Permanent sequestration of CO_2 in industrial wastes

The report from the Carbon Dioxide Capture and Conversion (CO2CC) Program gives an overview of the potential for capturing and converting CO_2 into valuable products using different kinds of wastes or byproducts from industrial processes.

The report, “Permanent sequestration of CO_2 in industrial wastes/byproducts” looks at the economic feasibility, technical performance and life cycle of various processes for mineral carbonation (MC) and assesses the industrial applications of CO_2 capture using solid wastes as a feedstock.

It then outlines the main challenges for MC research and development, such as increasing the CO_2 uptake and decreasing the energy requirements and cost, and how the processes could be scaled up to meet the requirements of CO_2 reduction for climate goals.

First an overview of the technology is presented discussing the fundamental principles of mineral carbonation from natural processes to engineering systems. The report then introduces the use of industrial wastes/byproducts as a viable and effective feedstock for the mineral carbonation process.

A detailed techno-economic analysis of numerous carbonation techniques that use a variety of industrial wastes then assesses each in terms of their technical performance, economic feasibility, and life cycle. The report concludes with a presentation and discussion of current and potential industrial applications of CO_2 sequestration using solid wastes.

Key takeaways from the report

- Life cycle assessment of steel slag in the US showed that it can sequester 7.5 million tons of CO_2 annually of which 7 million tons are from direct CO_2 capture from the mineralization process and 0.5 million tons from the avoided emissions by using the MC products
- Although studies on life cycle assessments of solid waste utilization are rather limited and often restricted to case studies on a specific waste, all assessments seem to confirm the economic feasibility and profitability of utilizing solid wastes for MC
- Despite the growing interest in MC, most recent studies are still in the bench scale stage and only a few studies have evaluated industrial demonstration units of MC process using industrial wastes
- This could be attributed to the limited research funding for pilot scale applications as well as lack of regulatory policies for the application of the solid products
- It could also be attributed to the fact that experts often discuss carbon capture and sequestration in terms of geological storage, which pushes CO_2 mineralization to the margins making it less likely to be included in policymaking
- In general, the main challenges for MC research and development are increasing the CO_2 uptake and decreasing the energy requirements and cost
- This can be addressed through effective optimization of the process by identifying the most influential parameters that can mainly affect the overall efficiency
- Hence, taking a holistic approach towards the MC process optimization can be very insightful and set the future direction for MC research
- In addition, more studies on lifecycle and technoeconomic assessments are needed to pave the way for technically and economically viable large-scale applications

Overview of mineral carbonation

MC is a process that involves the reaction of CO_2 with alkaline compounds such as calcium and magnesium oxides and has the potential to sequester considerable amounts of CO_2 with a capacity that can be scaled to match the amount of CO_2 emissions released from several industries.

MC is also one of the most sustainable approaches for CO_2 sequestration. It ensures leakage-free fixation of carbon dioxide and generates valuable products such as calcium and magnesium carbonates, which can be used in different applications, such as adsorbent materials and cement additives.

The MC process can be carried out through direct and indirect carbonation techniques, and it is often controlled by several parameters, such as alkalinity, pretreatment method, particle size, solid to liquid ratio, temperature, and pressure. These parameters directly influence the CO_2 uptake capacity by changing the kinetics and mass transfer of the process. Different process parameters and feedstocks can lead to wide array of uptake capacities.

Alkaline solid wastes, such as steel dusts and slags, cement and construction materials waste, fly ash, and red mud can be used for mineral carbonation to permanently sequester CO_2, stabilize these solid wastes and produce valuable products. Collectively, the overall CO_2 emissions reduction potential by direct MC using industrial byproducts has been estimated to be 310 million tons globally.

Sources of industrial waste

The steel industry produces different types of wastes such as blast furnace slag and basic oxygen, electric arc and ladle furnaces waste. It is estimated that producing one ton of steel generates 250 kg of alkaline waste. Life cycle assessment of steel slag in the US showed that it can sequester 7.5 million tons of CO_2 annually.

Cement manufacturing generates between 15 to 20 tons of cement kiln dust (CKD) per 100 tons of produced cement, and the global amount of CKD generated annually is estimated to be 30 million tons. The annual production of CKD in the US is 1.67 million tons.

Mineral carbonation of fly ash can be regarded as one of the most cost-effective ways to sequester carbon dioxide, as large amounts of fly ashes are being continuously generated from the combustion of coal and oil shale power plants. Fly ashes are also generated during the incineration of municipal solid wastes. Globally, around 750-1000 million tons of fly ash is generated every year.

Red mud (RM) is another industrial waste that is often generated during the processing of bauxite into aluminum. The global reserves of bauxite, which is a sedimentary rock with very high aluminum content, are estimated to be around 55-75 billion tons. Globally, alumina production from bauxite resulted in more than 2 billion tons of RM.

Over the last few years, there has been increasing interest in studying the tailings generated during the extraction of Nickel from ores. Nickel tailings typically contain very high concentrations of magnesium oxides along with other alkaline oxides. Several studies have investigated the techno-economics of mineral carbonation of mine tailings in Canada.

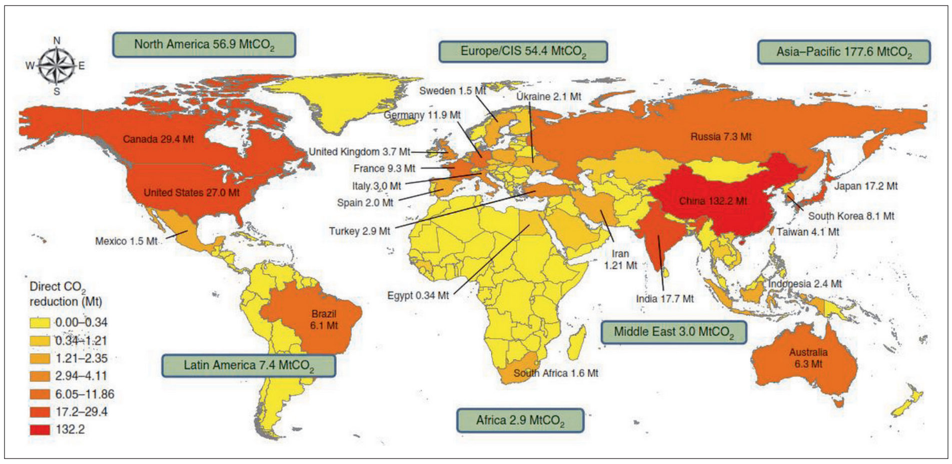

Figure 1- Estimates of the regional CO2 reduction potential using industrial alkaline waste (Pan et al., 2020)

Conclusions

The area of industrial waste mineral carbonation is rapidly evolving and expanding in different directions depending on the type of the waste and the process, but only in lab or bench scale. It is worth noting that studies on life cycle assessments (LCA) of solid waste are rather limited and often restricted to case studies on a specific waste. However, all assessments seem to confirm the economic feasibility and profitability of using solid wastes for MC.

Major industrial wastes emitting industries, such as steel and cement manufacturing, have yet to get seriously involved in MC efforts at a large scale, and this can be seen in the low number of industrial and pilot scale MC implementation using the wastes.

Nonetheless, using various types of wastes can offer an attractive route for the problematic waste disposal and at the same time mitigate CO2 emissions and produce value added products.

Next articles

This is a series of articles summarising recent key reports from The Catalyst Group Resources Carbon Dioxide Capture and Conversion (CO2CC) Program. Look out for "State of the art and future prospects for catalytic and electrochemical routes to CO2 conversion" in the next issue.

More information

More information about this report and other services of the CO2CC Program can be found at:

www.catalystgrp.com/tcg-resources/member-programs/co2-capture-conversion-co2cc-program/