**Truth and False-Carbon Dioxide Mitigation Technologies**

**Muhammad Imran Rashid1,2\***

1Department of Chemical, Polymer and Composite Materials Engineering, University of Engineering and Technology, Lahore (New Campus), 39021, Pakistan

2Discipline of Chemical Engineering, University of Newcastle, NSW 2308, Australia

\*Corresponding author: muhammadimran.rashid@uon.edu.au

**Abstract**

Research progress is required to be enhanced for those storage technologies which store CO2 fast and permanently. However, temporary storage technologies importance cannot be denied to immediately reduce global warming and reduce higher CO2 concentration in the atmosphere. Continuous CO2 storage facilities, semi-batch and batch pilot plants deemed necessary to build for future survival of the earth planet. Membranes can be used to separate CO2 from common flue gases followed by mineral carbonation to convert CO2 into stable carbonates. Modifications in cement industry, coal fired power plants, fertilizer industries and other chemical process industries appears essential.

**Keywords:** carbon dioxide storage technologies, membranes and mineral carbonation, carbon

dioxide conversion to urea, carbon dioxide conversion to chemicals and biochemicals,

mineral carbonation, Polymeric Materials

**INTRODUCTION**

Extreme weather patterns, recent floods especially in Europe, Antarctica glaciers melting and appearance of new lakes, extreme temperatures (54 °C, Middle East), thousands of deaths in Karachi (Pakistan) due to heat waves are as result of increased CO2 emissions. It is reported that greenhouse gas emissions can be reduced using mineralization, geological storage, chemical production and oceanic storage and other storage technologies. It is required that all CO2 storage technologies to be compared tentatively to sort out the best option regarding permanent storage, temporary storage and how fast or slow storage is occurring. Membranes are commonly used for different gases separation. CO2 separated from common flue gases through membranes can be easily converted in stable carbonates using mineral carbonation. Various CO2 utilization options and there interlink with industry is discussed in this communication.

1. **Couple membranes and mineral carbonation**

Various types for membranes can be employed for CO2 separation from common flue gases. This separated CO2 can be converted into stable mineral carbonates (MgCO3, CaCO3, FeCO3 etc) using aqueous mineral carbonation with various rocks (dunite) and minerals (olivine, lizardite, antigorite) (Figure 1). This CO2 separation using membranes followed by its fixation may contribute a lot in future research.



Figure 1. Use membranes for CO2 separation from common flue gases followed by mineral carbonation to convert CO2 into stable mineral carbonates

1. **CO2 Conversion to Urea**

Worldwide CO2 is being converted into urea whose estimation is difficult, but it may be the best choice to do. Following reactions are being used to convert CO2 into Urea in fertilizer industries [[1](#_ENREF_1)].

CO2+2NH3=NH4COOHNH2

NH4COOHNH2=NH2CONH2+H2O

Overall reaction

CO2+2NH3=NH2CONH2+H2O

Urea is produced through reaction of CO2 and ammonia which results in carbamate formation. Carbamate decompose into urea. This seems an appropriate choice as urea is being consumed by the plants. This is the best and permanent storage and at large scale.

1. **SOx capture at coal fired power plants**

SOx emissions can be reduced through coal fired power plants which is one of the major cause of acid rain. SOx emissions are also important as CO2 emissions. However, for energy generation, CO2 emissions are greater as compared to CO, NOx, SO2, particulates, formaldehyde and mercury. Natural gas is a better fuel to reduce NOx emissions as it produce 20% less NOx as compared to coal and oil.

1. **CO2 conversion to carbonates**

CO2 can be converted into various (MgCO3, CaCO3, FeCO3 etc) stable mineral carbonates. Peridotites and serpentinites reserves are available worldwide. Mineral carbonation is an emerging technology. Direct carbonation is better compared to indirect carbonation. Direct carbonation especially using aqueous solution is preferable. Julcour et.al performed fundamental research on concurrent grinding [[2](#_ENREF_2)]. Concurrent grinding has shown promising results for dunite [[3](#_ENREF_3)], heat-activated lizardite [[4](#_ENREF_4)] and olivine. Six times higher yields were observed with dunite which is an alternative feedstock. Zirconia media is best among different medias tested so far. However, various other grinding medias are required to be tested. Heat-activated dunite, heat-activated lizardite and other rocks and minerals need to be tested using concurrent grinding. Coupling heat-activation and concurrent grinding for various peridotites and serpentinites may provide the best optimum conditions viable for sustainable development. Concurrent grinding is yet not explored during carbonation of industrial wastes (steel slags, fly ash etc). Silanol nests formation mechanism need to be explored as their formation retard higher yields. Regrinding also slightly increase yields or Mg extractions but still not comparable with concurrent grinding. Undesirable side reactions also consume amorphous materials and retard higher yields and affect process efficiency. Mineral carbonation feed and especially by-products can be used in cement manufacture. This will offset the mineral carbonation process cost and also provide a solution to waste disposal. Further research is required to explore various other mineral carbonation by-products and find why raw lizardite is not as effective as heat-activated lizardite. Acid treated silica-enriched residue has better pozzolanic activity compared to mostly used silica fume [[5](#_ENREF_5)]. Pilot scale experiments have confirmed that yield results does not significantly differ compared to laboratory scale results proving that this mineral carbonation technology can be extended to a commercial scale continuous process industry. However, for serpentinites it has been observed that heat-activation is a necessary step as intermediate Mg-silicate phases I and II were more reactive [[6](#_ENREF_6)].

1. **CO2 utilization by microalgae**

Microalgae consume CO2. It has been reported that different types of microalgae growth parameters increased with increased percentage of CO2 [[7](#_ENREF_7)]. Biomass produced from microalgae can again be utilized for combustion process. Microalgae are more effective compared to terrestrial plants [[8](#_ENREF_8)]. Plants hemicellulose can be converted into chemicals using a bioprocess. Biodiesel can be produced using ethanol through microalgae impregnating [[9](#_ENREF_9)]. Increased temperature reduces production cost.

1. **Enhanced oil recovery**

CO2 is used in enhanced oil recovery but its not a permanent storage. However, its trapped temporarily but leakage chance exists. Excessive CO2 from gas treating facilities can be supplied to fertilizer industries for urea production or for use in other industries but not related to food production.

1. **Geological CO2 storage**

Definitely CO2 is stored in geological storage, but chances exist for leakage. However, its importance cannot be denied regarding immediate reduction of CO2 emissions. Safety risk assessments and future utilization of escaped CO2 are required to be sorted out. An erupted lake in Africa released CO2 which killed thousands of people.

1. **CO2 to chemicals**

CO2 can be converted into following chemicals (Table 1) [[10](#_ENREF_10)]. Urea production is the highest among all chemicals. Converting CO2 into chemicals is a permanent storage.

Table 1. List of chemicals produced by CO2 conversion

|  |  |  |
| --- | --- | --- |
| Urea | Ethylene Carbonate | Salicylic Acid |
| Methanol  | Di-methyl Carbonate | Cyclic Carbonates |
| Formaldehyde | Copolymers | Fine Chemicals |
| Formic Acid | Polymer Building Blocks | Other new chemicals |

1. **CO2 conversion to biochemicals**

CO2 can be converted into different biochemicals such as glucose, methane, methanol, oxygenates, synthetic fuels and carbon monoxide. However, this is a slow process and enzymes are required for CO2 fixation.

1. **CO2 storage in Trees/Plants**

Worldwide estimation of trees and plants may not be possible, however they consume CO2 through a photosynthesis process. This is a fast and permanent storage. Plants and trees plantation is required to be significantly increased worldwide. Plantation in deserts and bare lands requires significant attention.

1. **CO2 capture through brick kilns**

Brick kilns also significantly emit CO2 and particulate matter. Scrubbers can be used to separate particulate matter while different amines can capture flue gas emissions from chimney stacks. Worldwide measures of such sort can significantly reduce greenhouse gas emissions and lead towards sustainable development. Trees and plants surrounding the brick kilns will be significantly affected from this pollution [[11](#_ENREF_11)].

1. **CO2 storage in polymers**

CO2 is also consumed during polymerization reactions. CO2 is also consumed during plastic manufacturing. Various polymeric materials including organic polymers can store CO2 through absorption and adsorption methods [[12](#_ENREF_12), [13](#_ENREF_13)]. This research area is required to be more progressing.

1. **Oceanic CO2 storage**

Oceanic storage is difficult and may pose threat to aquatic life and disturb ecological system. CO2 escape is easy in oceanic storage but it may be considered as last option. However, vast number of oceans are available worldwide. In case of water shortage, oceanic water may be the last choice.

1. **CO2 reduction via photoelectric catalysts**

This research area is significantly considerable. Various catalysts and plasma technologies are being used to enhance this process [[14](#_ENREF_14), [15](#_ENREF_15)].

1. **CO2 separation, reduction and reuse from cement industry**

Ninety wt% CO2 separation and reduction is possible through various proposed modifications and other released CO2 after passing through scrubbers and more treatments can be sent to fertilizer industries where urea manufacturing is possible using this carbon dioxide. Using compressors, this CO2 can be injected into the process lines feeding CO2 to urea units. Either way, it’s a CO2 reduction and fixation.

**Conclusions and recommendations**

Converting CO2 into urea is the best choice. Plants consume urea and CO2 is fixed permanently. SOx emissions can be reduced through coal fired power plants to avoid acid rain. Natural gas is preferable fuel compared to coal and oil. Mineral carbonation fix CO2 into stable carbonates. Concurrent grinding proved good for dunite, heat-activated lizardite and olivine. Different uninvestigated grinding medias need to be explored. Industrial wastes are required to be tested using concurrent grinding. Microalgae consume CO2 and produced biomass can be reused for combustion after drying. CO2 used for enhanced oil recovery may not be called a permanent storage. Trapped CO2 can be supplied to fertilizer industry after minimal treatment. CO2 leakage chance exist in geological storage. CO2 can be converted into various chemicals and biochemicals. Membranes can be used for CO2 separation from common flue gases followed by mineral carbonation to convert CO2 into stable carbonates. CO2 storage in trees and plants is fast and permanent. Amines can be used to capture CO2 from brick kilns. Various polymer materials also absorb and adsorb CO2. Oceanic CO2 storage may pose threat to aquatic life and disturb ecological system. CO2 reduction via photoelectric catalysts is also important. CO2 from cement industry can be used for urea production after minimal treatment.

**References**

[1] M.I. Rashid, N. Ramzan. Fluid Mechanics and Heat-Transfer Operations Combination Involved in Urea Unit of Fertilizer Complex, Non-Metallic Material Science 1(1) (2019) 5-10.

[2] C. Julcour, F. Bourgeois, B. Bonfils, I. Benhamed, F. Guyot, F. Bodénan, C. Petiot, É. Gaucher, Development of an attrition-leaching hybrid process for direct aqueous mineral carbonation, Chemical Engineering Journal 262 (2015) 716-726.

[3] M.I. Rashid, E. Benhelal, F. Farhang, T.K. Oliver, M.S. Rayson, G.F. Brent, M. Stockenhuber, E.M. Kennedy, Development of Concurrent grinding for application in aqueous mineral carbonation, Journal of Cleaner Production 212 (2019) 151-161.

[4] M.I. Rashid, E. Benhelal, F. Farhang, T.K. Oliver, M. Stockenhuber, E.M. Kennedy, Application of a concurrent grinding technique for two-stage aqueous mineral carbonation, Journal of CO2 Utilization 42 (2020) 101347.

[5] E. Benhelal, M.I. Rashid, M.S. Rayson, T.K. Oliver, G. Brent, M. Stockenhuber, E.M. Kennedy, “ACEME”: Synthesis and characterization of reactive silica residues from two stage mineral carbonation Process, Environmental Progress & Sustainable Energy 38(3) (2019) e13066.

[6] Emad Benhelal, J. Hook, Guangyu Zhao, Muhammad Imran Rashid, Tim Oliver, Mark Rayson, Geoff Brent, Michael Stockenhuber, Eric Kennedy, Insights into chemical stability of Mg-silicates and silica in aqueous systems using 25Mg and 29Si solid-state MAS NMR spectroscopy: Applications for CO2 capture and utilisation, Chemical Engineering Journal (2020).

[7] E. Aghaalipour, A. Akbulut, G. Güllü, Carbon dioxide capture with microalgae species in continuous gas-supplied closed cultivation systems, Biochemical Engineering Journal 163 (2020) 107741.

[8] D. Tang, W. Han, P. Li, X. Miao, J. Zhong, CO2 biofixation and fatty acid composition of Scenedesmus obliquus and Chlorella pyrenoidosa in response to different CO2 levels, Bioresource Technology 102(3) (2011) 3071-3076.

[9] A. Jafari, F. Esmaeilzadeh, D. Mowla, E. Sadatshojaei, S. Heidari, D.A. Wood, New insights to direct conversion of wet microalgae impregnated with ethanol to biodiesel exploiting extraction with supercritical carbon dioxide, Fuel 285 (2021) 119199.

[10] E. Alper, O. Yuksel Orhan, CO2 utilization: Developments in conversion processes, Petroleum 3(1) (2017) 109-126.

[11] K. Achakzai, S. Khalid, M. Adrees, A. Bibi, S. Ali, R. Nawaz, M. Rizwan, Air pollution tolerance index of plants around brick kilns in Rawalpindi, Pakistan, Journal of Environmental Management 190 (2017) 252-258.

[12] A. Sattari, A. Ramazani, H. Aghahosseini, M.K. Aroua, The application of polymer containing materials in CO2 capturing via absorption and adsorption methods, Journal of CO2 Utilization 48 (2021) 101526.

[13] H. M. Safaa, A.S. Hameed, E. Yousif, M. H. Alotaibi,, M.H. Alotaibi, D.S. Ahmed, G.A. El-Hiti, New Porous Silicon-Containing Organic Polymers: Synthesis and Carbon Dioxide Uptake, Processes 8 (2020).

[14] Ni, Z. L. Liang, Yi, Z., R. Guo, C. Liu, Y. Liu, H. Sun, X. Liu, Research progress of electrochemical CO2 reduction for copper-based catalysts to multicarbon products, Coordination Chemistry Reviews 441 (2021) 213983.

[15] C. Xu, X. Zhang, M.-N. Zhu, L. Zhang, P.-F. Sui, R. Feng, Y. Zhang, J.-L. Luo, Accelerating photoelectric CO2 conversion with a photothermal wavelength-dependent plasmonic local field, Applied Catalysis B: Environmental 298 (2021) 120533.