A study of carbon sequestrating pathways in microorganism for the removal of carbon dioxide from the atmosphere

Dr. S.SAI SUBHASHINI & Dr.S.KALIAPPAN

Abstract— Climate has a major influence on life that is existing on the earth. Change in climate can have dominant effects on the types of soil and the vegetation that is growing on them. Humans are more dependent on this vegetation as there are the essential sources for the food production, health, and comfort. Humans are the major reason for the transformation of the environment, which in turn results in the climatic change. Carbon dioxide removal (CDR) can primarily be done by better land management techniques like planting forests, grasses, crops. CDR is the process of abating the stock of CO_2 in the atmosphere by planting of trees, soil carbon sequestration, biomass energy with carbon capture and storage, and some innovative technologies resembling the storage for direct air capture. In the current study, identification of the efficient pathway of the CO_2 sequestrating microbes are reported. Calvin-Bassham-Benson (CBB) pathway's stability can be maintained due to the easy fluctuation of mutations in the E.coli. The World Bank Group upholds the Sustainable Energy goals by increasing the rate of energy efficiency thereby serving renewable energy as an energy for global level from 18 percent to 36 percent by 2030. Reaching these goals is key to low-carbon growth.

Index Terms— carbon dioxide removal, carbon sequestration, calvin-Bassham Benson, climatic change, E.coli, global warming.

1 INTRODUCTION

DEVELOPMENT- - the term can only achieved by lots of effort and determination. India is trying its level best to achieve the term 'Developed'. It has a lot of meaning to our country. We are now focusing on sustainability development as it is imperative for the survival of our future generation. Climatic change is another important aspect that should be mitigated in order to achieve the development of our country. Greenhouse gases (GHGs) play a major role in the climatic change. Increased anthropogenic activities releases the GHGs in the atmosphere, which leads to global warming. The objectives of the Paris Agreement is to reduce global warming from 2^{o}C and strive for the achievement of SDGs. The actions which are going to implement the SDGs should be economically, socially and environmentally acceptable, such as the core value of the Climate-resilient development pathways. The main reason for risks that are prevailing to climate change should be controlled effectively this primarily means the reduction and mitigation measures of CO_2 that are eliminated by the anthropogenic activity.

As per the Climatic Change Performance Index (CCPI) 2019 India ranks 11th in the emission of greenhouse gases, which means that we are not at the peripheral edge. The major cause of climatic change is CO_2, which is emitted by the intolerable emissions from the industries that are secured by the nations itself. The improvement in the emission of the greenhouse gases can be done through the renewable energy.[1]. The research unit namely climatic action tracker is tracking the climatic change policy of the countries who made the commitment in the Paris agreement of 2015. India is focusing towards its pledge to achieve the target of reduction of Gross Domestic Product in the range of 33-35%. About 68% of the GHGs emissions is by coal power plants. Now India is targeting to change the source to Non- Coal Sources by 2040.

Among the other greenhouse gases, the emission of CO_2 is increased about 50-60% due to the anthropogenic activities. In the case of Chennai, it emits about 4.79 tonnes of Carbon dioxide to the atmosphere compared to the other cities like Hyderabad, Bengaluru, Delhi, Ahmedabad and Kolkata. Even in Chennai, the Domestic sectors emit more CO_2 than the Industrial Sectors. The Industries that are the main contributors of CO2 emission are thermal, chemical and manufacturing plants.

Carbon dioxide removal is done to in order to protect the existing resources that are available in our environment. Removal can be achieved either by reducing, fixation or by decreasing it at the source itself. In the present study, the Carbon Sequestration is done using biological materials to remove the carbon dioxide from the atmosphere [3]. The process of converting the Carbon dioxide into a form does not have any adverse effects on global warming. This carbon sequestration is a long-term storage technique, which helps in the trapping of atmospheric carbon and balancing its level in the threshold limit. The main objective of the present study is to use the biological material for the sequestration strategies.

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2 Biological Sequestration

Biological sequestration involves plant and microorganisms to be used in the trapping of Carbon dioxide. The use of biological materials help us to make the process more natural. Generally, Carbon dioxide is circulated in between the atmosphere, biological components as well as in geological elements, which is shown in Figure 2. Ocean sequestration and territorial sequestration are the main types in the biological methods. In the terrestrial sequestration methods, Soil carbon sequestration and Photo sequestration are involved [4].

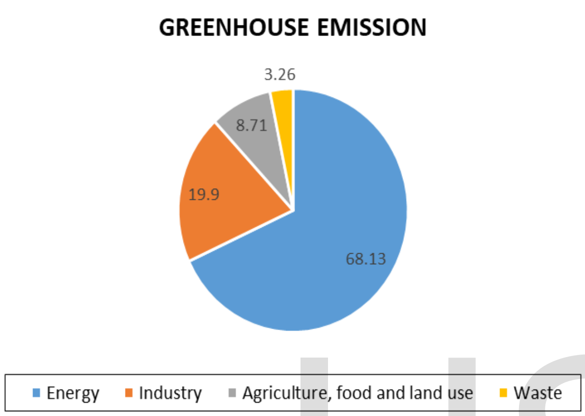


FIGURE 1: Source: Global Carbon Project 2019 [2]

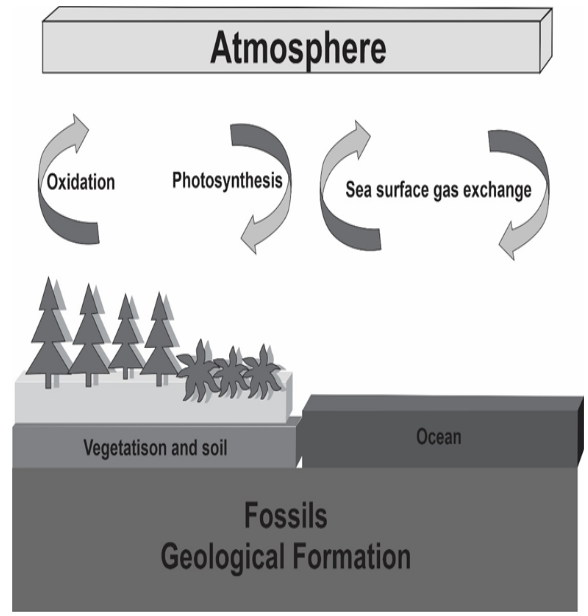
The reaction, which is considered as most important in the carbon cycle, is as follows.

$$C_2H_{12}O_6 + 6O_2 \longrightarrow 6O_2 + 6CO_2$$

For the development of the economic growth of our country, we need to implement the different global pools of the sequestration of the Carbon Dioxide. These biological pools are classified into biotic and abiotic group. Abiotic sequestration is more effective than the biotic in that it has more CO_2 injecting and capturing capacity. Biotic sequestration is the method that uses the biological material (Higher Plants) or the microorganism to capture the atmospheric CO_2. [6].

• Author :Dr.SAI SUBHASHINI ,Assistant professor, SRM institute for training and develoment,Ekkathuthangal,Chennai-600032,saisubhashini@gmail.com

• *Co-Author* :Dr.S. KALIAPPAN,Professor, former vice chancellor, Anna University, Chennai-600025,drkalsun@gmail.com



3 Microorganisms for CO_2 Sequestration

Microorganisms have the ability to fix the atmospheric carbon into the cell components either by photosynthetic or non-photosynthetic pathways. The major benefit of using the microorganisms are (a) fast growth of the microorganisms that leads to high carbon sequestration from the atmosphere (b) getting the variety of biologically modified gene for our requirements (c) production of the natural products such as acetate, ethanol, butanol, lactate, acetone etc. as a supplement. The heading below will brief about the various microbes in the carbon dioxide sequestration.

3.1 Archaea

It is a single celled prokaryotic microbe that is abundantly found in nature. The name extremophiles are given to these organisms as they grow in extreme conditions such as high salinity/acidic or anaerobic conditions. Archaea have the capacity to utilize CO_2 and produce methane as a byproduct. The commonly known Methonogenic archaea have the capacity to produce methane, which is a double benefit of remediation as well as CO_2 sequestration. In this, the CO_2 is used as a substrate. Some of the Methonogenic Archaea are Sulfolobus, Archaeoglobus, Cenarchaeum, and Metallosphaera spp, which utilize CO_2 as a substrate in the 3-Hydroxypropionate-4-HydroxyButyrate cycle. [7]

3.2 Clostridia

Gram-positive clostridia are facultative anaerobes, which use CO_2 as a substrate. They play a vital role in the Carbon fixation as Acidogenic bacteria. CO_2 is fixed in the Wood–Ljungdahl pathway as acetyl- CoA. Carbon monoxide dehydrogenase is an enzyme that is involved in the pathway for the conversion of Carbon monoxide and Carbon dioxide and produces acetate, acetone, ethanol, butanol and lactate as a by-product. The cost of biodiesel produced by the Clostridia heterotrophically with the glucose shows the US $ 0.9 L^{-1} or US $ 3.40 gal^{-1} of Glucose consumption.[8]

3.3 Proteobacteria

In case of the Proteobacteria the CO_2, metabolism occurs in the Calvin cycle. CO_2 is fixed inside the cytoplasm of the cell where it will synthesize the polyhydroxyalkanates (PHAs). Polyhydroxyalkanates is a bioplastic, which can be biodegradable and has low impression in the environment. By utilizing the carbon compounds, the medicinal compounds are also derived.[9,12]

4 Mechanism involved in the CO_2 sequestration

Light is the major component involved in the conversion of the NADP+ and ADP into NADPH and ATP, which is possible only through the Photosynthetic reaction. In the Calvin Benson Cycle, CO_2 is consumed for the synthesis of the energy components.[5,11,13] This reaction is possible only through the enzyme Ribulose bisphosphate carboxylase/oxygenase (RuBisCo). The enzymes play a double role as it helps in Photosynthesis as well as photorespiration (Figure 3)

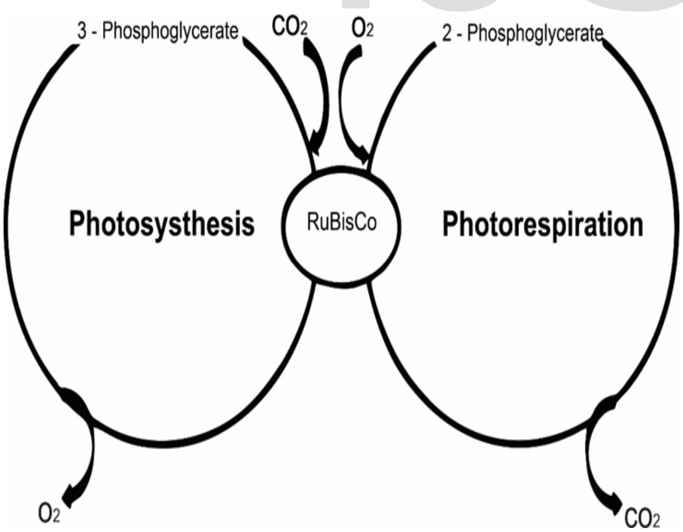


Figure 3: Dual nature of RuBisCo enzyme in carrying out photosynthesis and photorespiration [5, 13]

5 Evaluation of the CO_2 sequestration microbial components

To manage the global carbon dioxide, various organisms exist in the environment. The study mainly focuses on the discerning organisms that can bio-fix the maximum CO_2 from the atmosphere. For understanding the bio- fixation, it is necessary to know about the pathways of the CO_2 sequestration. The Table 1 shows the CO_2 sequestration in different biological system and their by-products.

Table 1 CO_2 sequestration in different biological system and their by-products

Biological systems	Co_2 Sequestration pathway	By-products	References
Archaea	3-hydroxypropionate-4-hydroxybutyrate cycle.	Methonal	[7]
Clostridia	Wood–Ljungdahl pathway	acetate,acetone,ethanol, butanol, lactate	[8]
Proteobacteria	Calvin Benson Cycle	Biofuels, bioplastic	[9]

Finding out a better microorganism for the carbon dioxide removal is a challenging task. The microbe, which we are going to use, should have the capacity to fix the CO_2 in its pathway. Using the pathway, it should be able to produce energy and disperse the carbon flux as the cell resource [14] . Recent researchers showed that some bacteria have the capacity to convert CO_2 into $CaCO_3$. The *Escherichia coli* bacterium is identified to act as a very competent carbon sequestration. This bacterium has the ability to convert CO_2 into $CaCO_3$.[9,10] The bacteria converts the Calcium into calcium carbonate with the oxalate carbonate pathway, which makes the soil pH high due to the conversion. Recent investigation of the CO_2 sequestration showed that the carbon capture and storage could be effectively attained by these kinds of microbes [15].

There are certain important reasons for using E.coli:

A. E.coli uses Calvin-Benson cycle for the sugar synthesis.
B. Its Metabolic break down helps in the production of the efficient biomass.
C. The bioreactor has the capacity to produce sugar-using CO2 as a substrate.
D. Calvin-Bassham-Benson (CBB) pathway's stability can be

maintained due to the easy fluctuation of mutations in the E.coli.

6 CONCLUSIONS

Using microorganisms, the CO_2 fixation becomes more efficient as the terrestrial CO_2 fixation consumes a lot of time i.e. years for the growth. The bio-fixation of the CO_2 requires a large land area for its growth, which is the main disadvantage in this study. The proposed work can be done in the agricultural fields where the enrichment of the soil will help in maintaining the relationship between the microbes and the crops. The microbes that utilize carbon dioxide for respiration i.e. non-photosynthetic microorganisms can be effectively used in the mitigation of CO_2 in the industrial scale.

Microbial CO_2 sequestration is useful as it offers a green and natural method for countering the threat of global warming. It is not only a sustainable technique but has an added advantage as it concurrently produces biofuels and chemicals. Nonetheless, the low efficiency of microbial CO_2 fixation is an area of concern. Apart from this, the related microbial CO_2 emission also reduces the carbon yield of desired chemicals.

Various tactics have been devised to counter these issues. They include the development of energy-harvesting systems in order to increase the efficiency of CO_2 fixation in autotrophic and heterotrophic microorganisms, as well as engineering CO_2-fixing pathways. Moreover, it is possible to rewire the metabolic pathways and boost the energy metabolism to reduce microbial CO_2 emissions, as well as to increase the carbon yield of value-added products. The potential of biotechnology to promote microbial CO_2 sequestration is emphasized in this review. It also gives an overview of the ways to properly utilize and encourage the broader use of microorganisms as attractive carbon sinks. The effective utility of E coli for the purpose of CO_2 Sequestration, and its various advantages are analyzed. The hazard of global warming is an imminent one and immediate steps have to be taken on an international scale in order to counter it. The survival of the future generation and the sustenance of the planet depends on it.

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