the initial step of capturing the CO_2, and none of the current available CO_2 capture processes are economically feasible on commercial scale. Thus, improved CO_2 capture technologies are vital if the promise of geologic sequestration, EOR, and ECBM is to be realized [24]. According the US Department of Energy, in the late 1970s and early 1980s, U.S. oil producers found it profitable to extract oil from previously depleted oil fields by means of enhanced oil recovery (EOR) methods and that today, EOR operations account for 9 million (metric) tons of carbon (MtC) or about 80% of the CO_2 used by industry every year [24]. Thus, in Nigeria the application of these technologies can significantly improve the rate of oil and gas production daily.

CCS technology shows a promising alternative for increasing energy efficiency and the use of carbon-intensive energy sources. Carbon capture technologies are not really new. Over 60 years ago, specialized chemical solvents were developed to remove CO_2 from impure natural gas, and natural gas operations continue to use these solvents today. In addition, several power plants and other industrial plants use the same or similar solvents to recover CO_2 from their flue gases for application in the foods-processing and chemicals industries [25]. Alternative methods are used to separate CO_2 from gas mixtures during the production of hydrogen for petroleum refining, ammonia production, and in other industries. All of these capture technologies are considered to be relatively matured but substantial technical improvements and cost reductions are required to apply these technologies at a scale that would make CCS reduce carbon emissions significantly and justify the investment in the large infrastructure required to implement the process [25].

Researches on CCS in Nigeria have great possibilities of many other storage locations apart depleted oil and gas wells for the captured CO_2. Although, CCS technologies are currently not widely used as a way to avoid carbon emissions, but this paper has shown that there are many efforts dedicated to making this technology feasible at a scale that could significantly lower emissions. In the presence of a sufficiently high implicit or explicit price on carbon, there is evidence that CCS technologies can be economically sensible. Prospects for CCS technology in Nigeria appear to be most promising for carbon capture from electric power generation and some industrial sources, with storage in geologic formations such as depleted oil and gas reservoirs and deep aquifers [26]. The issue with implementing CCS technology is not the process feasibility of the technology, but the economic feasibility. However, the environmental benefits of the process provide incentives to give CCS technology financial help, as there is a worldwide effort to reduce carbon emissions into the atmosphere due to greenhouse effects. CCS could constitute a substantial share of mitigation effort within several decades, significantly reducing the cost of mitigation; however, a large number of technical and political issues regarding the suitability of storage options need to be resolved before widespread application [26].

V. CONCLUSION

Due to the large geographic range that a CCS process would cover, and the lack of data available for many potential storage sites, the future of this technology is not clear yet. Different carbon capture technologies are being developed to improve the overall economy of the CCS process, but improvements are still necessary to make the process economically viable. Although CO_2 transportation has been well researched globally and the requirements and safety measures are known, large infrastructure is required if CCS is to be implemented at a commercial scale in Nigeria. This is due to the fact that there currently no pipelines built for transporting CO_2 to potential storage sites. The next main issue with the technology is the uncertainty regarding the amount of carbon that can be stored in potential sites, and the safety issues concerning each type of reservoir. Also the potential for causing earthquakes or large CO_2 leaks possess threat for the process. In order to make CCS a commercial scale process, regulatory measures are essential. The design of transportation technologies depends heavily on the purity and conditions of the CO_2 captured. If large infrastructures are to be built to transport CO_2 to storage sites, then the output of the carbon capture process directly impacts the cost of transportation. These conditions should be established on a worldwide (or at least a national scale) in order to allow different CCS projects to combine efforts in transporting CO_2 to the reservoirs, thus reducing cost of transportation overall. While capture technology is an effort that is completely separate from plant to plant, economic CO_2 transportation and storage can be achieved through a combined effort between all CCS projects. One controversial issue regarding CCS is the potential dangers of injecting CO_2 underground. Due to the uncertain nature of the storage capacity available, and the potential for leaks, the immediate benefits of CCS are clearly defined but the effects of using this technology on the future are not. Carbon emissions can be reduced by storing CO_2 in the ways described in this paper, but these reservoirs are limited.

A major driving force behind CCS is the reduction of carbon emissions and, while this presents a solution to the problem, it is only temporary. Current efforts also include reduction of carbon emissions by strict regulation of sources of carbon emission, which would present a more permanent solution. The Vision 20:2020 envisages a rapidly growing economy that will make Nigeria to significantly increase its energy production and as Nigeria's economy improves, its per capita greenhouse gas emissions may tend towards those of the developed nations of the world today, especially if it pursues an energy intensive development approach [27]. This combined with continued gas flaring and a large population will further worsen Nigeria's standing as a key emitter of greenhouse gases globally. Since Nigeria has a goal of reducing greenhouse gas emissions by at least 25% in 2020 [27], CCS presents more potential for meeting this target than do simple regulatory limitations on emissions.

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