

# **Sustainable Carbon Dioxide Capture and Utilization System ( SCDCUS)**

## **Abstract**

Climate change is an imminent threat to most global ecosystems, hence we have urgent calling for sustainable technologies in carbon capture and utilization. SCDCUS is a sustainable concept which biomimetically replicate ecosystem services like climate control through a specifically developed system that captures atmospheric carbon. This theoretical system integrates advanced nanostructures for light harvesting, synthetic chloroplast-like entities for CO<sub>2</sub> fixation, innovative biomimetic membranes for selective gas separation, artificial stomata and synthetic photosynthesis. It provides a very effective method towards using atmospheric CO<sub>2</sub> for the production of value added products such as plastics, fuels, and building materials, within a circular carbon economy framework by working in tandem with nature's processes for carbon sequestration and mineralization and therefore may be considered as a answer for global warming. The following work describes the design and operation of the SCDCUS.

## **Introduction**

Ecosystem services are defined as critical functions performed by natural systems, such as the regulation of climate, filtration of water, and plant pollination. However, human activities disturb this balance through increasing the concentration of greenhouse gases and breaking down climate stability. According to the Millennium Ecosystem Assessment, 2005, biomimicry is promising engineering response to this challenge which is the development of devices modeled after nature's best solutions. SCDCUS is a theoretical concept which uses biomimicry from nature to solve climate change which is a global problem. SCDCUS aligns with the net zero carbon emission goal of United Nations which is crucial to save our planet.

SCDCUS is a theoretical concept which is a sustainable system of capturing a potent greenhouse gas (CO<sub>2</sub>) and utilizing this CO<sub>2</sub> by forming valuable compounds which can be used in building materials, synthetic fuel such as ethanol, methanol and it can be used as a raw material for the formation of biodegradable plastics. Thus by doing this it saves the environment, it is economical as it gives valuable products and it doesn't affect the social system so it aligns with the triple bottom layer of sustainability.

SCDCUS draws inspiration from Crassulacean Acid Metabolism (CAM) plants like Cactus, Agave, *Clusia Pratinensis*, whose biological function is the intake of CO<sub>2</sub> at night time. CAM plants store water effectively by fixing CO<sub>2</sub> at night. By using this function of carbon capture we can make a system that captures CO<sub>2</sub> through artificial stomata. After carbon capture, it performs CO<sub>2</sub> fixation which is inspired from chloroplasts and then calcification processes which are inspired from marine organisms like corals and mollusks. Marine organisms use dissolved CO<sub>2</sub> from seawater to form calcium carbonate through a process called calcification. SCDCUS system is envisioned to capture atmospheric CO<sub>2</sub> and convert it into value-added chemicals, therefore encouraging a circular carbon economy in which carbon emitted would be recycled. It is also combined with an artificial photosynthesis process to convert CO<sub>2</sub> into chemicals like polycarbonate.

The primary mission is to actively contribute toward positive mitigation of climate change by capturing atmospheric CO<sub>2</sub> into sustainable materials, thus opening up new pathways toward a carbon emission reduction roadmap.

### **Methodology**

SCDCUS follows four steps which are

- Capturing of CO<sub>2</sub>
- CO<sub>2</sub> fixation or conversion
- Utilization of CO<sub>2</sub>
- Product formation

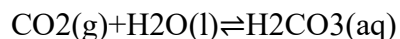
### **Capture of CO<sub>2</sub>:**

CO<sub>2</sub> is captured from artificial stomata which is made from nanoengineered membranes with tunable pores, which functionally emulate the stomata-like natural activity of leaves. Zhu et al. (2024) explores artificial stomata systems that mimic the gas exchange functions of plant leaves, providing a model for tunable pore technologies. From this we can make artificial stomata which can mimic the function of stomata.

It enables higher intake of CO<sub>2</sub> during the night while releasing oxygen. The system contains sensors devised from natural processes of plants, aiding it to regulate the opening of pores for optimal capture of CO<sub>2</sub>.

According to Robeson (2008), recent advancements in membrane technology have significantly enhanced the efficiency of CO<sub>2</sub> separation processes, particularly through the use of polyimide membranes that selectively allow CO<sub>2</sub> to pass while blocking other gases like nitrogen. This artificial stomata can be made from material such as polyimide which has self-assembly copolymer membranes which are used for gas separation. These type of membranes are best as In this case, these membranes allow CO<sub>2</sub> to pass effectively while blocking N<sub>2</sub> or other gases.

The primary reaction for CO<sub>2</sub> capture involves the interaction of CO<sub>2</sub> with water to form carbonic acid, which can subsequently participate in various reactions.



### **CO<sub>2</sub> Fixation-Conversion**

Calvin cycle (natural)

According to Nocera (2012), the principles of artificial photosynthesis and the design of synthetic systems is mimicking natural processes which are crucial for developing effective energy conversion technologies. SCDCUS uses synthetic chloroplast like entities which are designed to mimic the natural process of how plants absorb and utilize CO<sub>2</sub> for energy. This theoretical system is, in fact, similar in a broad sense to the whole process of uptake and utilization of CO<sub>2</sub> by plants for its energy generation. The system adopts genetically modified enzymes like RuBisCO (Ribulose-1,5-bisphosphate carboxylase/oxygenase) which enhance carbon fixation and therefore give a much higher effective conversion of CO<sub>2</sub> into useful compounds like sugar, biofuels and chemical feedstocks.

This reaction is the fixation of carbon dioxide into sugar or biofuels. The key enzyme involved is RuBisCO, which catalyzes the first step in the Calvin cycle:

1. Carboxylation:  $\text{RuBP}(\text{aq}) + \text{CO}_2(\text{g}) \rightarrow \text{Using catalyst RuBisCO} \rightarrow 2\text{3-PGA}(\text{aq})$  Where RuBP = Ribulose-1,5-bisphosphate, and 3-PGA = 3-phosphoglycerate.
2. Reduction:  $2\text{3-PGA}(\text{aq}) + \text{ATP} + \text{NADPH} \rightarrow \text{G3P}(\text{aq}) + \text{ADP} + \text{NADP}^+$  Where G3P = glyceraldehyde 3-phosphate.

### 3. Regeneration: $\text{G3P(aq)} \rightarrow \text{RuBP(aq)}$

- Synthetic Photosynthesis

Apart from marine organisms which convert  $\text{CO}_2$  into solid compounds we can integrate artificial photosynthesis which can give sugars, polycarbonates. This process mimics how plants use sunlight to transform  $\text{CO}_2$  into sugars. This synthetic photosynthesis employs light-harvesting nanostructures and catalysts to produce  $\text{CO}_2$  in the forms of some valuable products like polycarbonates or other chemicals. SCDCUS uses advanced catalytic systems like manganese catalyst cores which are combined with polypyridyl ligands for enhanced catalytic performance for  $\text{CO}_2$  Reduction and Water Oxidation.

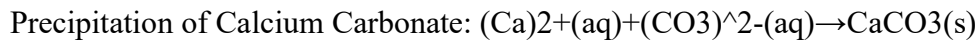
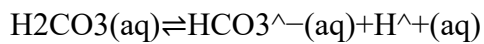
### **Utilization of $\text{CO}_2$**

The development of synthetic systems that mimic natural processes is essential for advancing artificial photosynthesis (Nocera, 2012). SCDCUS performs carbon mineralization which chemically transforms  $\text{CO}_2$  into stable minerals. It is inspired from biomimicking from marine organisms which convert  $\text{CO}_2$  into their solid shell forms, like corals. This form of storage is in a solid phase. In carbon mineralization,  $\text{CO}_2$  reacts with minerals, typically involving metal ions (such as calcium) to form stable compounds like calcium carbonate ( $\text{CaCO}_3$ ). This process effectively locks away carbon in a solid phase, preventing it from re-entering the atmosphere. We can accelerate carbonate formation method by following two-step mechanism: one, the emulsification of carbon dioxide gas into the form of a bicarbonate; and two, the precipitation of calcium carbonate with the assistance of designer proteins into stable mineral deposits. By offering supplementary paths to  $\text{CO}_2$  removal, SCDCUS decreases the load from natural carbon sinks, such as forests or oceans. Notably, it reduces the general concentration of  $\text{CO}_2$  and allows

for a reduced rate of ocean acidification, which contributes to richer biodiversity in the marine fauna.

Formation of Calcium Carbonate:

- The mineralization of CO<sub>2</sub> through reaction with calcium ions can be represented as follows:



### **Product formation**

Subsequently, captured CO<sub>2</sub> is valorized in the form of plastics, fuels, and even building materials by tapping into pathways for a circular carbon economy. This, in essence, means reuse of carbon is involved; this would reduce the levels of emission that contribute to climate change.

Product Formation

Conversion of CO<sub>2</sub> into Fuels and Plastics:

1. Production of Methanol (from CO<sub>2</sub>):  $\text{CO}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow \text{CH}_3\text{OH}(\text{g})$
2. Production of Polycarbonate (from CO<sub>2</sub>):
  - Polycarbonates can be synthesized through the reaction of bisphenol A with phosgene, with CO<sub>2</sub> serving as a carbon source in some synthetic routes.



## Conclusion

SCDCUS offers an sustainable biomimetic approach to address the global warming by capturing and converting atmospheric CO<sub>2</sub> into products like fuels, plastics, and building materials by biomimicking from natural processes which are found in CAM plants, marine calcifiers, and photosynthesis. SCDCUS provides a sustainable solution for saving the planet by reducing GHG gases which are the main causes for climate change. The system's integration of advanced nanomaterials, synthetic chloroplasts, and artificial stomata demonstrates the potential for carbon capture technologies to not only mitigate CO<sub>2</sub> emissions but also create economic value. Ultimately, SCDCUS holds promise as a key contributor to achieving the global net-zero emissions goal of United Nations and combating climate change.

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