Assuaging Climate Change: Sequestration of Carbon Footprints into Concrete

Mohd Shoaib Ali[1], Rohit Pujara[2], Dharmendra Kushwaha[3], Peer Mohd Fazil[4]

[1]*M.Tech Scholar, Dept. of Civil Engineering, Swami Vivekananda Subharti University, U.P., India*
[2]*Assistant Professor, Dept. of Civil Engineering, Swami Vivekananda Subharti University, U.P., India*
[3]*Assistant Professor, Dept. of Civil Engineering, Swami Vivekananda Subharti University, U.P., India*
[4]*Assistant Professor, Dept. of Civil Engineering, Swami Vivekananda Subharti University, U.P., India*

---***---

Abstract - *Concrete, Its main ingredient-cement is responsible for 7% of global CO2 emission. It is the second most consumed substance on planet earth after water. Concrete is the mixture of rock, sand, water and most importantly cement to bind it altogether. But cement has a huge carbon footprint. One pound of cement releases one pound of CO2 emissions. Cement is the second highest industrial source of CO2 on the planet. What if there is a way that instead of releasing CO2, concrete could trap it forever. There is a reason concrete is everywhere, there is no material that will do the same. It provides the good fiber strength level and durability. But without cement, concrete does not hold up skyscrapers. Tank carbon cure is the newest thing in concrete. This innovative system injects carbon dioxide into the concrete as it being mixed. When concrete hardens those otherwise harmful emissions are sequestered before ever even reach our atmosphere. It converts the CO2 into a mineral, it's stone, it's getting trapped in the concrete forever. The best part of it is that the mineral itself improves the compressive strength of concrete, adding CO2 makes the concrete stronger. The procedure can use less cement than usual in a mixture and still achieve the same strength which ultimately lessens the CO2 emissions. And the compression test on this type of sample of concrete proves that the concrete made by carbon mineralization is just as hard as traditional concrete.*

Key Words: Climate Change, Global warming, CO2 sequestration, carbon mineralization, carbonation, Concrete technology, Carbon cure, sustainable construction.

1. INTRODUCTION

Today, there seems to be considerable scientific evidence that human activities may cause climate change due to the enhanced greenhouse effect. Carbon dioxide (CO2) is the primary greenhouse gas emitted by human activities. It is believed that the massive amounts of carbon dioxide released into the atmosphere have seriously aggravated greenhouse effect. Actually, the average ground temperature on earth has increased by 0.5°C in the past century [1]. The consequences of possible climate change include e.g. melting of polar ice caps and glaciers, a sea level rise, mainly due to thermal expansion of the ocean water, and increased extreme weather events - IPCC, 2001[2]. Carbon dioxide is by far the largest contributor to the assumed enhanced greenhouse effect among the various greenhouse gases, such as CO2, CH4, N2O, and halocarbons. The Carbon dioxide emissions due to human activities are mainly caused by the use of fossil fuels for energy supply. Concrete is the most abundant artificial material on earth, but the production of its main ingredient, cement, unfortunately has a huge carbon footprint about one ton of carbon dioxide per ton cement. Cement functions as a glue to hold the other ingredients of concrete together. To make cement, calcium carbonate also known as limestone, is heated, which releases massive amounts of CO2 into atmosphere. Cement is responsible for 7% of global greenhouse emissions, the second largest industrial source [3]. Another major contributor to global warming is the emissions of power plants. This is why several teams of scientists are trying to reduce both of those factors by making concrete and cement out of carbon dioxide emissions.

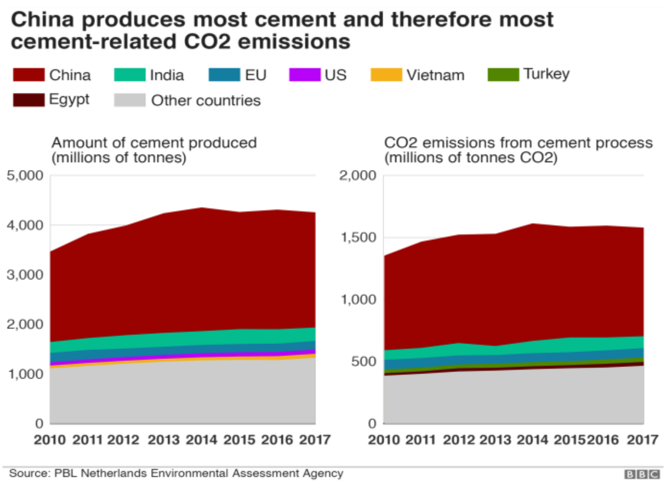

Figure – 1: Cement production & CO2 emissions

An international team of climate scientists recently pointed out, the sooner the better, because the task of reducing greenhouse gases will only become larger and more daunting the longer we delay. Carbon Cure came up with a method to trap CO2 emission forever, while also reducing the need for cement to make strong concrete. The system takes captured CO2 and injects it into concrete during the mixing phase. The carbon dioxide reacts with the concrete, turning into a mineral. When the concrete hardens, the carbon is sequestered forever, even if the building is torn down. The main advantage of this method is of course that since the CO2 is trapped, it can't be released into the atmosphere, adding to global warming. In addition, the carbon makes the concrete stronger, reducing the need for cement.

1.1 Emissions Reduction Approaches

The global annual emission of CO2 was about 23.5 Gigaton CO2/yr in 2000 – IPCC IPCC (Intergovernmental Panel on Climate Change), 2005. The concentration of CO2 in the atmosphere has increased progressively since the beginning of the Industrial Age by about 30% from 280 (1750) to 367 ppm (1999) – 2001 [2]. In order to prevent a major climate change, the atmospheric CO2 concentration should be stabilized by either increasing the (biological) CO2 up-take from the atmosphere or reducing the CO2 emissions.

Three major approaches for reduction of CO2 emissions can be distinguished:

(1) Reduction of the energy consumption based on fossil fuels.

(2) Energy generation by non-fossil sources such as solar, wind, biomass, and nuclear energy.

(3) Carbon capture and storage (CCS). In CCS-technologies, CO2 is separated from the flue gas of a stationary CO2 source, such as a fossil fuel based power plant, and subsequently stored for long-term isolation from the atmosphere.

Back in 2008, several companies such as Calera started making cement from CO2 emissions, by turning CO2 into carbonic acid and then making carbonate. The heat of the flue gas is used to employ heat sprayers to dry the slurry that results from mixing the water and pollution, turning in a white cement-like substance, which can either be used on its own or in combination with ordinary cement. A team of researchers at the University of California, Los Angeles discovered a way to turn CO2 into a building material in its own right, which they – fittingly – called CO2NCRETE[10]. Combined with lime, they have managed to 3-D print small cones. The biggest challenge is to face making the building material on a larger scale [4]. German scientists from the Technical University Dresden were nominated for the Deutscher Zukunftspreis 2016 (German Future Prize) for their project C3 – Carbon Concrete Composite. This material is a corrosion-resistant and resource-conserving alternative to the conventional reinforced concrete. It is made with special concrete and carbon fibres. Around fifty thousand fibres, significantly thinner than a human hair, are woven into a yarn and processed into a coated grid structure [11]. Carbon, compared to steel, is four times lighter and has six times the bearing capacity, so the construction material can be thinner, decreasing the amount of raw materials used, as well as costs in production, transport, and installation. It would seem that there is a bright future for construction materials made with carbon dioxide. This is good news for the environment, of course – so let's keep building a cleaner world.

1.2 Reduction in CO_2 emissions during COVID-19

Global carbon dioxide emissions could fall by up to 7% this year, depending on ongoing restrictions and social distancing measures during the Coronavirus pandemic. The study, by a group of scientists from institutions in Europe, the United States and Australia, analyzed daily CO2 emissions across 69 countries, 50 U.S. states, 30 Chinese provinces, six economic sectors, and three levels of confinement, using data from daily electricity use and mobility tracking services. In 2019, the world emitted around 100 million tonnes of carbon dioxide per day by burning fossil fuels and cement production. In early April 2020, emissions fell to 83 million tonnes per day, a drop of 17%, and some countries' emissions dropped by as much as 26% on average during the peak of the confinement. If pre-pandemic conditions return by mid-June, then 2020 emissions could decline by 4% compared to 2019 but if restrictions remain worldwide until the end of the year, then emissions could drop by 7%. This would be the largest single annual decrease in absolute emissions since the end of World War II [9].

Abbreviations:

IPCC – Intergovernmental Panel on Climate Change
IEA – International Energy Agency
GHG – Green House Gas
CCS – Carbon Capture and Storage
CCU – Carbon Capture and Utilization

2. METHODS

The procedure used to explore the research question from the perspective of climate change mitigation is predominately through a literature review of both qualitative and quantitative aspects of CO2 sequestration into concrete.

2.1 CO2 mineralization

The CO2-Concrete technology turns carbon dioxide emissions into CO2-Concrete products that can replace traditional concrete, with a much lower CO2 footprint. The technology is based on the concept of "CO2 mineralization" – the conversion of gaseous CO2 into solid mineral carbonates (e.g. CaCO3) within the Concrete products. CO2 mineralization also known as carbonation, is one of the Carbon Capture & Utilization (CCU) technologies [5]. Let's discover how it transforms the climate change molecule CO2 into valuable products for the construction industry.

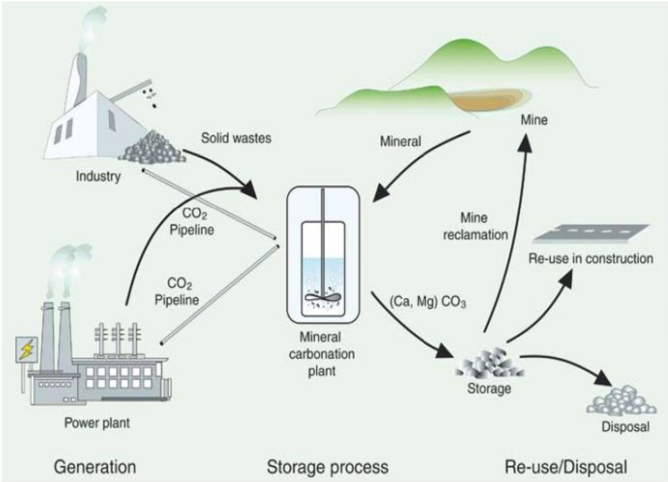

Figure – 2: Mineralization Process

Carbonation is a natural phenomenon, where Ca (calcium) or Mg (magnesium) containing minerals react with carbon dioxide (CO2) to produce calcium or magnesium carbonate (CaCO3 or MgCO3), also known as limestone or dolomite, one of the most abundant rock types formed throughout the 4000 million year history of the Earth. This natural carbonation reaction, which happens in nature over thousands of years, can be purposefully accelerated to take only a few minutes in anthropogenic manufacturing processes (accelerated carbonation) by using high CO2 concentrations and optimized reaction conditions [6].

CaO (s) + CO2 (g) → CaCO3 (s) (ΔH = -179 kJ/mol) (eq 1)

MgO (s) + CO2 (g) → MgCO3 (s) (ΔH = -118 kJ/mol) (eq2)

The reaction is exothermic, meaning that it releases energy as heat and leads to the creation of stable products in which the CO2 is permanently captured. Over the last 15 years, novel industrial processes have been developed to use CO2 as an input in the manufacture of products which meet the technical requirements of the building sector. Unlike other CCU technologies, these carbonation processes do not need any significant input of renewable energy [7].

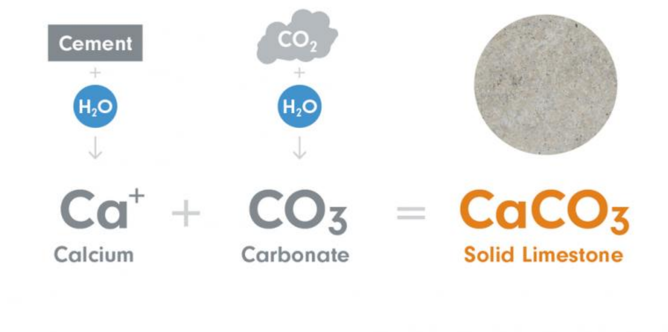

Figure – 3: Mineralization Reaction

CO2 mineralization processes fall under three main categories:

Carbonation: CO2 reacts with calcium (Ca) or magnesium (Mg) oxide to form a solid carbonated mineral. The technology is typically retrofitted onto existing industrial/power plants to capture flue gas. These carbonated products can be used in building materials, engineering fill, or specialist construction materials.

Concrete Curing: A similar process to carbonation, but with a focus on producing solid calcium carbonate ($CaCO_3$), replacing energy intensive steam concrete curing methods, resulting in an increased strength. It can also be added to concrete, ready-made concrete when it is mixed, or to precast concrete.

Novel Cements: CO2 is used as an ingredient within the cement. The CO2 is mineralized within the cement as a solid carbonate, creating a new carbon negative cement.

2.2 CO2 Sequestration

CO2 can be infused during the curing of concrete in ready-mix or precast procedures without significant changes expected to the procedure or ingredients with the impact of quickening the hydration of the concrete. Alternate methods prevail for curing of concrete with CO2 rather than water:

this requires a novel cement and special curing chambers, yet the measure of CO2 taken up in the product is higher – up to 250 kg of CO2 for each tonne of cement utilized.

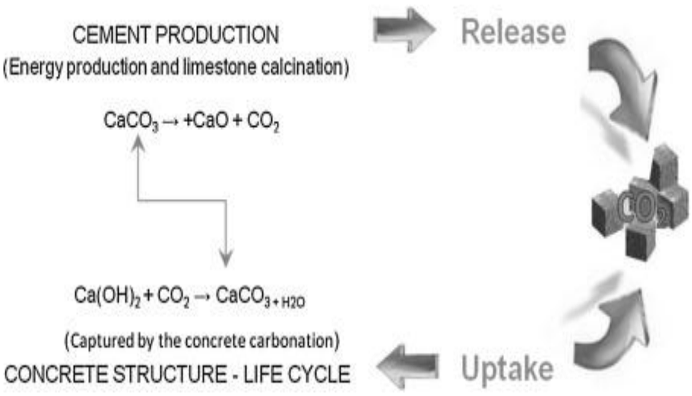

Figure – 4: Carbon Sequestration Process [8]

CO2 sequestration is one of the main alternatives that outcomes in lasting stockpiling of CO2 as a solid, with no requirement for long haul observing. The CO2 is synthetically changed into a mineral, which implies it will never be discharged into the environment as a green house gas (GHG). Other usage innovations simply defer the time that the CO2 takes to return into the environment. For instance, CO2-fuel and CO2 for use in bubbly beverages discharges the CO2 when the product is ingest.

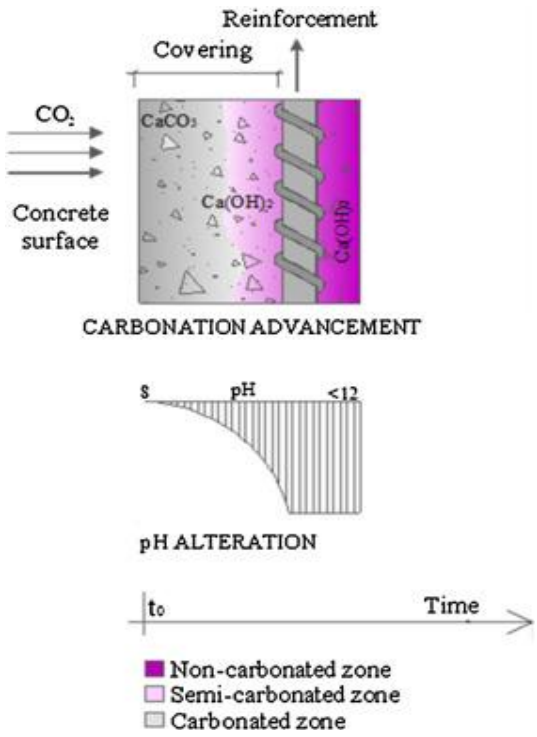

Figure – 5: Carbonation and pH Variations [8]

When carbon dioxide is absorbed into concrete many chemical reactions take place. These usually result in a lowering of the pH in the portion of the concrete where significant amounts of carbon dioxide have been absorbed. The pH is a measure of how acidic (low pH) or basic (high pH) a solution is. Some reinforcing materials in contact with concrete that has a lower pH are not as well protected from corrosion as these materials in contact with concrete that has a higher pH. Carbon dioxide slowly absorbs into a concrete structure from the source of the carbon dioxide and the depth at which this absorption has resulted in a significant pH change is usually referred to as the carbonation front. Usually applications with reinforcing material which might be affected by a change in pH are designed so that the carbonation front does not reach these materials over its intended life. The carbonation front will move more quickly with adequate levels of moisture, higher porosity, and higher ambient CO2 levels, and with certain concrete mixes. Therefore we assume that applications with similar conditions will have absorbed more carbon dioxide than other applications in a shorter period of time. However, throughout a concrete structure there is some carbon dioxide absorption, usually more near the CO2 sources, and less in interior regions.

3. RESULTS AND DISCUSSIONS

Every cubic yards of concrete saves an average of 25 pounds CO2 emissions from entering the atmosphere. Speaking to the possibility to spare around 27 million pounds of trapped CO2 from the concrete produced. A normal elevated structure spares approx. 1.5 million pounds CO2 emissions which are proportionate to the carbon consumed by 888 acres of forest in a year. The total human-induced Green House Gas (GHG) emission is about 49.5 Gigatonnes of CO2 equivalent per year [12]. If we able to reduce 5% of the carbon footprints of the concrete industry that's a significant change. By implementing the procedure of sequestration of carbon dioxide into concrete across the globe we could reduce about 700 mega tones of CO2 every year and it's the same as taking 150 million cars off the road every year. Every inch of concrete is infused with CO2 in 48 thousand cubic yards of a 12 storey 200 million dollar development at Atlanta, U.S. In this project alone 1.5 million pounds of CO2 is infused. If we can pretend that theses were trees it would be the same as 800 acres of forest sequestering CO2 for a year. It is the largest structure carbon cure has ever worked on. It has been able to prevent 10 million pounds of CO2 emissions since installing carbon cure technology at 23 plants. If deployed to its full potential anthropogenic carbonation could lead to a net reduction of global CO2 emissions estimated at around 250-500 Megatonnes/year in 2030.

The amelioration in energy efficiency and modifications to concrete, the average CO2 concentration of cement production has declined by 18% globally in the course of two decades. A 25% of the total CO2 sequestration required for climate change mitigation is expected to result from carbon capture and storage.

Table -1: Reduction in CO2 emissions

Carbon capture & storage	*95-100%*
Novel cements	*90-100%*
Clinker substitutions	*70-90%*
Alternative fuels	*40%*
Energy efficiency	*4-8%*

Several researches have been developed in order to estimate the amount of carbon dioxide reabsorbed by concrete, whose answers point out to different results. In Norway, Jacobsen and Jahren estimated that 16 % of CO2 emissions in cement production are reabsorbed by concrete due to carbonation during its life cycle [13]. Garda reports 7.6 % and Naik and Kumar 19% [14-15]. In Denmark, for 100 years of perspective considering a demolition of a structure, carbonation concrete uptake corresponds to 57 % of CO2 emissions in cement production. If structure demolition is not considered, this value is reduced to 24 % [16]. In a similar study, Dodoo et al. calculated a 45-percent rate considering building demolition [17]. And these differences recorded in literature are due the influence of several factors in concrete carbonation (such as strength, exposure environment, cement content and type, time of a structure, etc.) and depends on what king of methodology has been employed.

Quantification of CO2 Uptake The CO2 contents of the carbonated products were quantified considering the change in mass of the sample before and after carbonation. CO2 uptake estimated by mass gain (Eq. 1) is determined by considering the initial mass, the final carbonated mass (including the lost water) and the original mass of the dry binder: dry binder dry binder [18].

$$Mass\ gain\ (\%) = \frac{(Mass_{after\ co_2} + Water_{lost}) - Mass_{before\ co_2}}{\text{Mass dry binder}} = \frac{\Delta Mass}{Mass_{dry\ binder}}$$

"It's almost impossible that we would hit 2°C, and even less so 1.5°C, without some sort of negative emissions technology," said Pete Smith, chair in plant and soil science at the University of Aberdeen and one of the world's leaders in climate change mitigation. In fact, scientists from around the world who recently drew up a road map to a future that gives us good odds of keeping warming below the 2ºC threshold lean heavily on reducing carbon emissions by completely phasing out fossil fuels—but also require that we actively remove CO2 from the atmosphere. Their scheme calls for sequestering 0.61 metric Giga tonnes of CO2 per year by 2030, 5.51 by 2050, and 17.72 by 2100. The global average amount of carbon dioxide hit a new record high in 2018: 407.4 parts per million [19].

Negative emissions Under the 2015 Paris Agreement on climate change, nearly 200 countries agreed to limit warming to "well below" 2°C above pre-industrial levels and to aim for no more than 1.5°C [20]. Maintaining balance between greenhouse gas emissions and sinks in the second half of the century is equivalent to reaching global net-zero emissions. A few appraisals propose as much as 5 billion tonnes of CO2 would need to be expelled from the environment, and afterward trapped underground, every year by 2050 Direct air capture and storage can possibly trap 3 to 16 Giga tonnes CO2/year.

In a recent perspective for Science magazine, Prof Chris Field, a former co-chair of the Intergovernmental Panel on Climate Change's (IPCC), and Dr Katharine Mach, director of the Stanford Environment Facility, wrote: "Engineered, nonbiological approaches to negative emissions, such as enhanced weathering and direct air capture are energy-intensive and expensive but may eventually provide useful options for CO2 removal at scale." A report from IEA and the industry led Cement Sustainability Initiative notes that the industry, in its current form, is inconsistent with trajectories that would allow the world to meet a 2-degree Celsius temperature target. Reaching this goal, the report suggests, "implies significantly greater efforts to reduce emissions from cement makers." "Today's society would not have been possible without concrete," said Robert Courland, author of the book Concrete Planet.

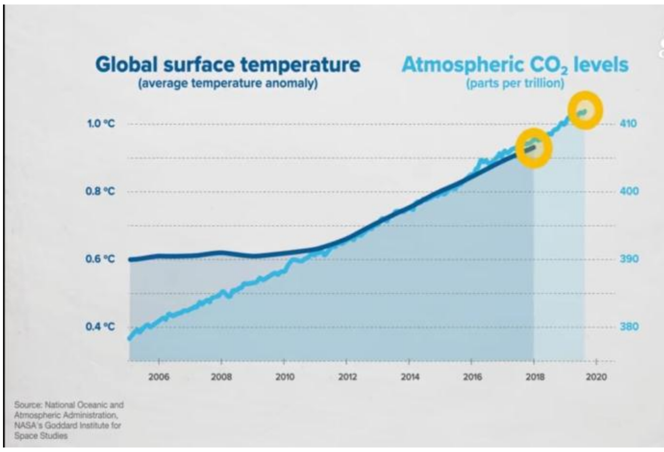

Figure – 6: Global Warming – CO2 Emissions

It is estimated that the global warming is currently increasing at 0.2°C per decade due to past and ongoing emissions, according to the IPCC report. The Earth's average temperature data showed a warming of 0.85°C over the period 1880 to 2012. It was 0.87°C for the decade 2006-2015. Most of the warming occurred in the past 35 years, with 16 of the 17 warmest years on record occurring since 2001. The planet's average temperature has risen about 1.1°C since the late 19th century, according to analyses by scientists at NASA's Goddard Institute for Space Studies. The world has seen the consequences of this 1°C rise in temperature through more extreme weather, rising sea levels and diminishing Arctic sea ice, among other changes in the last few years [21].

Some companies are taking on the rest of the equation by pursuing technologies to mitigate the climate change that can capture the carbon dioxide resulting from concrete production : *LafargeHolcim, the multinational construction materials manufacturer*, in July 2019 launched a project to capture and reuse CO2 from a cement plant and is expected to replace 50 percent of fossil fuel usage and reduce emissions by 20% [22].

Christie Gamble, CarbonCure's director of sustainability, says that if the technology were to be adopted universally, it could lock away 700 million tonnes of CO2 every year. One 12-story building recently completed in Atlanta, made with CarbonCure treated concrete, contains 1.5 million pounds of sequestered CO2[22].

Solidia claims its process has the potential to "eliminate at least 1.5 GT of CO2, save 3 trillion liters of fresh water, reduce energy consumption by as much as 260 million barrels of oil." When that cement is used to make concrete, it is cured using carbon dioxide instead of water and absorbs up to 70 percent of that CO2. Not only does the process save on water—which is also a selling point in arid regions—but the curing process is complete in just 24 hours [22].

Finally, Blue Planet of Los Gatos, Calif., has developed a process that converts flue gas into a solid carbonate coating that is then applied to small pebbles (made from upcycled demolition debris). The resulting synthetic limestone is 44 percent carbon dioxide by mass. Because these pebbles themselves are carbon negative, adding them to concrete can offset the CO2 emitted by other parts of the concrete manufacturing process. Depending on other factors, concrete using those pebbles as aggregate can be net carbon neutral or even carbon negative [22].

4. CONCLUSIONS

If the cement industry were a country, it would be the third largest emitter in the world - behind China and the US. It contributes more CO2 than aviation fuel (2.5%) and is not far behind the global agriculture business (12%). concrete's ingestion potential infers that there might be approaches producing concrete carbon negative. If cement production facilities were completely equipped with carbon capture and storage technology, for example, at that point a significant measure of the emissions delivered nearby could be halted from entering the atmosphere. Afterward, the produced concrete would absorb significantly more carbon dioxide, which could in the long run add up to a net drawdown from the environment. Also, to assess lower-hazard and higher-chance pathways so we have to make a portfolio of solutions, as opposed to only one that fits explicit things.

The Intergovernmental Panel on Climate Change - the leading international body on global warming argued that the global average temperature rise needed to be kept below 1.5C - not 2C as noted in the Paris Agreement. This means CO2 emissions need to decline by 45% from 2010 levels by 2030.

REFERENCES:

[1] Tai, C.Y., Chen, W.R. and Shih, S.M., 2006. Factors affecting wollastonite carbonation under CO2 supercritical conditions. AIChE journal, 52(1), pp.292-299.

[2] https://www.ipcc.ch/site/assets/uploads/2018/03/ipcc_far_wg_I_full_report.pdf

[3] Benhelal, E., Zahedi, G., Shamsaei, E. and Bahadori, A., 2013. Global strategies and potentials to curb CO2 emissions in cement industry. Journal of cleaner production, 51, pp.142-161.

[4] https://materialdistrict.com/article/building-cleaner-world-co2-based-cement-concrete/

[5] Kelemen, P.B. and Matter, J., 2008. In situ carbonation of peridotite for CO2 storage. Proceedings of the National Academy of Sciences, 105(45), pp.17295-17300.

[6] Bertos, M.F., Simons, S.J.R., Hills, C.D. and Carey, P.J., 2004. A review of accelerated carbonation technology in the treatment of cement-based materials and sequestration of CO2. Journal of hazardous materials, 112(3), pp.193-205.

[7] Abanades, J.C., Rubin, E.S., Mazzotti, M. and Herzog, H.J., 2017. On the climate change mitigation potential of CO 2 conversion to fuels. Energy & Environmental Science, 10(12), pp.2491-2499.

[8] Possan, E., Thomaz, W.A., Aleandri, G.A., Felix, E.F. and dos Santos, A.C., 2017. CO2 uptake potential due to concrete carbonation: A case study. Case Studies in Construction Materials, 6, pp.147-161.

[9] Le Quéré, C., Jackson, R.B., Jones, M.W., Smith, A.J., Abernethy, S., Andrew, R.M., De-Gol, A.J., Willis, D.R., Shan, Y., Canadell, J.G. and Friedlingstein, P., 2020. Temporary reduction in daily global CO 2 emissions during the COVID-19 forced confinement. Nature Climate Change, pp.1-7.

[10] Linden, L.Z., 2017. Energy Analysis For Producing Low Carbon-footprint Cementitious Building Material (Doctoral dissertation, UCLA).

[11] Haentzsche, E., Frauendorf, M., Nocke, A., Cherif, C., Reichardt, M., Butler, M. and Mechtcherine, V., 2018. Multifunctional components from carbon concrete composite C3–integrated, textile-based sensor solutions for in situ structural monitoring of adaptive building envelopes. Textile Research Journal, 88(23), pp.2699-2711.

[12] Nasigri, M., 2015. Carbon Stock Under Four Different Land-Use Systems In The Savanna Ecosystems, In Ghana (Doctoral dissertation).

[13] Jacobsen, S. and Jahren, P., 2002, November. Binding of CO2 by carbonation of Norwegian OPC concrete. In CANMET/ACI international conference on sustainability and concrete technology, Lyon.

[14] Gajda, J., 2001. Absorption of atmospheric carbon dioxide by portland cement concrete. Portland Cement Association.

[15] Naik, T.R. and Kumar, R., 2010. Global warming and cement-based materials. UWM Center for By-Products Utilization.

[16] Pade, C. and Guimaraes, M., 2007. The CO2 uptake of concrete in a 100 year perspective. Cement and concrete research, 37(9), pp.1348-1356.

[17] Dodoo, A., Gustavsson, L. and Sathre, R., 2009. Carbon implications of end-of-life management of building materials. Resources, Conservation and Recycling, 53(5), pp.276-286.

[18] Shao, Y., Monkman, S. and Boyd, A.J., 2010. Recycling carbon dioxide into concrete: a feasibility study. In ProceedingS of the 2010 Concrete Sustainability Conference.

[19] https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

[20] Rhodes, C.J., 2016. The 2015 Paris climate change conference: COP21. Science progress, 99(1), pp.97-104.

[21] https://economictimes.indiatimes.com/news/environment/global-warming/how-rise-in-earths-average-global-temperature-is-affecting-our-planet/articleshow/72039042.cms?from=mdr

[22] Siegel, R.P., 2020. Cutting the Carbon from Concrete. Mechanical Engineering, 142(02), pp.38-43.