ISSN: 2734-3340 Print; 2734-3359 Online
UI Journal of Civil Engineering and Technology Vol. 3, No. 2; December, 2021

Recent Advances in Carbon Capture, Utilisation and Storage

[*1]Rabiu, K. O., [1]Okedere, O. B., [1]Oyewole, K. A., [2]Adeboye, B. S. and [2]Oyelami, S.

Department of Chemical Engineering, Osun State University, Osogbo, Nigeria
Department of Mechanical Engineering, Osun State University, Osogbo, Nigeria

***Corresponding Author:** *kazeem.rabiu@uniosun.edu.ng*

ABSTRACT

Climate change problems have necessitated global efforts to minimise the concentration of atmospheric carbon-dioxide (CO_2) emission. CO_2 Capture, Utilisation and Storage (CCUS) is a method considered to mitigate the CO_2 emissions being released into the atmosphere. CO_2 emission is captured primarily from power plants, compressed and injected into geological formations for timescale. In this paper, various aspects of CCUS are explored. The article reports techniques of capturing CO_2 on large immobile sources, utilisation of the captured CO_2 to useful materials, and injection of the remaining CO_2 into the subsurface for storage.

Keywords: Climate change, CO_2 emission, subsurface, storage.

1. INTRODUCTION

Carbon-dioxide Capture, Utilisation and Storage (CCUS) is a climate change reduction techniques whereby CO_2 is captured majorly from power plants and other industrial sources such as cement and steel industries (Ayub *et al.*, 2020; Song *et al.*, 2020; Ajayi *et al.*, 2019; Bui *et al.*, 2018; Aminu *et al.*, 2017). The captured CO_2 is then injected and stored underground for a significant period of time, preventing it from reaching the atmosphere indefinitely (Song *et al.*, 2020; Rabiu *et al.*, 2017). The processes involved in CCUS is demonstrated in Figure 1. The CCUS is important to attain the negative CO_2 emissions needed for the 1.5 and 2°C climate goals (Bandilla, 2020; Bui *et al.*, 2018; Metz *et al.*, 2005). The motivation of CCUS method is to capture CO_2 before it enters the atmosphere. This will subsequently reduce the amount of CO_2 entering the atmosphere in a way to find solution to the global warming problem (Rabiu *et al.*, 2017; Bachu, 2000). Figure 2 shows the framework for CCUS (Bandilla, 2020).

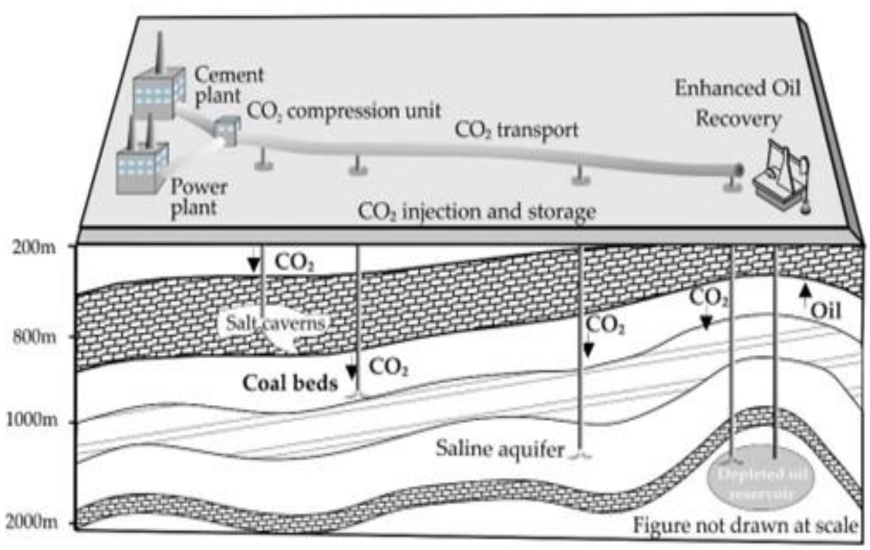

Figure 1: Processes in CCUS (Bandilla, 2020).

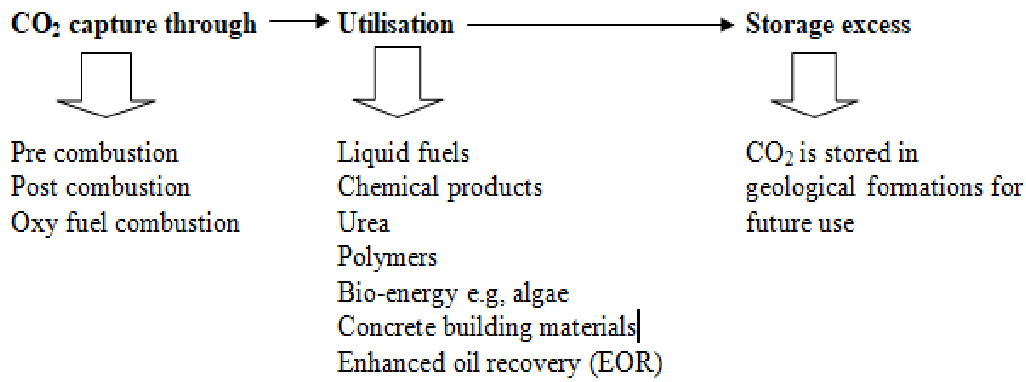

Figure 2: Framework for CCUS (Bandilla, 2020)

2. PRESENT CONDITION OF CCUS DEVELOPMENT

CO_2 capture, utilisation and sequestration is envisaged to play a vital responsibility in meeting the global warming targets set by the Intergovernmental Panel on Climate Change (IPCC) (Bui *et al*., 2018; Metz *et al*., 2005). The first step in CCUS is capturing of CO_2, followed by its transportation to storage locations and finally injected into the geological formations for timescale.

2.1 CO_2 Capture

The technologies for CO_2 capturing are available in the market but are very expensive. The cost of capturing only contributes to around 70-80% of the total cost of a full CCUS operation including capture, transport and storage**.** Hence, more research and development are required in finding the way of reducing the operating capturing costs. The CO_2 capture systems have three main technologies, namely, post-combustion, pre-combustion, and oxy-fuel combustion (Bandilla, 2020). Figure 3 shows an overview of the key capturing process technology (Metz *et al.*, 2005).

2.1.1 Post-combustion

The technology of post-combustion involves the separation of CO_2 from a flue gas or exhaust stream using solid adsorbents, and chemical solvent membranes. For capturing of CO_2 from subsisting coal fired power plants, post-combustion technology is suggested to be the most possible technique because of its "end-of-pipe" properties (Bandilla, 2020; Wang *et al*., 2017).

2.1.2 Pre-combustion

This is the process of removing CO_2 from fossil fuels before combustion is completed. The methods such as solvents, microporous solids, and membranes are used to separate CO_2 from hydrogen. The 'blue' hydrogen produced can be utilised in other processes such as power generation and ammonia production (Bandilla, 2020).

2.1.3 Oxy-fuel combustion

This is the method of burning a fuel using oxygen (O_2), or a combination of oxygen and re-circulated flue gas, in lieu of air. Oxy-fuel combustion presents some distinctive characteristics that can influence the emissions of major air pollutants, like SO_x, NO_x, fine particulate and trace metals (Bandilla, 2020).

ISSN: 2734-3340 Print; 2734-3359 Online
UI Journal of Civil Engineering and Technology Vol. 3, No. 2; December, 2021

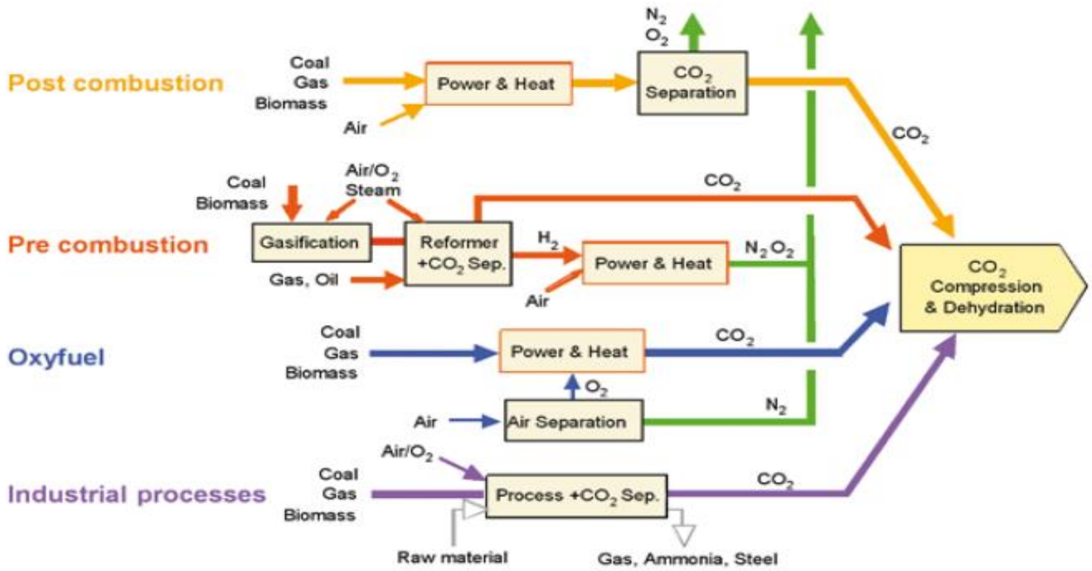

Figure 3: CO_2 Capture Processes and Systems (Metz *et al*., 2005)

2.2 CO_2 Storage Options

The storage of CO_2 is the last process of CCUS. Although, there is need to monitor the processes after storage to know if there is any complication. CO_2 can be sequestered via various trapping mechanisms such as structural, capillary, solubility and mineral trappings. The pressure and temperature of reservoir can determine the properties or phases of CO_2, for instance, CO_2 can be sequestered as gas, liquid, or in supercritical state. Nevertheless, the most economical and efficient way of storing CO_2 is in supercritical condition because considerable amount of CO_2 can be stored. For instance, sequestration of CO_2 at 31°C and 74 bar makes it denser, and consequently store significant amount of CO_2 (Ajayi *et al*., 2019). In other words, there are various types of CO_2 trapping mechanisms in which CO_2 can be stored. These trapping mechanisms can also determine the storage processes of CO_2. The trapping mechanism depends on the properties of sedimentary basin, for example, porosity, permeability, depth, interval thickness, residual water saturation and density. To choose a suitable CO_2 storage site, a thorough characterisation of the storage site must be carried out to know if it is suitable for carbon sequestration. Such characterisation can be conducted using some of the parameters pointed out in the Table 1 (Kali *et al*., 2022).

Table 1: Some of the parameters for effective CO_2 storage

Parameters	Positive signal	Warning signal
Permeability	>300 mD	10-100 mD
Depth	1000-2500	<700 m
Porosity	Greater than 20%	Less than 10%
Density	300-1000 kg/m^3	Less than 300 km
Internal thickness	Greater than 50m	Less than 20 m

Source: Kali *et al*., 2022; Rabiu *et al*., 2017

2.2.1 Geological storage

Geological storage is the process of injecting captured CO_2 from power plant/industrial processes into sedimentary basins, and subsequently removing it permanently from the atmosphere (Ajayi *et al*., 2019; Abidoye *et al*., 2015; De Silva *et al*., 2015). These formations must have some characteristics to be suitable for CO_2 storage. For example, it must be overlain by caprock i.e., impermeable formations to prevent the upward migration or leakage of CO_2. Also, the storage formation should have sufficient permeability and porosity to hold significant amounts of CO_2 (Bui *et al.*, 2018; Rabiu *et al.*, 2017; Bachu, 2000). Some of the examples of geological formations are shown in the Figure 4 and discussed in the following section.

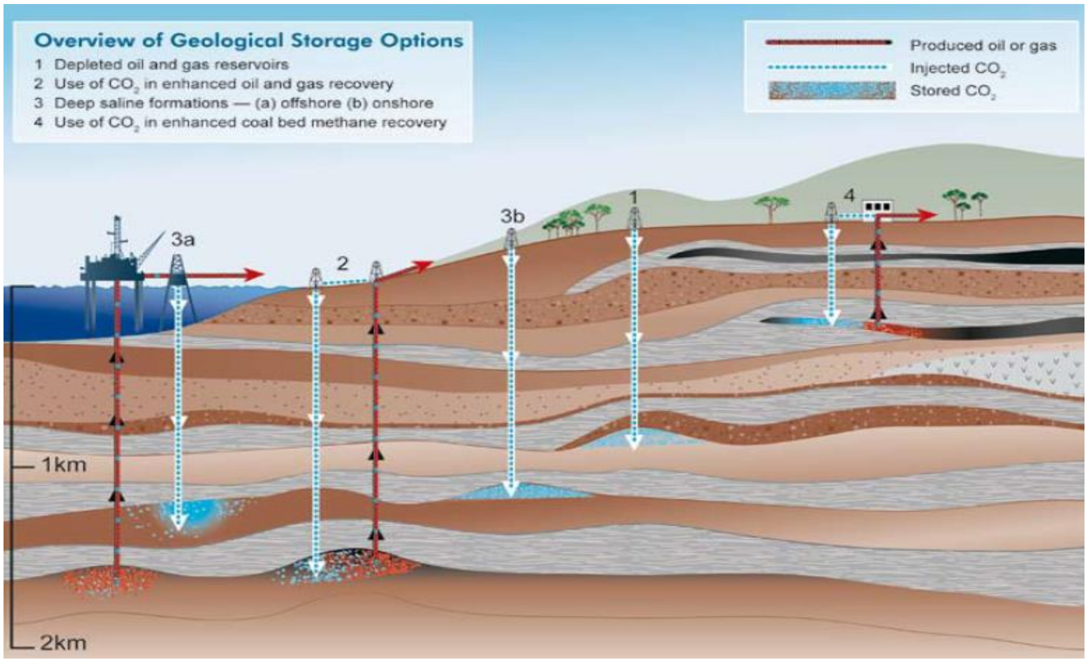

Figure 4: Various Methods for CO_2 Storage in Subsurface (Aminu *et al.*, 2017)

Saline aquifer

CO_2 sequestration in saline aquifers has been suggested as one of the most viable technologies. It is widely available worldwide and provides the largest potential storage volume. Table 2 shows the global potential CO_2 sequestration capacities (Ajayi *et al.*, 2019; Aminu *et al.*, 2017; De Silva *et al.*, 2015; Leung *et al.*, 2014; Bachu, 2000). Saline aquifers provide huge storage possibility in terms of volume for CO_2 sequestration, but they are much more expensive and difficult to characterize than hydrocarbon reservoirs because of the lack of an existing exploration data (Voormeij, 2004). Rabiu *et al*. (2017) carried out a comprehensive review on CO_2 sequestration in geological deep saline aquifers and concluded that CO_2 storage in deep saline aquifers is practically viable, and can have insignificant negative implications on the environment. Aminu *et al*. (2017) carried out a similar study on CO_2 storage and presented similar conclusions as Rabiu *et al*. (2017). These authors also reviewed the existing monitoring and verification methods and concluded that a more sophisticated monitoring tool is required for future CO_2 geological storage (Aminu *et al*., 2017; Rabiu *et al*., 2017).

Table 2: CO_2 storage capacities worldwide

Storage Option	Capacity (Gt-CO_2)
Deep saline aquifers	1 – 50
Depleted oil and gas reservoirs	25 – 30
Unmineable coal seams	5 – 10
Ocean storage	1000 – 10,000

Source: Rabiu *et al.*, 2017

Depleted hydrocarbon reservoir

CO_2 sequestration in depleted hydrocarbon reservoir has preference over other sequestration methods because of its economic benefits i.e., it can improve oil recovery and at the same time reduce the atmospheric CO_2 through its storage underground (Aminu *et al*., 2017; Rabiu *et al*., 2017). Researches have shown that almost half of the oil left in an existing storage reservoir can be recovered through enhanced oil recovery (EOR) (Kali *et al*., 2022; Ajayi *et al*., 2019; Aminu *et al*., 2017; Li and Fang, 2014; Kim *et al*., 2013; Bachu, 2000). Injection of liquid/supercritical CO_2 have been employed in oil and gas extraction industries for decades, to improve the oil and gas productions (Aminu *et al*., 2017; Rabiu *et al*., 2017).

Ocean storage

A possible CO_2 storage method is to inject captured CO_2 into the deep ocean i.e., at depths greater than 1,000 m, where majority of it would be separated from the atmosphere for millennium. In theory, ocean bed can conveniently store all the global CO_2 emission in the atmosphere, and can still have enough capacity to store more CO_2. Hence, this method has been of interest for decades, but the technology is not stable thermodynamically. The CO_2 may leak after storage and acidify the ocean, and consequently have negative implications on marine animals. Hence, research and development in ocean storage is important for future work. Figure 5 shows some of the major methods that could be utilised in ocean storage.

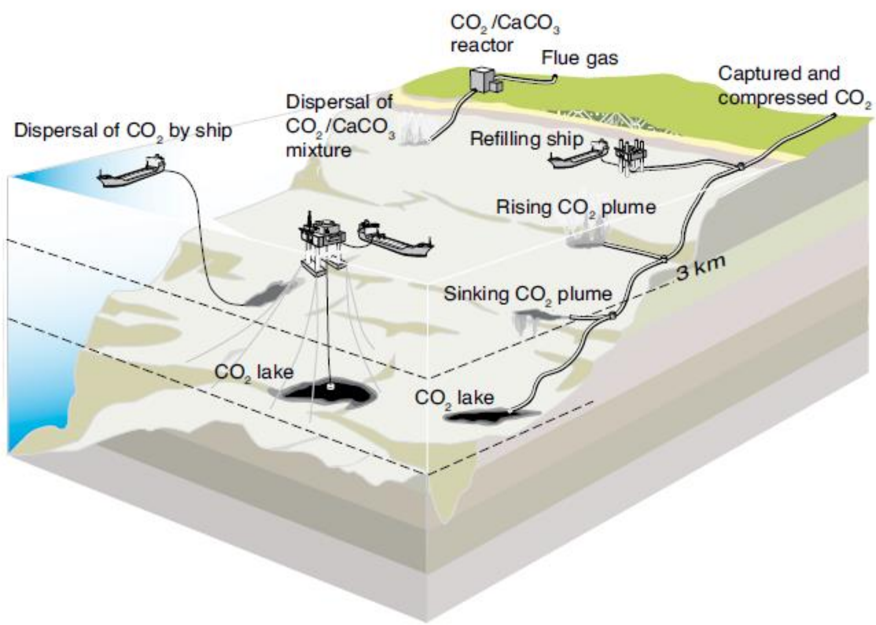

Figure 5: Ocean Storage Techniques in CCUS (Metz *et al*., 2005).

2.3 Global CO_2 Sequestration Projects

There are various on-going CCUS technology projects around the globe. Over the past two decades, many commercial and pilot plants for CO_2 storage on deep saline formations have been started. Some existing and planned projects of different scales (i.e. commercial, pilot and demonstration) can be found in the work of Metz *et al.* (2005), and are summarized in Table 3. It can be deduced that past and current projects are of small CO_2 injection capacity (less than or equal to 1.3 Mt/year), however, upcoming projects (such as the Latrobe Valley and the Gorgon projects in Australia) would have substantial CO_2 injection volume (less than or equal to 4.5 Mt/year) (Aminu *et al*., 2017).

Table 3: Existing and planned projects of CO_2 storage in geological formations

Name of project	Location	Year of commencement of the injection project
Sleipner	Norway	1996
Alberta Basin	Canada	1990
In Salah	Algeria	2004
Snovit	Norway	2008
Frio	USA	2004
Gordon	Australia	2014
MRCSP-Michigan Basin	USA	2008
MRCSP-Cincinnati Arch	USA	2009
Mountaineer	USA	2009
MGSC Decatur	USA	2010
ZeroGen	Australia	2012
Brindisi	Italy	2012
Gordon	Australia	2014
Latrobe Valley	Australia	2015
Nagaoka	Japan	2015
Edwardsport	USA	2015
San Juan Basin	USA	1996
Fenn Big Valley	Canada	1998
Recopol	Poland	2003
Yubari	Japan	2004
Hokkaido	Japan	2015
Weyburn-Midale	Canada	2000
Paradox Basin	USA	2005
Salt Creek	USA	2005
Williston Basin	USA	2011
Mongstad	Norway	2014
Trailblazer	USA	2014
Greengen	China	2015
Genesee (EPCOR)	Canada	2015

Source: Aminu *et al*., 2017; Metz *et al*., 2005

3. CO_2 UTILISATION OPTIONS

The CO_2 captured from various emission points have some applications. It can be used for EOR, i.e., the injection of CO_2 into depleted oil and gas reservoirs can be used to recover more oil from the abandon reservoirs. The technology for EOR is very popular in the USA, accounting for over 60% of total US crude oil production (Metz *et al*., 2005; Rabiu *et al*., 2017). Moreover, various chemicals (i.e., methane, ethylene, and formic acid), polymer, fertilizer, foams and fuels can be produced from CO_2. In other words, CO_2 can be used in preservative, packaging, drug, and decaffeination process (Rabiu *et al*., 2017; Metz *et al*., 2005). Also, the CO_2 carbonation processes that take place during mineralisation can be used in the cement production. Hence, research and development in carbonation process is required because the activity is very slow.

4. CONCLUSION

Carbon capture, utilisation and sequestration method is a vital climate change reduction process. This article reported the state-of-the-art developments in CO_2 capture, utilisation, and storage and discusses major problems that required solutions. The technologies for CO_2 capturing are available in the market but are very expensive, however, research and development are on-going to overcome this menace. On one hand, saline aquifers have a potential to store a significant amount of CO_2, though, saline aquifers are complex and very costly to characterize in comparison to oil and gas reservoirs. This can be attributed to the lack of an existing exploration data. Furthermore, captured CO_2 can be utilised for enhanced oil recovery and for the production of various chemicals and fuels. Conclusively, CCUS are efficient and effective method to mitigate the problem of climate change.

REFERENCES

Abidoye, L. K., Khudaida, K. J. and Das, D. B. (2015). Geological carbon sequestration in the context of two-phase flow in porous media: A review. *Critical Reviews in Environmental Science and Technology*, 45(11): 1105–1147. https://doi.org/10.1080/10643389.2014.924184

Ajayi, T., Gomes, J. S. and Bera, A. (2019). A review of CO_2 storage in geological formations emphasizing modeling, monitoring and capacity estimation approaches. *Petroleum Science*, 16(5): 1028–1063. https://doi.org/10.1007/s12182-019-0340-8

Aminu, M. D., Nabavi, S. A., Rochelle, C. A. and Manovic, V. (2017). A review of developments in carbon dioxide storage. *Applied Energy*, 208: 1389–1419. https://doi.org/10.1016/j.apenergy.2017.09.015

Ayub, S. A., Tsegab, H., Rahmani, O. and Beiranvand P. A. (2020). Potential for CO_2 mineral carbonation in the paleogene segamat basalt of Malaysia. *Minerals*, 10(12): 1-14. https://doi.org/10.3390/min10121045

Bachu, S. (2000). Sequestration of CO_2 in geological media: Criteria and approach for site selection in response to climate change. *Energy Conversion*, 18: 953–970.

Bachu, S. (2008). CO_2 storage in geological media: Role, means, status and barriers to deployment. *Progress in Energy and Combustion Science*, 34(2): 254–273. https://doi.org/10.1016/j.pecs.2007.10.001

Bandilla, K. W. (2020). Carbon Capture and Storage. In *Future Energy* (pp. 669–692). Elsevier. https://doi.org/10.1016/B978-0-08-102886-5.00031-1

Bui, M., Adjiman, C. S., Bardow, A., Anthony, E. J., Boston, A., Brown, S., Fennell, P. S., Fuss, S., Galindo, A., Hackett, L. A., Hallett, J. P., Herzog, H. J., Jackson, G., Kemper, J., Krevor, S., Maitland, G. C., Matuszewski, M., Metcalfe, I. S., Petit, C., … Mac Dowell, N. (2018). Carbon capture and storage (CCS): The way forward. *Energy and Environmental Science*, 11(5): 1062–1176. https://doi.org/10.1039/C7EE02342A

De Silva, G. P. D., Ranjith, P. G. and Perera, M. S. A. (2015). Geochemical aspects of CO_2 sequestration in deep saline aquifers: A review. *Fuel*, 155: 128–143. https://doi.org/10.1016/j.fuel.2015.03.045

Fang, Z. and Li, X. (2014). A preliminary evaluation of carbon dioxide storage capacity in unmineable coalbeds in China. *Acta Geotechnica*, 9(1): 109–114. https://doi.org/10.1007/s11440-013-0228-5

Kim, J., Nam, M. J. and Matsuoka, T. (2013). Estimation of CO_2 saturation during both CO_2 drainage and imbibition processes based on both seismic velocity and electrical resistivity measurements. *Geophysical Journal International*, 195(1): 292–300. https://doi.org/10.1093/gji/ggt232

Leung, D. Y. C., Caramanna, G. and Maroto-Valer, M. M. (2014). An overview of current status of carbon dioxide capture and storage technologies. *Renewable and Sustainable Energy Reviews*, 39: 426–443. https://doi.org/10.1016/j.rser.2014.07.093

Li, X. and Fang, Z. M. (2014). Current status and technical challenges of CO_2 storage in coal seams and enhanced coalbed methane recovery: An overview. *International Journal of Coal Science and Technology*, 1(1): 93–102. https://doi.org/10.1007/s40789-014-0002-9

Matter, J. M. and Kelemen, P. B. (2009). Permanent storage of carbon dioxide in geological reservoirs by mineral carbonation. *Nature Geoscience*, 2(12): 837–841. https://doi.org/10.1038/ngeo683

Metz, B., Davidson, O., Coninck, H., Loos, M. and Meyer, L. (2005). IPCC special report on carbon dioxide capture and storage, Intergovernmental Panel on Climate Change, Geneva (Switzerland). Working Group III. Cambridge University Press. https://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf [Accessed 31 March 2022].

Rabiu, K. O., Abidoye, L. K. and Das, D. B. (2020). Physico-chemical and dielectric parameters for the monitoring of carbon sequestration in basalt and silica media. *Environmental Technology and Innovation*, 20: 101052. https://doi.org/10.1016/j.eti.2020.101052

Rabiu, K. O., Han, L. and Bhusan Das, D. (2017). CO_2 Trapping in the Context of Geological Carbon Sequestration. In *Encyclopedia of Sustainable Technologies* (pp. 461–475). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.10124-1

Song, Y., Sung, W., Jang, Y. and Jung, W. (2020). Application of an artificial neural network in predicting the effectiveness of trapping mechanisms on CO_2 sequestration in saline aquifers. *International Journal of Greenhouse Gas Control*, 98: 103042. https://doi.org/10.1016/j.ijggc.2020.103042

Kali, R. F., Fan, D., Hazel, N. and Striolo, A. (2022). Techno-socio-economic analysis of geological carbon sequestration opportunities. *Environmental Science: Advances*, 1-18, 10.1039.D1VA00036E. https://doi.org/10.1039/D1VA00036E

Voormeij, D. A. (2004). Geological, ocean, and mineral CO_2 sequestration options: a technical review. *Geoscience canada*, 31(1): 11-22.

Wang, Y., Zhao, L., Otto, A., Robinius, M. and Stolten, D. (2017). A Review of post-combustion CO_2 capture technologies from coal-fired power plants. *Energy Procedia*, 114: 650–665. https://doi.org/10.1016/j.egypro.2017.03.1209