ISSN: 2639-7455

Research Article

Earth & Environmental Science Research & Reviews

Energy-neutral and socially inclusive abstraction of atmospheric CO_2

Claudio Vita-Finzi[1] John Marshall[2]

SETI Institute 339 Bernardo Ave Mountain View CA 94043 USA.

***Corresponding author:**
Claudio Vita-Finzi, SETI Institute 339 Bernardo Ave Mountain View CA 94043 USA.

Submitted: 2023, Apr 13; **Accepted**: 2023, May 18; **Published**: 2023, May 31

Citation: Vita-Finzi, C., Marshall, J. (2023). Energy-Neutral and Socially Inclusive abstraction of atmospheric CO_2. *Eart & Envi Scie Res & Rev, 6*(3), 481-486.

Abstract

A scheme is outlined for combating the overheated greenhouse effect by complementing measures to reduce CO_2 generation by extracting CO_2 at source and from the atmosphere. The gas is absorbed in sodium hydroxide (NaOH), as in many similar systems, but the process is powered by natural wind or solar pumps, the resulting Na_2CO_3 and $NaHCO_3$ are marketed, and fresh NaOH is generated mainly by electrodialysis of waste brine from solar desalination plants. The scheme could run at two main scales: domestic and industrial. The former requires integration into the social fabric, as has been waste recycling in the UK, the low CO_2 extraction throughput to be compensated by the deployment of many millions of domestic units. The second scale is exemplified by CO_2 traps mounted at favourable elevation, notably on some of the 350,000 major wind turbines operating worldwide. Atmospheric decarbonation would be complemented by CO_2 trapping at its source, whether major, such as power stations, or minor but numerous, such as vehicles powered by fossil fuels.

1. Text

The direct abstraction of atmospheric carbon dioxide (DAC) is the obvious route to tackling excessive levels of CO_2 while trapping CO_2 at source as well as reducing its generation would preempt further carbon overload [1]. The adoption of both measures hinges on social approval as much as on technical validity. The overriding rationale is to act gradually and in good time [2]. DAC would enable us to trap CO_2 which is being contributed currently to the atmosphere at dispersed and mobile sources, including livestock, land vehicles and shipping, as well as at stationary point-sources such as power stations and industrial plants. The International Energy Agency estimates that ~60% of CO_2 emissions come from such dispersed sources [3]. The fact that CO_2 concentration is very variable over time and around the globe (Figure 1) argues for a wide network of trapping stations. DAC is hampered by the fact that the atmospheric content of carbon dioxide is currently a mere 0.04% of the total volume compared with up to 12-15% in flue gases, so that 300 times as much air needs to be processed in order to extract the same amount of CO_2 as for the flue gases of a conventional power plant, equivalent to 3 million m^3 of air per ton of CO_2 removed [4].

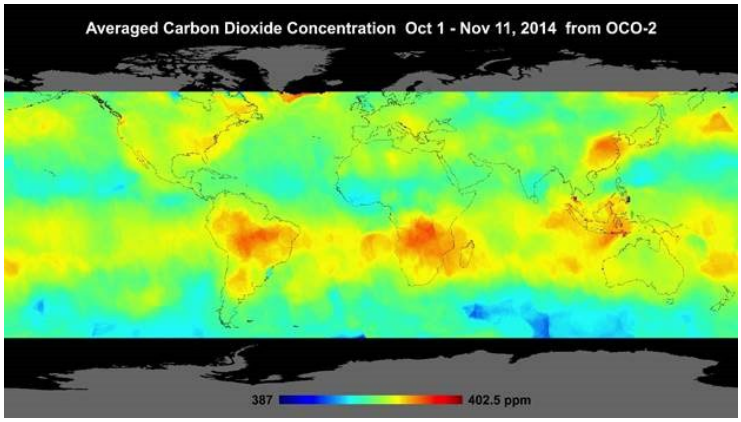

Figure 1: Atmospheric CO_2 concentration Oct 1-Nov 11 2014 (387-402.5 ppm) recorded by NASA's Orbiting Carbon Observatory-2. Credit: NASA-JPL-Caltech.

To be sure, DAC is routinely performed by various kinds of plant life, phytoplankton and rock weathering. The planting of trees has long been viewed as the ideal solution to excess CO_2 in its being on the whole aesthetically acceptable as well as usually natural. Their efficacy, like that of marine kelp and other organic sumps, is variable, but from an ecologist's viewpoint overwhelmingly benign. Oceans and lakes dissolve and store CO_2 even though their capacity has only recently been found limited and not always stable, with attempts to enhance it by biological or mineralogical stratagems found unconvincing if not irresponsible.

But the failure of artificial DAC to take off since it was first mooted doubtless owes something to apathy fuelled by widespread hostility to any kind of large-scale tampering with nature. And poor strategy has much to answer for. The great majority of DAC proposals undermined their case by including in the package recovery of the CO_2 and perhaps also of some of the reagents used in the trapping [5]. In its review of CO_2 capture technology the Intergovernmental Panel on Climate Change (IPCC) asserts that the purpose of CO_2 capture is to produce a concentrated stream that can be readily transported to a CO_2 storage site [6]. A committee set up by the American Physical Society found that direct CO_2 capture and storage by chemicals was not 'an economically viable approach to mitigating climate change' [7]. The US National Academies felt that 'cost and lack of technical maturity are factors limiting the deployment of carbon dioxide removal strategies for helping to reduce atmospheric CO_2 levels' and that such strategies in the future could at best form 'part of a portfolio of responses for mitigating climate warming and ocean acidification' [8].

2. Effective DAC

Of the numerous stratagems for removing post-combustion CO_2 there is substantial support for trapping in ethanolamine (= monoethanolamine, MEA). MEA has been mooted for CO_2 capture on a global scale but its potential value is outweighed by the CO_2 emitted in its manufacture and during its regeneration as well as by issues of toxicity and equipment corrosion [9]. Other amines, aqueous ammonia, sodium carbonate-bicarbonate slurry, and amino acids are among the alternative agents that have been considered [10, 11]. Lithium hydroxide (LiOH) is the alkali hydroxide with the lowest molecular weight (Na: 23 g/mol; Li: 7 g/mol) and is therefore used as CO_2 absorbent in space flights.

When it comes to DAC the CO_2 capture capacity of MEA drops drastically at low CO_2 partial pressures [12, 13]. Most of the CO_2 trapping systems for which accounts have been published employ wet scrubbing using sodium hydroxide (NaOH) in a spray device [14,15], in absorption columns [16], or by air flow over the chemical sorbent [17].

The main reasons for the widespread selection of sodium hydroxide (NaOH, lye, caustic soda) as absorber or trapping agent appear to be its high binding energy, low cost, and safety, although the argument tends to be obscured by an emphasis on regeneration of the absorber or the CO_2 or both [18]. In industry NaOH is usually employed as the monohydrate ($NaOH \cdot H_2O$). Its manufacture from waste brine resulting from desalination of seawater is of interest in the present context when the requisite reverse osmosis is solar-powered as energy is a major item in the production of caustic soda by the chlor-alkaline process [19]. Moreover, photovoltaic solar electrodialysis using bipolar membranes yields valuable HCl as well as NaOH [20].

In published assessments of competing routes to DAC the laboratory set up is complicated by an emphasis on gas purification and on the requirements for regeneration or recovery of the chemicals employed and on quantitative monitoring of the trapping procedure. For example the analysis of carbon dioxide capture capacity of NaOH aqueous solution where the CO_2 is emitted at relatively high concentrations at a fixed point, such as a power plant flue, may embody mass flow and temperature controllers for the gas supply; a sparger, thermometers, stirrer and pH meters in the reactor zone; a pump and a gas analyser for the sampling component; and a computer for data acquisition [21]. Where the CO_2 source is dispersed, 'air capture' again with NaOH in solution may be performed by wet scrubbing in packed towers or by means of a fine spray sometimes with recovery of both NaOH and the CO_2 in mind [22].

3. The NOaH system

The NOaH version of DAC is in the spirit of first-order ^{14}C dating, which was devised to counter the high cost and time-consuming character of conventional radiocarbon assay [23]. Our CO_2 trapping stratagem is nicknamed NOaH, an anagram of NaOH, to celebrate the life-saving intention and the association with a prospective rising sea. It was devised for operation at two levels: domestic and industrial. The first, which receives most attention here, would rely on a cheap, safe, modular device which is readily installed on terraced or detached homes and vehicles, and requires the kind of maintenance that is already routinely available in many urban and suburban settings.

Consider as a guide to the domestic version of NOaH the installation and operation of rooftop solar panels (Figure 2). DAC at this level could contribute to a reduction in atmospheric CO_2 levels without harming or antagonising the population at large, just as waste recycling eventually became acceptable in many urban populations. Indeed it might come to be seen as part of a collective assault on the global warming problem analogous to the successful attack on the 'ozone hole' by the renunciation of certain ozone-depleting substances by the 43 initial signatories of the international Montreal Protocol in 1987. What is more, a helpful precedent for NOaH was set when, for all the substances whose use is controlled by the Protocol, the phaseout schedules were delayed for less developed countries and certain medicinal applications.

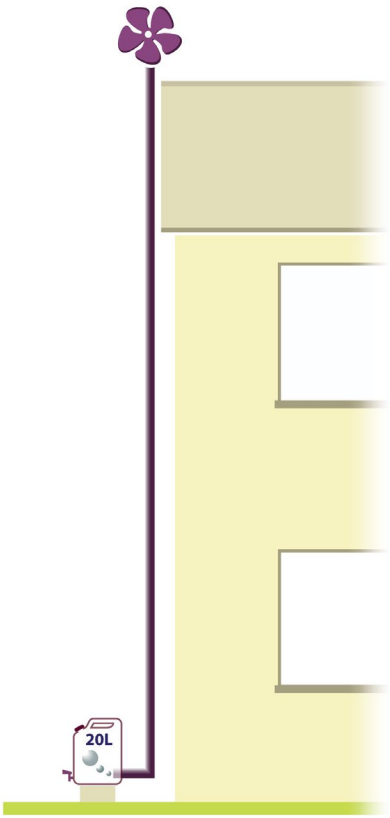

Figure 2: The domestic-level NOaH module. The basic component is a portable 20 litre NaOH container (bottom left) into which ambient air is driven by a roof-top or ground level solar-driven windmill fan or by airflow generated by vehicle movement and out of which a sample can be taken for pH assay to identify saturation.

Any estimate of the likely impact of basic level NOaH installation is destined to remain very approximate given the nebulous upper limits of the atmosphere. Granted its global volume is ~10^{15} m_3, the current CO_2 component, 0.04 %, amounts to 10^{15} m^3 while the annual volume of anthropogenic CO_2 introduced into the atmosphere is generally put at 10^{13} m^3. A simple bubbling system holding 20 m^3 of NaOH can process 1.6. 10^4 m^3 of air or 6.4 m^3 of CO_2 annually. If each of the 28.3 million UK households in the UK which in 2021 regularly recycled items of domestic waste (according to the Gov.UK website) were equipped with such a modular device and operated it effectively the resulting 2.10^8 m^3 of Na_2CO_3 (Table 2) would be available for industrial use annually. The world sodium carbonate market amounted in 2021 to 61.5 10^6 metric tons, with demand mainly in the manufacture of glass, soaps, detergents and paper; sodium bicarbonate $NaHCO_3$, currently produced in the UK from flue gas emissions, is used for kidney dialysis and various pharmaceutical products.

In short, providing novel emissions are reined in [24], even the modest postulated UK system would make a useful contribution to stabilising the present atmospheric CO_2 levels without penalising the contributing communities. What is more, to judge from the near-real-time 8.8% decrease in CO_2 emissions recorded from the OCO-2 probe in 2020 in response to COVID 19-related lockdown [25], progress can be monitored and, with the contribution of OCO-3, anomalous CO_2 sources on the ground identified.

In contrast with conventional radiocarbon labs, the UCL first-order ^{14}C line was powered by the vigorous reaction owed to the use of 50% HCl. Bubbling in the NOaH trap may be driven by natural wind, by solar-powered pumps as modest as the aerators common in suburban garden ponds, or by the airflow created by moving vehicles. For second level NOaH operation the site would have to benefit from reasonably fast and consistent winds. The obvious location is on the shafts of the 350,000 or so large wind turbines that are operating around the world (Figure 3), are generally located in order to capture steady winds - usually >5 m/s - and benefit from good road or boat access for maintenance. The intakes would be optimally positioned on the shafts to take advantage of the natural winds and also the secondary air currents generated by the turbine blades, possibly enhanced by a wind concentrator, an early version of which was granted a patent almost a century ago [26] and which is actively under development in a variety of guises none of which requires extraneous power [27]. Wind tunnel experiments and computer modelling are of course required for the air feed especially where groups of turbines complicate airflow [28, 29].

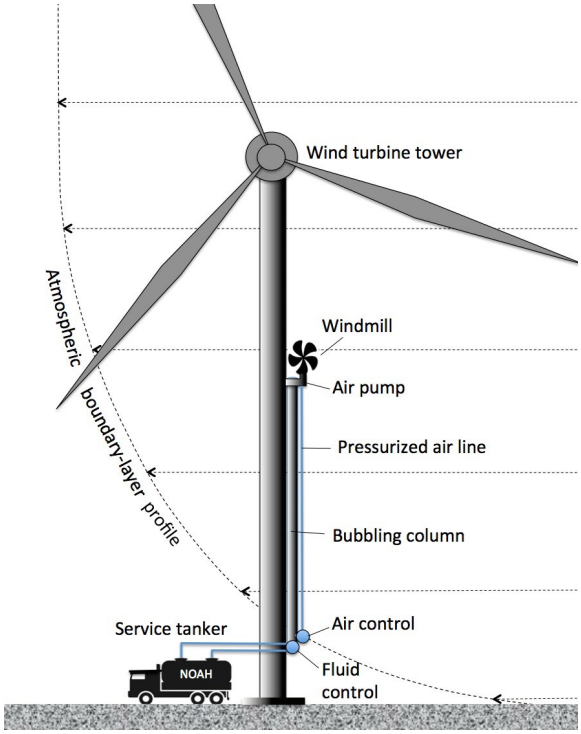

Figure 3: Exploitation of natural wind flow on a wind turbine tower supplied with NaOH by a tanker or other large container.

To sum up, CO_2 trapping in NaOH is promoted until saturation, when the resulting sodium carbonate or bicarbonate (Table 2) is exchanged for fresh NaOH and sold on the chemicals market to meet some of the costs of setting up and running NOaH. Storage, one of the major costs of conventional DAC, is largely avoided. Similarly the NaOH is generated by one or other green routes and generates useful by-products. The chemistry is simple and its safety is easily managed.

The need remains for a robust method for determining saturation. The ideal measure would be pH (Figure 4). However there is no simple way of measuring changes in pH remotely in a sealed container. Medical-grade soda lime ($Ca(OH)_2$ ~75%, H_2O ~20%, NaOH ~3%, KOH ~1 %, with NaOH playing a catalytic role) includes a dye that changes colour when the soda lime reaches its carbon dioxide absorbing capacity. The dye was removed from use by the US Navy in 1996 when it was suspected of releasing chemicals into the circuit. In NOaH at levels 1 and 2 saturation could be identified by the critical change in pH (Figure 4) in a sample drawn from the trap using a simple aquarium pH meter (Figure 2). The delivery agent or householder would replace the trap only after saturation. Doubtless mass production of NOaH traps would encourage the development of pH meters within the housing.

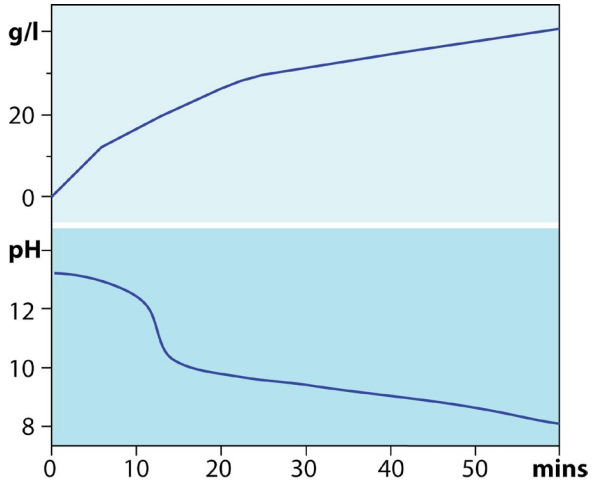

Figure 4: Rate of CO_2 absorption in 4 ww% NaOH and related change in pH 31. Upper panel: CO_2 absorption g/l; lower panel: associated pH change in minutes.

Table 1

The key reactions: CO_2 carbon dioxide + NaOH caustic soda
I) if the NaOH is dilute (with a pH lower than 8) the reaction yields $NaHCO_3$ (sodium bicarbonate) + H_2O
2) if the NaOH is concentrated (pH >10) the $NaHCO_3$ reacts with additional NaOH to yield Na_2CO3 (sodium carbonate) +H_20

Figure 5: Current, future and previous sites for TCCON (total carbon column observing network) ground-based Fourier transform spectrometers recording direct solar spectra in the near-infrared spectral region. From these spectra are derived column-averaged abundance of CO_2, CH_4, etc to validate OCO-2 and OCO-3 as well as other missions. After TCCON Site Map

In a sense the increase in the scale of operation at the higher NOaH levels – industrial and national – simplifies matters, first by drastically reducing the number of units to be managed and by putting their security in the hands of professionals; second by 'sanitising' their toxic fumes, rather like the catalytic converters compulsorily fitted to internal combustion vehicles owned by the general public, which manage CO_2 as well as CO, NOx, SO_2, and C_6H_6 (benzene); and third by rendering the production and management of NaOH and its two desirable derivatives a routine solution to the CO_2 problem. Extending the NOaH treatment to coal as a fuel by trapping the CO_2 released by its combustion would be the logical way forward [30].

4. Conclusions

The aim of the proposed DAC is to contribute to environmental protection without the sacrifice of cheap energy or of petrochemicals in medicine. Rendering fossil fuels inoffensive by trapping their past or future waste CO_2 is ecologically abstemious, although its success hinges on widespread implementation whether voluntary or legally enforced. It is here seen as complementary to the many measures being proposed to reduce CO_2 generation by the burning of fossil fuels and other components of modern industrial society.

The progressive healing of the Antarctic ozone hole provides an encouraging precedent for citizen cooperation at global scale, and rehabilitating oil and coal rather than vilifying them retains their still unfulfilled potential.

References

1. Lackner, K., Ziock, H. J., & Grimes, P. (1999). Carbon dioxide extraction from air: is it an option? (No. LA-UR-99-583). Los Alamos National Lab.(LANL), Los Alamos, NM (United States).
2. Lackner, K. S., Brennan, S., Matter, J. M., Park, A. H. A., Wright, A., & Van Der Zwaan, B. (2012). The urgency of the development of CO_2 capture from ambient air. Proceedings of the National Academy of Sciences, 109(33), 13156-13162.
3. Varro, L. Carbon capture, utilisation and storage finally catches the spotlight (IEA, 2023).
4. Zeman, F. (2007). Energy and material balance of CO_2 capture from ambient air. Environmental science & technology, 41(21), 7558-7563.
5. McQueen, N., Gomes, K. V., McCormick, C., Blumanthal, K., Pisciotta, M., & Wilcox, J. (2021). A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future. Progress in Energy, 3(3), 032001.
6. Metz, B., Davidson, O., De Coninck, H. C., Loos, M., & Meyer, L. (2005). IPCC special report on carbon dioxide capture and storage. Cambridge: Cambridge University Press.
7. Socolow, R., Desmond, M., Aines, R., Blackstock, J., Bolland, O., Kaarsberg, T., ... & Wilcox, J. (2011). Direct air capture of CO_2 with chemicals: a technology assessment for the APS Panel on Public Affairs (No. BOOK). American Physical Society.
8. Board, O. S., & National Research Council. (2015).

Climate intervention: Carbon dioxide removal and reliable sequestration. National Academies Press.
9. Luis, P. (2016). Use of monoethanolamine (MEA) for CO_2 capture in a global scenario: Consequences and alternatives. Desalination, 380, 93-99.
10. Yu, C. H., Huang, C. H., & Tan, C. S. (2012). A review of CO_2 capture by absorption and adsorption. Aerosol and Air Quality Research, 12(5), 745-769.
11. Varghese, A. M., & Karanikolos, G. N. (2020). CO_2 capture adsorbents functionalized by amine–bearing polymers: A review. International Journal of Greenhouse Gas Control, 96, 103005.
12. Samari, M., Ridha, F., Manovic, V., Macchi, A., & Anthony, E. J. (2020). Direct capture of carbon dioxide from air via lime-based sorbents. Mitigation and adaptation strategies for global change, 25, 25-41.
13. Choi, S., Drese, J. H., Eisenberger, P. M., & Jones, C. W. (2011). Application of amine-tethered solid sorbents for direct CO_2 capture from the ambient air. Environmental science & technology, 45(6), 2420-2427.
14. Stolaroff, J. K., Keith, D. W., & Lowry, G. V. (2008). Carbon dioxide capture from atmospheric air using sodium hydroxide spray. Environmental science & technology, 42(8), 2728-2735.
15. Zhenqi, N., Yincheng, G., & Wenyi, L. (2009, October). Experimental studies on CO_2 capture in a spray scrubber using NaOH solution. In 2009 International Conference on Energy and Environment Technology (Vol. 3, pp. 52-55). IEEE.
16. Yincheng, G., Zhenqi, N., & Wenyi, L. (2011). Comparison of removal efficiencies of carbon dioxide between aqueous ammonia and NaOH solution in a fine spray column. Energy Procedia, 4, 512-518.
17. Mazzotti, M., Baciocchi, R., Desmond, M. J., & Socolow, R. H. (2013). Direct air capture of CO_2 with chemicals: optimization of a two-loop hydroxide carbonate system using a countercurrent air-liquid contactor. Climatic change, 118, 119-135.
18. Zeman, F. S., & Lackner, K. S. (2004). Capturing carbon dioxide directly from the atmosphere. World Resource Review, 16(2), 157-172.
19. Thiel, G. P., Kumar, A., Gómez-González, A., & Lienhard, J. H. (2017). Utilization of desalination brine for sodium hydroxide production: technologies, engineering principles, recovery limits, and future directions. ACS Sustainable Chemistry & Engineering, 5(12), 11147-11162.
20. Herrero-Gonzalez, M., Diaz-Guridi, P., Dominguez-Ramos, A., Ibañez, R., & Irabien, A. (2018). Photovoltaic solar electrodialysis with bipolar membranes. Desalination, 433, 155-163.
21. Yoo, M., Han, S. J., & Wee, J. H. (2013). Carbon dioxide capture capacity of sodium hydroxide aqueous solution. Journal of environmental management, 114, 512-519.
22. Mahmoudkhani, M., & Keith, D. W. (2009). Low-energy sodium hydroxide recovery for CO_2 capture from atmospheric air—Thermodynamic analysis. International Journal of Greenhouse Gas Control, 3(4), 376-384.
23. Vita-Finzi, C. (1983). First-order ^{14}C dating of Holocene molluscs. Earth and Planetary Science Letters, 65(2), 389-392.
24. Matthews, H. D., & Caldeira, K. (2008). Stabilizing climate requires near-zero emissions. Geophysical research letters, 35(4).
25. Liu, Z., Ciais, P., Deng, Z., Lei, R., Davis, S. J., Feng, S., ... & Schellnhuber, H. J. (2020). Near-real-time monitoring of global CO_2 emissions reveals the effects of the COVID-19 pandemic. Nature communications, 11(1), 5172.
26. Sovereign, L. G. (1926). U.S. Patent No. 1,595,578. Washington, DC: U.S. Patent and Trademark Office.
27. Shonhiwa, C., & Makaka, G. (2016). Concentrator augmented wind turbines: A review. Renewable and Sustainable Energy Reviews, 59, 1415-1418.
28. Cal, R. B., Lebrón, J., Castillo, L., Kang, H. S., & Meneveau, C. (2010). Experimental study of the horizontally averaged flow structure in a model wind-turbine array boundary layer. Journal of renewable and sustainable energy, 2(1), 013106.
29. Porté-Agel, F., Bastankhah, M., & Shamsoddin, S. (2020). Wind-turbine and wind-farm flows: A review. Boundary-layer meteorology, 174, 1-59.
30. Chen, P. C., Huang, C. F., Chen, H. W., Yang, M. W., & Tsao, C. M. (2014). Capture of CO_2 from coal-fired power plant with NaOH solution in a continuous pilot-scale bubble-column scrubber. Energy Procedia, 61, 1660-1664.
31. Leventaki, E., Baena-Moreno, F. M., Sardina, G., Ström, H., Ghahramani, E., Naserifar, S., ... & Bernin, D. (2022). In-Line Monitoring of Carbon Dioxide Capture with Sodium Hydroxide in a Customized 3D-Printed Reactor without Forced Mixing. Sustainability, 14(17), 10795.
32. Liu, Z., Ciais, P., Deng, Z., Lei, R., Davis, S. J., Feng, S., ... & Schellnhuber, H. J. (2020). Near-real-time monitoring of global CO_2 emissions reveals the effects of the COVID-19 pandemic. Nature communications, 11(1), 5172.