Exploring the Science Behind Earth's Green Gem

by Bob Hoogendoorn PhD.

Using Olivine for Carbon Capture

Our innovative proposal is to harnesses the unique properties of olivine, an abundant naturally occurring mineral[1], to address one of the most pressing challenges of our time: reduction of carbon emissions into the atmosphere. By leveraging olivine's ability to chemically react with CO2, we aim to create a sustainable and effective solution to eliminate carbon, thereby contributing to global efforts to combat climate change. Rising CO2 levels in the atmosphere are a significant driver of climate change and its associated impacts[2,3]. Industries, services and individuals across the globe continue to emit massive amounts of CO2. Mitigation actions, including conventional carbon capture methods, often come with high costs and limited scalability. Our challenge is to develop a practical, cost-efficient, and environmentally friendly approach to capturing and sequestering CO2. Our solution revolves around the unique properties of olivine, a magnesium iron silicate mineral abundantly found in the Earth's crust[4]. When olivine comes into contact with CO2, it undergoes a natural process known as mineral carbonation. During this process, olivine reacts with CO2 to form stable minerals, thereby locking away carbon dioxide in a solid state. We propose processing, and utilizing olivine as a catalyst for accelerated mineral carbonation.

Scientific Evidence for using Olivine in Carbon Capture

Olivine, a magnesium iron silicate mineral abundant in the Earth's crust, possesses a unique ability to undergo mineral carbonation. This natural process involves the chemical reaction of olivine with carbon dioxide (CO2), resulting in the formation of stable carbonate minerals. The primary reaction can be represented as follows

Mg_2SiO_4 (olivine) + $2CO_2$ (carbon dioxide) → $2MgCO_3$ (magnesium carbonate) + SiO_2 (silica)

The mineral carbonation of olivine is a well-studied phenomenon and has been observed in various geological settings, providing a solid scientific basis for its potential application in carbon capture[5]. Studies have demonstrated that the reaction between olivine and CO2 occurs over a range of temperatures and pressures, with the rate of reaction influenced by factors such as temperature, particle size, and the availability of water. Researchers have investigated reaction kinetics under different conditions to optimize the carbonation process for practical applications[6].

The carbonate minerals formed during olivine carbonation are stable over geological timescales. This stability ensures the long-term storage of captured carbon dioxide, preventing its release back into the atmosphere. Geological formations containing carbonate minerals are found naturally and provide evidence of the effectiveness of mineral carbonation as a carbon sink[7].

Olivine-based carbon capture is environmentally non-intrusive, as it mimics natural geological processes. The reaction products (carbonates) are non-toxic and benign, posing no harm or immediate threat to ecosystems[8]. Furthermore, the reaction consumes CO2, contributing to the mitigation of climate change impacts[9,10].

Numerous laboratory and pilot-scale experiments have validated the potential of olivine-based carbon capture[1,2]. Researchers have investigated the reaction kinetics, optimal conditions, and potential challenges associated with scaling up the process. These studies provide empirical evidence supporting the feasibility and effectiveness of using olivine for carbon capture. Field demonstrations and pilot projects have been conducted to assess the practical application of olivine-based carbon capture in real-world settings[11, 12, 13]. These demonstrations have provided valuable insights into the challenges and opportunities associated with integrating olivine carbonation into industrial processes, such as power plants and cement production facilities[14].

The IPCC report[15] on Carbon Capture from 2005 already mentions use of Olivine. A commercial process would require mining, crushing and milling of the mineral-bearing ores and their transport to a processing plant receiving a concentrated CO2 stream from a capture plant. The best case studied so far is the wet carbonation of natural silicate olivine. The estimated cost of this process is approximately 50–100 US$/tCO2 net mineralized. This would therefore be a large operation, with an environmental impact similar to that of current large-scale surface mining operations. A number of issues still need to be clarified before any estimates of the storage potential of mineral carbonation can be given. The issues include assessments of the technical feasibility and corresponding energy requirements at large scales, but also the fraction of silicate reserves that can be technically and economically exploited for CO2 storage. The environmental impact of mining, waste disposal and product storage affect the potential. The extent to which mineral carbonation may be used has not been fully determined at this time, since it depends on the amount of silicate reserves that can be technically exploited, and environmental and social issues. However, advancements in science and engineering have facilitated the development of innovative techniques to enhance olivine carbonation. These include methods to increase the surface area of olivine particles, optimize reaction conditions, and improve the overall efficiency of the process.

The scientific community, including researchers from numerous universities, research institutions, and industry, continues to collaborate and validate the potential of olivine-based carbon capture[16]. Ongoing research contributes to refining our understanding of the process and addressing any technical challenges that may arise.

The scientific evidence outlined supports the viability and efficacy of utilizing olivine for carbon capture. The mineral's ability to undergo mineral carbonation, the stability of the resulting carbonates, and the compatibility of the process with natural geological systems provide a solid foundation for building a robust business case for olivine-based carbon capture. Ongoing research, technological advancements, and field demonstrations further reinforce the scientific legitimacy of this innovative approach to mitigating carbon emissions.

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Technology scan

In 2023 RTL news[1] in cooperation with climate scientist presented a scan of the available methods for carbon capture and evaluated these methods based on their merits and side effects. They concluded that using olivine was one of the two viable options, although still much technological development would be required before it can be applied on an effective scale.

	Concept	Short description	Comment
1	Plant trees	First of all, plant trees. That sounds like the most important and easiest option, but unfortunately the effect is less than many people think. When the tree dies, it will eventually decay back into CO_2. Planting trees only makes sense if the total amount of forest increases: then you know for sure that more CO_2 is actually stored. Although CO_2 can also be stored by using trees as building material.	Besides the fact that CO_2 sequestration in trees is not permanent. It is good to compare the scale of the problem and the solution. If we want to keep pace with current CO_2 emissions through planting trees, we need to get a forest the size of the Amazon every 8 years Of course, planting trees, and certainly protecting existing forests, and expanding forests is useful, especially for the benefit of biodiversity, but it is not an alternative for emission reduction: you cannot fly carefree because you compensate for the flight by planting trees.
2	Capturing and storing CO_2 underground	The industry can capture CO_2 that is released during production. This can be done through a technological process called Carbon Capture and Storage (CCS). The captured CO_2 can be placed in empty gas fields.	Storage of CO_2 in depleted gas fields and aquifers is in principle possible on a large scale. It is not without risks, although IPCC calls these risks "reasonably controllable and much less than the risks of climate change itself".
3	CO_2 Storage in subsurface fungi	There is more carbon in the soil than in the atmosphere and the biosphere (trees and plants) combined. Subterranean fungi appear to play a major role in this natural carbon storage. That makes it all the more important to keep the soil in a healthy state.	It is still unclear how much carbon actually remains underground. Some of it is absorbed by plants. Some of the carbon in the atmosphere is also certainly disappearing.
4	Charring organic material	Another way to store more carbon in the soil is through biochar, a type of charcoal. For thousands of years, biochar has been used by indigenous peoples in the Amazon. Smoldering organic material causes it to char	Biochar is rich in carbon, and much of it stays where it is – so it doesn't go back into the air, as does the normal decomposition of plant debris. However, the total amount of CO_2 that can be stored is limited.

[1] Kunnen we die CO2 niet gewoon uit de lucht halen en ergens opslaan? | RTL Nieuws (in Dutch)

		slowly. The resulting black earth, was used as a soil improver.	
5	Direct Air Capture	Couldn't we make some kind of artificial trees that just take CO2 out of the air? Research is being done on this in various places, although this technique is still in a very early phase. How does it work? You pump air through an absorbent filter to capture the CO2. By heating the saturated filter, the captured CO2 is released in a concentrated form. You then collect it and store it underground. The last step is the same as for the option of storing CO2 from a bio-energy plant.	There are a number of start-ups that are experimenting with this, but the amount of CO2 that has been stored so far is not very large. The largest 'Direct Air Capture' factory in the world, from Climeworks in Iceland, annually removes as much CO2 from the air as 450 Dutch people collectively emit. The relatively high energy consumption can make it difficult to apply such techniques on a large scale.
6	Combating ocean acidification	The ocean is a gigantic carbon reservoir. But that reservoir is weakened by the acidification caused by extra CO2. Let's counteract this acidification by adding lime or olivine to the ocean, for example, is the idea behind this option. Then the ocean can absorb extra CO2 again.	it takes a lot of energy. In addition, there are risks of unforeseen side effects on marine life if it were to be applied on a large scale.
7	Fertilize the ocean via plankton	The idea of this is to accelerate the growth of phytoplankton by adding iron to seawater.	When the plankton die, the carbon captured by photosynthesis is drained into the deep ocean. This option has many side effects on marine life, which has slowly but surely fallen out of favor.
8	Deep ocean CO2 storage	Injecting CO2 into the deep ocean was often suggested a few decades ago. The ocean is on average 4 kilometers deep, and the water at great depth only slowly returns to the surface after about a thousand years. It is therefore not a permanent storage, but still significantly longer than a tree.	This method has since been shelved due to its feasibility and side effects on marine life.

9	Weathering of olivine	Olivine is a mineral that absorbs CO_2 when exposed to the elements. That normally goes excruciatingly slow, but by finely grinding olivine-containing rock we can speed up the CO_2 absorption considerably. This is already happening on a limited scale, for example at this inspection path along the railway line, which we wrote about earlier.	Grinding of olivine to an effective grain size and required space for weathering remain challenges. On the other hand, it is quite easy to apply as an alternative to gravel or stones, for surface cover. Benefit is that weathered olivine can be used for the soil improvement or aggregate for cement.

Proposition Carbon Vanish

Early 2018 Bob Hoogendoorn (Deltares) contacted Ap Verheggen. To see if he was interested to collaborate in a Art & Science project to try and visualize the weathering process of olivine and show how it captures CO2. In order to gain support for projects to apply olivine in the field for (passive) Carbon Capture.

Ap showed great enthusiasm and went to work, after numerous experiments, Ap created the Olivine Tree. A set-up with a display showing the ambient concentration of CO2 and a second display showing the CO2 concentration in the transparent cylinder where olivine (fine sand fraction) was mixed with water using small air bubbles.

Serendipity. The combination of a fine grain size for the olivine, fully water saturation and using air bubbles provided an instant reaction. In addition, the turbulent setting provided an abrasive action in which the surface of the olivine grains was "cleaned". This combination of chemical and physical processes provided weathering rates that exceed any expectations.

After the lockdown, we, Ap, Theo and Bob, teamed up and created Carbon Vanish. It is our mission to scale up the use of olivine for carbon capture.

Efficiency and Scalability: Olivine-based carbon capture offers a highly efficient and scalable solution. It can be integrated into various industrial processes, such as power generation, cement production, and steel manufacturing, where CO2 emissions are substantial.

Low Environmental Impact: Unlike some conventional carbon capture methods that rely on chemical solvents, olivine-based carbon capture is natural and non-toxic. The process mimics the Earth's own carbon cycle and leads to the formation of stable, environmentally harmless minerals.

Long-Term Carbon Sequestration: The captured CO2 is stored in a solid form, ensuring long-term carbon sequestration. This helps prevent the released CO2 from re-entering the atmosphere and contributing to the greenhouse effect.

Economic Viability: By monetizing the captured CO2 through various mechanisms, such as carbon credits or the utilization of minerals produced in the production of valuable materials, the olivine-based carbon capture model can create a revenue stream for businesses.

Public Relations and Sustainability: Companies adopting olivine-based carbon capture can showcase their commitment to sustainability and environmental responsibility, enhancing their brand image and meeting the growing consumer demand for eco-friendly products and practices.

Market Potential: The global carbon capture and storage market is projected to grow significantly as nations and industries intensify efforts to reduce carbon emissions. Our olivine-based carbon capture solution positions us to tap into this market demand by offering a competitive, efficient, and environmentally friendly option.

Conclusion: Harnessing olivine for carbon capture presents an innovative, scientifically grounded, and commercially viable solution to address the urgent challenge of carbon emissions. By offering an efficient, scalable, and sustainable approach, our business aims to play a pivotal role in shaping a more sustainable and resilient future for our planet while providing tangible benefits to industries, the environment, and society at large.