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Climate change mitigation with carbon capture: An overview

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ABSTRACT

The world is at the verge of catastrophe occasioned by the effect of climate change. Drastic action needs to be taken to reverse this ugly trend. Some of the proffered solutions to global warming is the adoption of renewable energy usage and a stop of fossil fuels combustion. However, the low capacity factor and energy return has been the bane on the usage of some renewable energy sources. A leeway however, exists in the technology of removal of greenhouse gases referred to as Carbon Capture. The widely adopted method being at point source because of its high concentration favouring easier processes of removal. This technology has received increased attention over the years as evident from data for the past five years. However, this technology alone cannot guarantee atmospheric CO2 levels required to maintain global temperature rise below the 1.50C mark. Negative emission technology processes of which the Direct Air Capture (DAC) is one needs to be developed. The infancy of the DAC technology and the uncertainties that surrounds its cost still pose as challenges. The cost of removing a tonne of CO2 with DAC technology can be as high as $600, this is unsustainable and has to be drastically reduced. While it is projected that DAC technology can take out 980 Metric Tonne (MT) CO2/annum by 2050, current figures stand at 0.008 MT. It is our view that the development of solid adsorbents and the harnessing of the thermal energy inherent in the sun can be a game changer.

Contribution/Originality: This study evaluates some measures of mitigating climate change occasioned by greenhouse gas emissions and proffers a possible solution to economically develop the technology of direct air capture by reducing the energy cost.

1. INTRODUCTION

The level of comfort being demanded by humans around the world had continually made energy demand to be on the increase. Meeting this demand requires energy generation from available sources. While the technology for energy generation from non-renewable sources have matured over time, the contributions it has on climate change has continued to be a source of concern. The combustion of fossil fuels for the generation of energy comes with the emission of Greenhouse Gases (GHG) (High et al., 2022; Towoju, 2021; Towoju, 2021; Towoju, 2022; Towoju, 2022; Towoju & Oladele, 2021) although, this is not the only source of GHG emissions. Energy generation from nuclear processes although a non-renewable energy source produce negligible amounts of GHG (Pioro & Duffey, 2015). Shifting the generation of energy to nuclear sources comes with its own challenges despite being more reliable in comparison to that from renewables (Towoju & Ishola, 2020) also with low carbon footprints. Chief among the challenges are radioactive wastes/risks of radiation (safety), and relative low thermal efficiencies (Olatunji, Ishola, Ayo, Towoju, & Akinlabi, 2019; Pioro & Duffey, 2015), however, with the security and safety risks kept at bay, nuclear powered energy generation is the most viable for future electricity generation due to its huge potentials (Pioro & Duffey, 2015; Towoju & Ishola, 2020).

Many factors continue to constrain the generation of energy from renewables. Low capacity factor and energy return on investment has continued to be the bane of Solar and Wind energy plants (Breeze, 2016; Jônatas da Mata & Mesquita, 2017; Olatunji et al., 2019; Towoju & Ishola, 2020). The large expanse of land required for the construction of renewable energy generation plants is also a factor that is of great concern; it results to a competition for space with other germane human needs (Jônatas da Mata & Mesquita, 2017; Towoju & Oladele, 2021). Another issue of major concern pertains partly to energy security; stockpiling of renewables and subsequent immediate deployment is difficult if not impossible, a major plus which non-renewables have over it (Towoju, 2021; Towoju & Oladele, 2021). It is however, important to note that not all renewable energy sources are clean, a good example being biofuels (Towoju, 2021; Towoju & Ishola, 2020; Towoju & Oladele, 2021).

There is therefore no gainsaying that at least in the nearest future, the reliance on non-renewable (fossil) energy has to continue. Some section of the industrial sectors generally classified as the hard-to-abate also continues to contribute to GHG emissions. The realization of the negative impacts of climate change on our environment and the need for continuous energy generation from non-renewables is a case of dilemma. Average global temperatures is to be below the 1.5 ^{o}C benchmark to checkmate global warming (Bandilla, 2020; Towoju, 2021; Towoju, 2021; Towoju & Ishola, 2020; Towoju & Oladele, 2021). A leeway is however, offered with the technology of Carbon Capture Storage and Utilization (CCSU), which can ensure the trapping of the greenhouse gas emission for possible storage and utilization after its emission. The technology is a means to an end in achieving the average global temperature increment target (Bandilla, 2020; Leeson, Mac Dowell, Shah, Petit, & Fennell, 2017). An exciting potential for captured Carbon is in the generation of synthetic fuel, which promises to be an energy source of the future (Towoju, 2021).

Maintaining average global temperature rise below the 1.5 ^{o}C benchmark requires a quick and sustainable fix. Carbon Capture Storage and Utilization has the potential to achieve this, if we get the technology right. This study focus on the trends in the Carbon capture technology to project the ray of hope that exists for climate change mitigation and thus, a better world to live in.

2. CARBON CAPTURE

Carbon capture is the technology of capturing/extracting the CO_2 emitted from power and industrial plants thereby preventing it from escaping to the atmosphere (Bandilla, 2020) and is more economical and technically feasible in comparison with Direct Air Capture (DAC). Carbon can be captured and stored as applicable in Carbon Capture and Storage (CCS) or be used as applicable in Carbon Capture and Utilization (CCU). Carbon capture and utilization is not a new technology. Its usage dates back to over two decades for enhanced oil recovery by its injection into geological formations and industrial processes (Bandilla, 2020; Climate, 2005; Demirel, Matzen, Winters, & Gao, 2015). There are several enhanced oil recovery programmes in Brazil, Canada, and the United States, and about 75% of the global captured Carbon is utilized in the United States for this purpose.

The technology of Carbon capture (CO_2) is currently possible via any of the following methods; chemical absorption, physical absorption, physical adsorption, chemisorption, chemical bonding, and phase separation (Gozalpour, Ren, & Tohidi, 2005; High et al., 2022; Singh & Dhar, 2019), which are executed via pre-combustion, post-combustion, or oxy-fuel combustion (Bandilla, 2020; Climate, 2005; Finney, Akram, Diego, Yang, & Pourkashanian, 2019). The technology offers the economic benefits of infrastructure re-use, the provision and sustenance of high-value jobs, deferral of shut-down costs, and just transition (Climate & Project, 2005).

Pre-combustion capturing entails the conversion of the greenhouse gas yielding fuel to CO_2 and fuel that is Carbon free (Bandilla, 2020; Climate, 2005).

Post-combustion capture entails the capturing of CO_2 after the combustion of greenhouse gas yielding fuel from the flue gases. The concentration of CO_2 determines the energy requirement for its sequestration and has a correlation with the capture configuration for optimized performance (Keith, 2009).

Low concentration CO_2 capture is commonly done with chemical absorption technology using chemical solvents. The degradation of the solvents by other flue gases adds to the challenge of the high cost of the technology due to its high energy requirement for stripping (Bandilla, 2020; Finney et al., 2019; Liang et al., 2015). Chemical absorption, physical absorption, physical adsorption, chemical bonding and to a lesser level phase separation are employed in post-combustion capture.

Oxy-fuel combustion capture technique entails the use of pure Oxygen for the combustion of greenhouse gas yielding fuel by extracting the Oxygen from air (Bandilla, 2020; Climate & Project, 2005; Finney et al., 2019). This can be achieved through the methods of chemisorption and phase separation.

The merits and demerits of the different combustion capture methods are briefly summarized in Table 1.

Table 1. CO_2 Capture methods.

Capture methods	Merits	Demerits
Pre-combustion capture	i. The efficiency of capture is higher in comparison to post-combustion capture (Finney et al., 2019; Gazzani, Macchi, & Manzolini, 2013) ii. The technology is mature making the process easy to understand (Jansen, Gazzani, Manzolini, van Dijk, & Carbo, 2015).	i. Requires specialized plant designs (Finney et al., 2019). ii. It is very capital intensive (Bandilla, 2020).
Post-combustion capture	i. The absorbent can be regenerated and this impacts cost. ii. Existing plants can be easily retrofitted to accommodate the technology (Finney et al., 2019).	i. The high energy demands for separation makes it capital intensive to operate (Bandilla, 2020; Climate & Project, 2005). ii. The efficiency of capture is lower in comparison to the other techniques, however an exception is the CaL process (Finney et al., 2019).
Oxy-fuel combustion capture	i. The efficiency of the capture is high due to high concentration of CO_2 in the flue gas. ii. There is a possibility of obtaining a pure stream of CO_2 at conditions favourable for usage/transport (Allam et al., 2013; Boot-Handford et al., 2014; Finney et al., 2019).	i. Requires plant modification especially when chemical looping is employed. ii. The process of separation of Oxygen from air is energy intensive therefore increasing cost (Finney et al., 2019; Jansen et al., 2015).

3. PRESENT STATE OF CARBON CAPTURE STORAGE AND UTILIZATION TECHNOLOGY

The emissions from the iron and steel industries, cement industries, and the electricity generation industries accounts for about half of the global total emissions, it is therefore appropriate to site CCS facilities around them being areas of high CO_2 concentration. This is the reason for the initial research emphases on Carbon capture from sources of production like refineries, power plants, and industrial plants. However, a shift towards negative emission technologies is now trending because of former's limitations to achieving the level of GHG required to maintain average global temperature levels below the 2^{o}C mark. This is to ensure that CCS technology achieve the quad purposes of: the de-carbonization of the hard-to-abate industries, delivery of negative emissions, provision of low Carbon dispatchable energy, and low-carbon Hydrogen production at scale (Climate & Project, 2005). Existing CO_2 capture plants by location is presented in Figure 1.

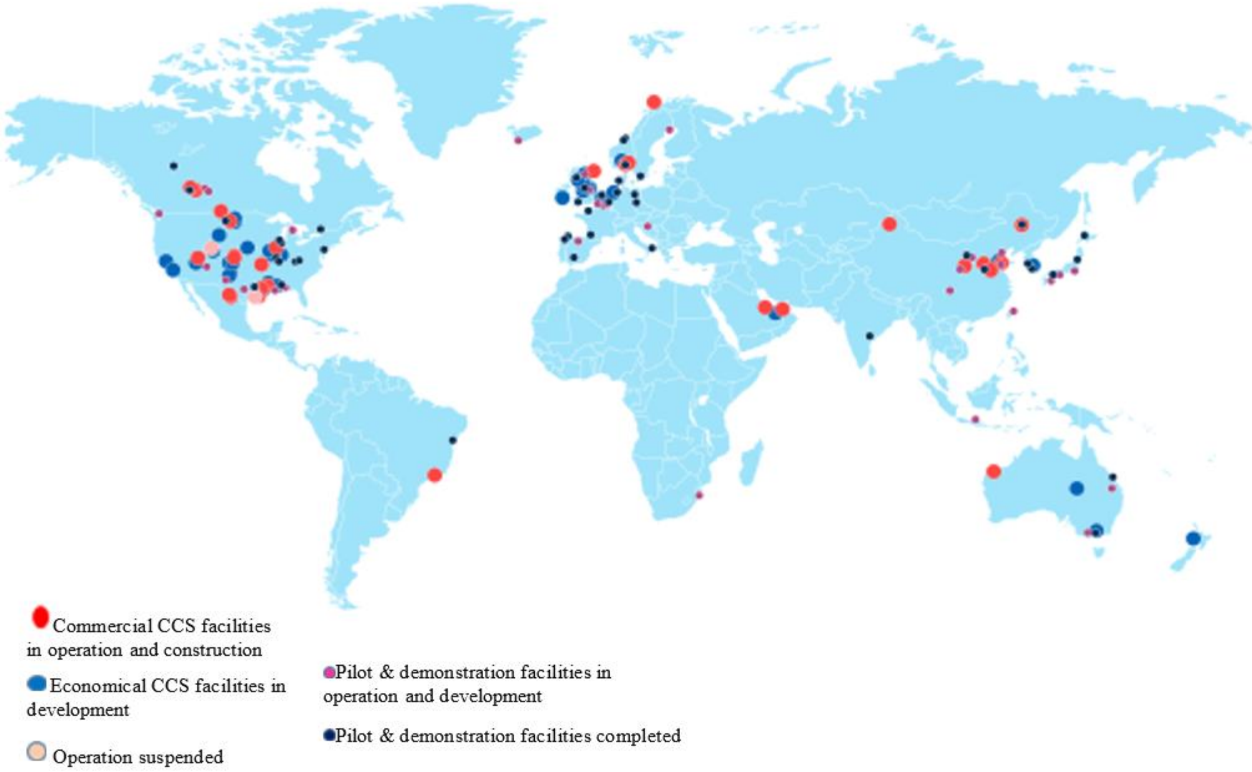

Figure 1. Global geographical distribution of CO_2 Gas capture plants.

Source: Climate and Project (2005).

Africa, South America, and the Middle East have to join the league of other continents by building CCS infrastructures and help to increase the tempo of mitigating climate change. The average amount of CO_2 captured per annum in mega tonnes for the year 2014 to 2020 based on data curated from literature (Climate & Project, 2005) is presented in Figure 2.

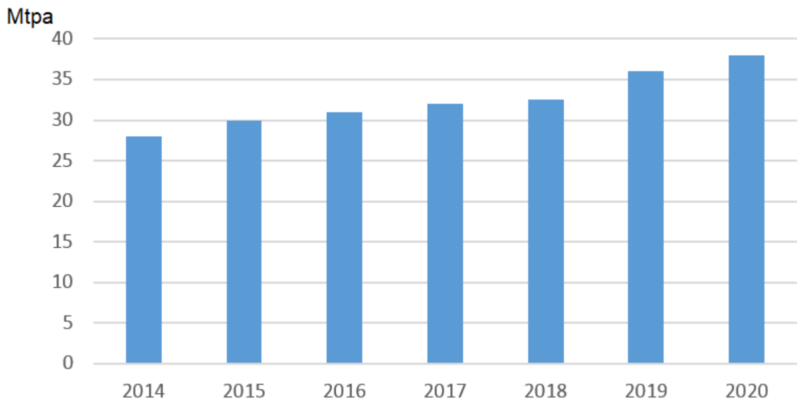

Figure 2. CO_2 Capture facilities.

The average CO_2 capture and storage capacity stands at about 40Mtpa which is lesser than the estimated CO_2 generation from the ethanol industry in the US and a far cry from the average amount of about 3.6 Gtpa needed to be taken-off the atmosphere as we draw towards 2050 (Climate & Project, 2005).

Over the past seven (7) years, the CCSU technology have been witnessing increased patronage. This is evident in a series of plants under construction that were completed and commissioned and an increase in the number of projects that are reaching advanced development stages. The recent growth in commercial CCS project can be attributed to incentives and factors; enhanced tax credits, policy support, identification of hubs and clusters, and the need to produce low-cost Hydrogen fuel (Climate & Project, 2005).

4. CARBON CAPTURE STORAGE AND UTILIZATION TECHNOLOGY PROSPECTS

Oil and Gas fields are identified storage sites for captured CO_2 because of the matured technology of Oil and Gas exploration and the proven capacity of the fields to hold CO_2 for millions of years (Climate & Project, 2005), however, their geographical distribution can be a constraint in several cases. Saline formations are more widely geographically distributed and can fill the gap; moreover, extensive studies are required to determine their CO_2 storage potential and capacity. It is a general believe that geological storage potential for CO_2 gas is sufficient to meet the global net-zero emissions requirements.

Oblivious of the fact that storage resources for captured CO_2 will not pose a major challenge, it is necessary to pay closer attention to the capturing technology while not neglecting studies on the former. Carbon IV Oxide capture can also provide a route to fossil-free fuels through its conversion to synthetic fuels and thus fit into the concept of circular economy (Li, Irtem, Iglesias van Montfort, Abdinejad, & Burdyny, 2022; Towoju, 2021). The sustenance of the tempo created from the year 2016 to 2020 for CO_2 capture projects is a hope for increased patronage of the technology. Figure 3 depicts the position of CO_2 capture facilities at early and advanced stage of development.

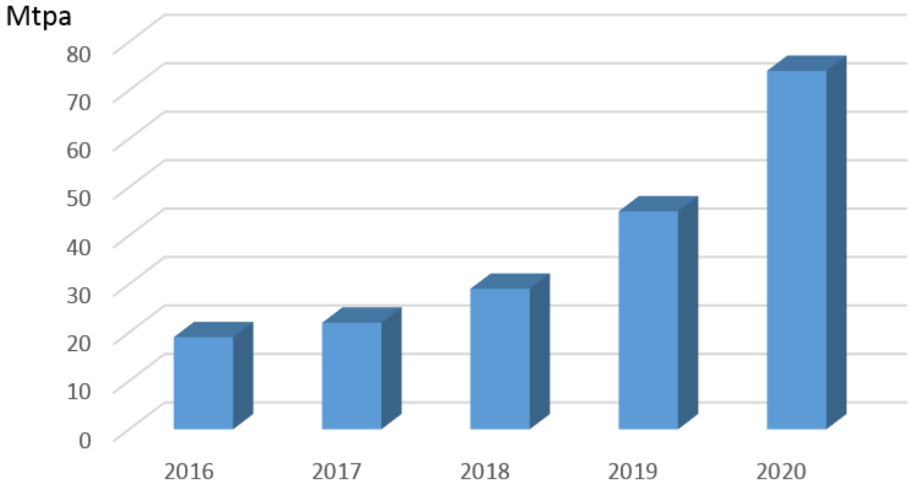

Figure 3. CO_2 Capture facilities in development.

However, sustaining this tempo is largely cost dependent, aside from the political-will and the need to mitigate climate change. The carbon circular economy seems a good incentive for the advancement of CCSU technology and mitigation of climate change as this seeks to eliminate pollution, circulate products, and regenerate nature.

Biomass with CCS referred to as Bioenergy with Carbon Capture and Storage (BECCS) is a type of negative emission technology and fits into the concept of the carbon circular economy. This can proffer a cheaper means of Carbon capture; plants are cultivated to later-on be used as a fuel whose Carbon release is then captured using the available capturing technologies. The cultivation and growth of the plants helps in capturing atmospheric CO_2 (elimination/reduction of pollution) without the requirement of any form of artificial absorbent. The biogenic CO_2 released on combustion of the bio-fuel is then captured using Carbon capture technology. The BECCS also include the waste-to-energy plants processing coupled with capturing and is a potential area for the promotion of carbon circular economy. The decay of these waste will result into the release of methane which has more potent effect on the climate that CO_2 (Mar, Unger, Walderdorff, & Butler, 2022; Towoju & Ishola, 2020).

Despite having the disadvantage of high cost attributed to the dilute nature of CO_2 gas in air which increases cost, the Direct Air Carbon Capture and Storage (DACCS) technology is now seriously been revisited as it offers the advantage of negative emissions. Although, the technology is still at infancy, it is projected that it can be used to achieve an annual amount of 980 million tonnes of CO_2 capture by 2050, however current capacity stands at 8000 tonnes with nineteen projects coming onboard since 2010 (Hanak, 2022) this seems a herculean task to achieve. The growth in the DACCS technology from 2015 to 2021 as sourced from the International Energy Agency (IEA) is presented in Figure 4.

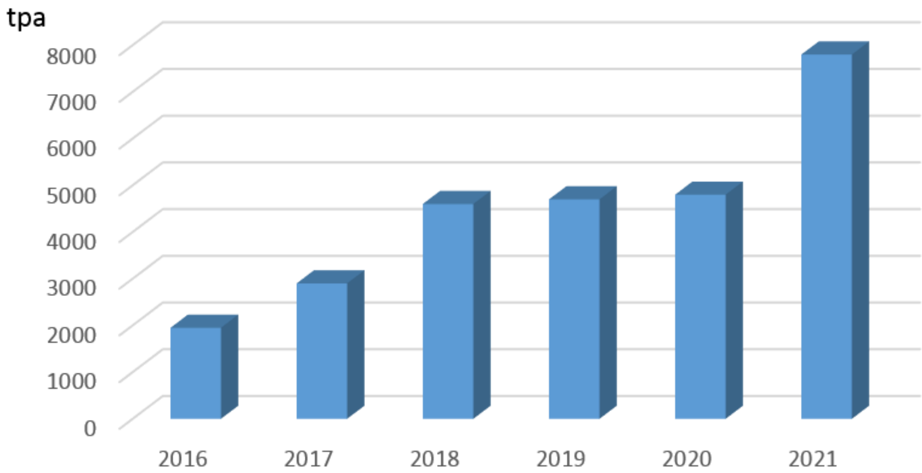

Figure 4. DACCS facilities capacity.

The high cost of deploying DACCS technology mainly dependent on the absorbents can be partly reduced by locating it near storage sites to bring down the cost of transportation and at windy areas to reduce or eliminate the cost of operating blowing fans (Li et al., 2022). These flexibilities give it an advantage over the BECCS deployment. The CCSU facilities require enormous amount of energy for their operations. The flexibility to site DACCS facilities around renewable energy sources creates a win-win solution as against powering it with fossil fuel generated energy.

The solvent-based Carbon capture technique has been available for a long time for the purification of natural gas and is now the backbone of the expanding CCSU industry (Li et al., 2022). The amine scrubbing technology offers the most practical use (Kato, Murai, Muraok, Muramatsu, & Saito, 2013), the least expensive of the commercial capturing process technologies like the alkaline capture and the solid sorbents (Li et al., 2022), and is adapted for the most advanced post-combustion capture process using the principle of temperature swing. However, this does not implies that it does not come with its challenges despite the proven technology, some of which can be upset with the use of ammonia solvent (Kim et al., 2013). The general utilized amine solvent is the Monoetholamine (MEA). The high cost involved attributed to desorption energy price in using this solvent and some other challenges has however, led to studies on other possible solvents and of interest are mixed amines. Solvents like the potassium salt of sarcosine (KSar), Piperazine (PZ), CANSOLV DC-201 developed by Cansolv technologies, "APBS" developed by Carbon clean solutions Ltd, "KS-1" by Mitsubishi, hindered amine (Amine-A), "TS-1" developed by Toshiba etc. offers better performance to the commonly used MEA (Just, 2013; Kato et al., 2013; Ma'mun & Kim, 2013). These solvents have the potentials to be the future in the CCSU facilities, however, more studies on absorption-based technology is still required. Affordable absorbents with large CO_2 adsorption capacities, long-term stability under ultra-low CO_2 concentration and humid conditions are required for DACCS applications.

The absence of large scale demonstration on the use of solid sorbents which promises to be an alternative to liquid sorbents has continue to be the bane of its acceptance. The uncertainties that surrounds its cost estimates at present is high, even for use at point sources (Lier & Rubin, 2013). An example of the results on advances on solid sorbents is the zinc-based Metal-Organic Frameworks (MOFs) developed by a research team in Canada that retains its effectiveness even at 40% relative humidity (Lopatka, 2022). Aqueous Potassium Hydroxide solution (KOH) relying on solid adsorbent properties have also been developed by Carbon Engineering for use in DAC technology.

The possibility of utilizing waste heat in CCSU plants connotes a reduction in the cost of such facilities (Kim et al., 2013) and can be an incentive for the construction of more plants. However, as stated earlier, CCSU plants built around sources of emissions alone cannot guarantee the required global atmospheric CO_2 volume. Negative emission facilities have to come to the rescue. The cost of removing a tonne of CO_2 with direct air capture technology can be as high as $600 (Hanak, 2022). It is necessary that we look into the harvesting of the huge thermal energy of the sun to provide the energy required for desorption by incorporating it into DACCS facilities. Kim et al. (2013) reported in their work that ammonia solvent utilization for Carbon capture while incorporating waste heat for heating drastically brought down its cost in comparison to the conventional amine based solvents (Kim et al., 2013). Having a cheap desorption energy source which can be harvested using solar devices can produce a huge reduction in the cost of using the DACCS plants and can be a great game changer. Desorption process accounts for eighty percent of the cost, a reduction in the cost of achieving this is a reduction in the cost of the entire process. Studies along this line needs to be seriously pursued to change the current narratives of the DACCS technology.

5. CONCLUSION

The maturity of CCSU technology is a requirement to mitigating the average global temperature increment due to greenhouse gas emissions because of the reliance on fossils and the hard-to-abate industries at least in the nearest future. The CO_2 can be removed pre-combustion, post-combustion, or through oxy-fuel combustion. While CCSU technology is now growingly applied at point source, this level of reduction is not enough to keep global temperature increase below the 1.5^{0}C level. Negative emission methods like the BECCS and DCCS need to be adopted to make this happen. The huge cost associated with the infant DACCS technology is a discouraging factor to its adoption. While it is projected that the DACCS technology can be used to achieve about 980 million tonnes of CO_2 capture annually by 2050, current figures stand at just 8000 tonnes. It is therefore, required to advance the technology of solid adsorbents which potentially promises to come cheaper and to also explore the harvesting of the thermal energy of the sun to reducing the energy cost requirement of DACCS technology.

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Authors' Contributions: Both authors contributed equally to the conception and design of the study.

REFERENCES

Allam, R. J., Palmer, M. R., Brown Jr, G. W., Fetvedt, J., Freed, D., Nomoto, H., . . . Jones Jr, C. (2013). High efficiency and low cost of electricity generation from fossil fuels while eliminating atmospheric emissions including carbon dioxide. *Energy Procedia*, *37*, 1135-1149. https://doi.org/10.1016/j.egypro.2013.05.211

Bandilla, K. W. (2020). 31 - carbon capture and storage editor(s): Trevor M. Letcher. *Future Energy (Third Edition)*, 669-692. https://doi.org/10.1016/B978-0-08-102886-5.00031-1

Boot-Handford, M. E., Abanades, J. C., Anthony, E. J., Blunt, M. J., Brandani, S., Mac Dowell, N., . . . Hallett, J. P. (2014). Carbon capture and storage update. *Energy & Environmental Science*, *7*(1), 130-189.

Breeze, P. (2016). Chapter 1 an introduction to wind power. *Wind Power Generation*, 1-8. https://doi.org/10.1016/B978-0-12-804038-6.00001-3

Climate, G. (2005). Project E. *Global Climate & Energy Project an Assessment of Carbon Capture Technology and Research Opportunities. Assessment*, 1-20.

Climate, G., & Project, E. (2005). An assessment of carbon capture technology and research opportunities. *GCEP Energy Assessment Analysis Stanford University*, 1-20.

Demirel, Y., Matzen, M., Winters, C., & Gao, X. (2015). Capturing and using CO2 as feedstock with chemical looping and hydrothermal technologies. *International Journal of Energy Research*, *39*(8), 1011-1047. https://doi.org/10.1002/er.3277

Finney, K. N., Akram, M., Diego, M. E., Yang, X., & Pourkashanian, M. (2019). Chapter 2 - Carbon capture technologies. *Bioenergy with Carbon Capture and Storage*, 15-45. https://doi.org/10.1016/B978-0-12-816229-3.00002-8

Gazzani, M., Macchi, E., & Manzolini, G. (2013). CO2 capture in natural gas combined cycle with SEWGS. Part A: Thermodynamic performances. *International Journal of Greenhouse Gas Control*, *12*, 493-501. https://doi.org/10.1016/j.ijggc.2012.06.010

Gozalpour, F., Ren, S. R., & Tohidi, B. (2005). CO2 EOR and storage in oil reservoirs. *Oil & Gas Science and Technology-Revue D Ifp Energies Nouvelles*, *60*(3), 537-546.

Hanak, D. (2022). Direct air capture: How advanced is technology to suck up carbon dioxide – and could it slow climate changes? The conversation. Retrieved from: https://www.google.com/amp/s/theconversation.com/amp/direct-air-capture-how-advanced-is-technology-to-suck-up-carbon-dioxide-and-could-it-slow-climate-change-189260.

High, M., Patzschke, C. F., Zheng, L., Zeng, D., Gavalda-Diaz, O., Ding, N., . . . Berenov, A. V. (2022). Precursor engineering of hydrotalcite-derived redox sorbents for reversible and stable thermochemical oxygen storage. *Nature Communications*, *13*(1), 1-14. https://doi.org/10.1038/s41467-022-32593-6

Jansen, D., Gazzani, M., Manzolini, G., van Dijk, E., & Carbo, M. (2015). Pre-combustion CO2 capture. *International Journal of Greenhouse Gas Control*, *100*(40), 167-187.

Jônatas da Mata, F. C., & Mesquita, A. Z., R. O. (2017). *Comparison of the performance advantages and disadvantages of nuclear power generation compared to other clean sources of electricity*. Paper presented at the 2017 International Nuclear Atlantic Conference – INAC.

Just, P.-E. (2013). Advances in the development of CO2 capture solvents. *Energy Procedia*, *100*(37), 314-324. https://doi.org/10.1016/j.egypro.2013.05.117

Kato, Y., Murai, S., Muraok, D., Muramatsu, T., & Saito, S. (2013). Evaluation of carbon dioxide absorption by amine based absorbent. *Energy Procedia*, *100*(37), 325-330. https://doi.org/10.1016/j.egypro.2013.05.118

Keith, D. W. (2009). Why capture CO2 from the atmosphere? *Science*, *325*(5948), 1654-1655.

Kim, J. Y., Han, K., Ahn, C. K., Lee, M. S., Rhee, C. H., & Chun, H. D. (2013). Operating cost for CO2 capture process using aqueous Ammonia. *Energy Procedia*, *100*(37), 677-682. https://doi.org/10.1016/j.egypro.2013.05.156

Leeson, D., Mac Dowell, N., Shah, N., Petit, C., & Fennell, P. S. A. (2017). Techno-economic analysis and systematic review of carbon capture and storage (CCS) applied to the Iron and steel cement oil refining and pulp and paper industries as well as other high purity sources. *International Journal of Greenhouse Gas Control*, *61*, 71-84. https://doi.org/10.1016/j.ijggc.2017.03.020

Li, M., Irtem, E., Iglesias van Montfort, H.-P., Abdinejad, M., & Burdyny, T. (2022). Energy comparison of sequential and integrated CO2 capture and electrochemical conversion. *Nature Communications*, *13*(1), 1-11. https://doi.org/10.26434/chemrxiv-2021-33k4d-v2

Liang, Z. H., Rongwong, W., Liu, H., Fu, K., Gao, H., Cao, F., . . . Sumon, K. (2015). Recent progress and new developments in post-combustion carbon-capture technology with amine based solvents. *International Journal of Greenhouse Gas Control*, *100*(40), 26-54.

Lier, J. C., & Rubin, E. S. (2013). Assessment of solid sorbents as a competitive postcombustion CO2 capture technology. *Energy Procedia*, *37*, 65-72. https://doi.org/10.1016/j.egypro.2013.05.086

Lopatka, A. (2022). Solid sorbent captures carbon. *Research and Technology - Physics Today*(1), 207. https://doi.org/10.1063/pt.6.1.20220207a

Ma'mun, S., & Kim, I. (2013). Selection and characterization of phase-change solvent for carbon dioxide capture: Precipitating system. *Energy Procedia*, *100*(37), 331-339. https://doi.org/10.1016/j.egypro.2013.05.119

Mar, K. A., Unger, C., Walderdorff, L., & Butler, T. (2022). Beyond CO2 equivalence: The impacts of methane on climate, ecosystems, and health. *Environmental Science and Policy*, *134*, 127-136. https://doi.org/10.1016/j.envsci.2022.03.027

Olatunji, O. O., Ishola, F. A., Ayo, O. O., Towoju, O. A., & Akinlabi, S. A. A. (2019). Perspective towards sustainable global nuclear security and safety. *International Journal of Scientific & Technology Research*, *8*(2), 92 – 96.

Pioro, I., & Duffey, R. (2015). Nuclear power as a basis for future electricity generation. *Journal of Nuclear Engineering and Radiation Science*, *1*(1), 1-19. https://doi.org/10.1115/1.4029420

Singh, J., & Dhar, D. W. (2019). Overview of carbon capture technology: Microalgal biorefinery concept and state-of-the-art. *Frontiers in Marine Science (Web)*, *6*, 29. https://doi.org/10.3389/fmars.2019.00029

Towoju, O. A. (2021). Carbon footprint reduction with the adoption of the electricity-powered vehicles. *International Energy Journal*, *21*(1), 101-106.

Towoju, O. A. (2021). Fuels for automobiles: The sustainable future. *Journal of Energy Research and Reviews*, *7*(3), 8-13. https://doi.org/10.9734/jenrr/2021/v7i330191

Towoju, O. A. (2022). Impact of adopting diesel-CNG dual-fuel engine on haulage. *International Journal of Sustainable Energy and Environmental Research*, *11*(1), 37-42. https://doi.org/10.18488/13.v11i1.2996

Towoju, O. A. (2022). Residues to energy: A study of improving the renewable energy mix in Nigeria. *Journal of Energy Research and Review*, *10*(1), 47-56. https://doi.org/10.9734/jenrr/2022/v10i130248

Towoju, O. A., & Ishola, F. A. (2020). A case for the internal combustion engine powered vehicle. *Energy Reports*, *6*(2), 315-321. https://doi.org/10.1016/j.egyr.2019.11.082

Towoju, O. A., & Ishola, F. A. (2020). Pros and cons of electricity generation from different available sources. *International Review of Mechanical Engineering*, *14*(6), 374-380. https://doi.org/10.15866/ireme.v14i6.19104

Towoju, O. A., & Oladele, O. A. (2021). Electricity generation from hydro wind solar and the environment. *Engineering and Technology Journal*, *39*(9), 1392-1398. https://doi.org/10.30684/etj.v39i9.2145