Sustainable synthesis of biopolymers from CO2 using chemo-biological approaches

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DECLARATION

I hereby declare that the major project work entitled *“Sustainable synthesis of biopolymers from CO2 using chemo-biological approaches”* has been solely submitted to the Department of Biotechnology and Bioinformatics, Jaypee University of Information Technology, Waknaghat in due of the literature review and research work i have done under the major project in guidance of our supervisor **DR. ASHOK NADDA.**

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SUPERVISOR'S CERTIFICATE

This is to certify that the major project work titled *"Sustainable synthesis of biopolymers from CO2 using chemo-biological approaches"* submitted by **Divyansh Rana** in his 8^{th} semester in May 2021 in fulfilment for the major project in Biotechnology of Jaypee University of Information Technology, Solan has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of any degree or appreciation.

(Signature of Supervisor)

Name of Supervisor - **Dr. Ashok Nadda**

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I take this opportunity to express my first and foremost gratitude to the "DEPARTMENT OF BIOTECHNOLOGY AND BIOINFORMATICS" for the confidence bestowed upon me and entrusting my project title "Sustainable synthesis of biopolymers from CO2 using chemo-biological approaches".

At this juncture, with proud privilege and profound sense of gratitude i feel honored in expressing my deepest appreciation to **Dr. Ashok Nadda,** for being a lot more than just a supervisor and going beyond the call of duty in our guidance, support, advice, and motivation throughout. He has been the source of inspiration of come what may, these issues cannot bring you down. Sincere thanks for his insightful advice, motivating suggestions, invaluable guidance, help and support in successful completion of this major project and also for his constant encouragement and advice throughout our major project work.

Special thanks to my parents for their infinite patience and understanding and project partners for the constant support and most importantly God, who in his mysterious ways, always made things work out in the end.

In gratitude,

Divyansh Rana (171810)

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ABSTRACT

Carbon dioxide (CO_2) is one of the significant reasons for global warming, which results in climate change. CO_2 emissions include burning of limestone by various cement industries and burning of fossil fuels due to which CO_2 concentrations in the atmosphere are increasing rapidly. CO_2 capture and its conversion into valued-added products has gained a lot of consideration from researchers. CO_2 emitted by the industries can be trapped by various CO_2-phillic adsorbents like nanomaterial-based metal-organic frameworks (MOFs), crystalline structure-based zeolite imidazolate frameworks (ZIFs) and porous network based porous organic polymers. This captured CO_2 is actually used as a raw material for the production of various value-added polycarbonates via chemical and biological routes. The photo-biocatalytic methods have been used for the production of polycarbonates such as polyhydroxyalkanoates (PHA), polyhydroxy butyrate (PHB), polyurethanes (PUs), and many industrial based polycarbonates by combining chemical and biological methods. In context to biocatalysis, cyanobacteria utilize CO_2 as a substrate and accumulate PHB whenever the nitrogen-deficient conditions are applied. This approach not only aims to reduce CO_2 emissions but also assisting in the production of valuable industrial-grade polycarbonates. Also, PHA and PHB find many applications in the biomedical field due to their low toxicity, biodegradability, and biocompatibility. These methods can be applied at an industrial scale and can produce polycarbonates from CO_2 in a sustainable way.

Keywords: CO_2, *polycarbonates, MOFs, POPs, ZIFs, Biocatalysis, photocatalysis, PHA, PHB, PU.*

1. INTRODUCTION

Global warming has a very devastating impact on the planet as it causes climate change which is making it inhabitable for humans. Carbon dioxide is a Greenhouse gas that absorbs and radiates heat in turn making the environment hot. According to the National ocean and atmospheric administration (NOAA), the global average atmospheric concentration of carbon dioxide was 417.16 parts per million which is still increasing at a very rapid pace. Carbon dioxide emissions arise due to the burning of fossil fuels for energy consumption in various industries. Fossil fuels contain carbon which has come from the photosynthesis by the plants over a span of millions of years, and by burning those fossil fuels, the carbon is returning back to the atmosphere in a very short span of time. Researches like (Cassia, Nocioni et al. 2018) have stated that most of the carbon dioxide emission come from activities like cement manufacturing deforestation fossil fuels, and combustion like Coal, Oil and natural gases which has a very negative impact on the planet. This high concentration of $CO2$ in the atmosphere is not necessarily bad for the plants as concluded by (Yang, Mu et al. 2015) that increased concentration of carbon dioxide in the atmosphere is known to have a Fertilization effect on the crops. They have stated that the photosynthetic activity is increased whenever there is an excess of carbon dioxide in the C3 plants because of the photosynthetic enzyme ribulose-1,5-bisphosphate carboxylase-oxygenase (RuBisCO). But the overall effect of the $CO2$ on the environment is a matter of concern because not only the earth's overall temperature rises due to Excess carbon dioxide but carbon dioxide also causes ocean acidification which is nothing but a drop in pH causing a major threat to marine life. NOAA has forecasted that the carbon dioxide concentration will exceed 900 PPM by the end of the century if we continued the use of fossil fuels. That is why we need to work on approaches or methods which will not only reduce carbon dioxide concentrations but will also generate industrial-grade polycarbonates. Polycarbonates are used extensively in the industries because of the advantages they possess like UV protection, high tensile strength, long life, and high conductivity. Many industrial-grade polycarbonates like polyhydroxyalkanoates (PHA) and polyhydroxybutyrate (PHB) have been synthesized by using $CO2$ as a raw material.

CO_2 is captured by various adsorbents like porous organic polymers (POPs), metal-organic frameworks (MOFs), and zeolite imidazole framework (ZIFs) as shown by (Singh, Lee et al. 2020). CO_2 molecules are trapped inside the networks of porous organic polymers and serve as a raw material for various kinds of chemo-biological processes. Various microorganisms have the ability to metabolize carbon dioxide as a substrate and used for the for the production of polycarbonates like PHA and PHB. (Carpine, Raganati et al. 2018) have used strain Synechocystis sp. PCC6803 which is a Gram-Negative bacterium capable of utilizing carbon dioxide and accumulating polyhydroxybutyrate. When this cyanobacterium is cultured under nitrogen-deficient conditions in which optimum nitrate concentration for growth is lowered, the bacteria induces drastic shifts in its Central carbon metabolism and accumulates polyhydroxybutyrate as a source of energy and carbon which has been demonstrated by (Koch, Berendzen et al. 2020). Genetically modified microorganisms have also been used to metabolize CO_2 as a substrate for the production of many polymers. Rhodospirillum rubrum is one such organism that has been modified genetically to produce medium-chain length PHAs as shown in the researches of (Heinrich, Raberg et al. 2016) in which all the gene sequences coding for enzymes has been inserted into the genome of Rhodospirillum rubrum. have used syngas which is a mixture of CO_2, CO and hydrogen. The bacteria are cultured into a media containing syngas which will be utilized by the bacteria and PHA will be produced as an end product. The scope of this bioconversion is very large due to presence of large number of microorganisms capable of producing biopolymers from CO_2 as stated by (Mohanrasu, Premnath et al. 2018). (Mohanrasu, Premnath et al. 2018) have isolated about 203 PHB producing bacteria from marine which clearly shows the potential of microorganisms in bioconversion. After the bioconversion has taken place, extraction and screening takes place because the polycarbonates like PHB gets accumulated inside the cells (Koch, Berendzen et al. 2020). The screening is based on the capability of the Nile red to bind to the PHB granules inside the cells (Juengert, Bresan et al. 2018) which is then extracted by using various kinds of chromatographic techniques like gas chromatography and HPLC (Hassan, Bakhiet et al. 2016). This bioconversion of CO_2 into polycarbonates not only aims to reduce the carbon dioxide concentrations in the atmosphere but also leads to the production of value-added polycarbonates. The polycarbonates produced from this are used in the industries as a raw material for various fire-resistant jackets, bulletproof vests and polycarbonate sheets (Mohanrasu, Premnath et al. 2018). Photoreduction is also employed to reduce the CO2 into hydrocarbon fuels (Kumaravel, Bartlett et al. 2020). The natural photosynthesis process is mimicked into the laboratories and hydrocarbon fuels are generated. This approach not only spontaneously hydrogenates CO2 emission but also simultaneously transforms CO2 into renewable organic compounds, like hydrocarbons (Nguyen, Nguyen et al. 2020). This method also combines solar driven water splitting and CO2 reduction and is mimicking natural photosynthesis. In this method, active H, which is directly produced from photocatalytic water splitting, is continuously used for the photoreduction of CO2 to produce solar fuel in the same photocatalytic systems.

2. **Review of literature:** Carbon dioxide can be converted into polycarbonates with the use of different kinds of materials and compounds. For efficient uptake of carbon dioxide Nanomaterials are used which provides a very high uptake of CO2 at higher pressure than the normal because of the extremely large specific surface areas that they possess and high volumes(Singh, Lee et al. 2020). Surface functionalized SiO_2 nanoparticles (SFSNPs) has been thoroughly investigated for their carbon capture activity and has shown impressive results(Kim, Fu et al. 2016). Polyethylene glycol (PEG) based gel matrix is used in which SFSNPs are incorporated and as the SFSNPs have very high affinity for CO2, they capture the carbon dioxide molecules inside the matrix. Porous-organic polymers (POPs) can also be used for the efficient capture of CO2. POPs are constructed by bottom-up assembly from Multi walled carbon nanotubes (MWCNTs) which results in the formation of POP@MWCNTs. These POPs have very high affinity for CO2 gas molecules (Haikal, Soliman et al. 2017). POPs include various frameworks like 2D or 3D structure based covalent organic frameworks (COFs), microporous material based hyper-crosslinked polymers (HCPs) and other subclasses which also mentions conjugated microporous polymers (CMP) which have high CO2 adsorption activity and very high specific surface area (Singh, Lee et al. 2020). POPs have easily tuneable pore structures and are also capable of surface modifications which makes them quite versatile materials for the capture of CO2. Metal-organic frameworks (MOFs) have also been used for the capturing of CO2. MOFs have very high surface area, unique structural properties and active metal sites which is making them

interesting candidates for the carbon capture. The adsorption capacity of MOFs can be enhanced by tuning their pore structures which in turn increases their performance. Various functional groups like (NH_2, OH, CO2H, CF_3) can be added onto the surface of MOFs by their organic ligands (Kazemi and Safarifard 2018). High surface area to weight factor is responsible for the uptake of CO2. Zeolites can also be used in the efficient capture of CO2. Zeolites are the crystalline structures based on the physical and chemical adsorbents which have a microporous cavities consisting of aluminosilicates. Zeolites help in capturing CO2 due to their high porosity and open cavities. Zeolites are made from structure directing agents (SDA) and they have adsorptive selectivity towards CO2 (Wongchitphimon, Lee et al. 2020). By the use of these CO2 adsorbing agents, carbon dioxide can be captured and further used in the biocatalysis process where it acts as raw material for the microorganisms for the production of polycarbonates.

3. Nanomaterials for CO2 conversion

Nanotechnology has played a crucial role in the CO2 capture and its utilization. Nanomaterials are very effective in reduction of CO2 owing to their surface area, morphology and structure. Nowadays many studies are focusing on the nanoparticles for entrapment of CO2 molecules because of their high potential. Various types of nanomaterials have been manufactured and identified which are being used for optimal CO2 uptake. Nanostructured carbon nitride (CN) has extraordinary optoelectronic, physiochemical properties and versatile surface functionalities which are used to capture CO2. Carbon nitride nanomaterials are hybrid molecules made from carbon (C) and nitrogen (N) which are being used as heterogenous catalysts which have a very high efficiency of CO2 reduction (Talapaneni, Singh et al. 2020). Nanoporous membranes are also used as effective means of carbon capture like nanoporous silica(5-25nm) in which, the entrapment of CO2 is dependent on the pore size and morphology of pore filing inclusions and also on the thickness of the layer (Ashley, Magiera et al. 2012). Individual carbon nanomaterials have also been studied like carbon nanotubes, graphene and nanofibers on the basis of their physical and chemical properties (Creamer, Gao et al. 2016). Titanium dioxide/graphene oxide (TiO_2/GO) nanocomposites have been constructed which act like adsorbents for CO2 (Chowdhury, Parshetti et al. 2015). Nano-casting technique can be used to synthesize carbon adsorbents in which melamine formaldehyde resin is used as a precursor. Via this technique properties of the synthesized adsorbents can be controlled and manipulated according to the extent of CO_2 required to capture. In mesoporous carbon adsorbents, nitrogen content is high and other parameters like surface area, pore volume and thermal stability affect the CO_2 adsorption rate (Goel, Bhunia et al. 2015). Interestingly, the carbon dioxide, emitted by the industries is captured by nanoparticles which are made of carbon itself, which provides a cycle in which carbon is getting captured by carbon itself. Advantages of using nanomaterials for carbon capture are enormous because of their excellent heat (Lee, Kim et al. 2020)and mass transfer properties (Lee, Kim et al. 2020). In a review given by (Lee, Kim et al. 2020), researchers have concluded that the adsorption rate of CO_2 by the use of nanoparticles can be maximized (Lee, Kim et al. 2020)when they exhibit high surface area, high thermal conductivity and magnetic properties. Nanoparticles having catalytic effects can increase the CO_2 adsorption by many folds, nanoparticle organic hybrid materials (NOHMs), have been developed which possess increased mass transfer performance for CO_2 capture (Yu, Wang et al. 2019). The increased levels of carbon dioxide have been very challenging to the environment and the conventional methods for reducing the CO_2 are not quite efficient, that is why there is a need for an efficient method which not only reduces the carbon dioxide in the atmosphere but is also cost friendly. There are many nanomaterials present in today's time which serves the purpose of carbon capture and is also quite versatile due to its manipulative characteristics (Kumar, Mangalapuri et al. 2020).

S No.	Nanoparticles	Application	Reference
1.	DD3R	High Selectivity for CO_2	(Himeno, Tomita et al. 2007)
2.	MgO nanoparticle	High CO_2 capture efficiency	(Creamer, Gao et al. 2018)
3.	Pd/Ce-Nanoparticle	High CO_2 capture activity	(Lin, Ibrahim et al. 2017)
4.	Zr-Ti-Si/PAI-HF	High CO_2 adsorption capacity	(Rownaghi, Kant et al. 2016)

5.	Au-Nanoparticle	High CO_2 selectivity	(Heo, Choi et al. 2020)
6.	NiO-Nanoparticle	High Surface area	(Li, Guo et al. 2018)
7.	CaO-Nanoparticle	High CO_2 capture capacity	(Sultana, Tran et al. 2015)
8.	Ag-Nanoparticle	High surface area and capture efficiency	(Ghosh, Khan et al. 2020)
9.	Li_2ZrO_3 Nanoparticle	Effective CO_2 capture	(Kang, Wu et al. 2010)
10.	TiO_2-Nanoparticle	High CO_2 adsorption capacity	(Tumuluri, Howe et al. 2017)

Table 1 showing various nanoparticles for CO2 capture

3.1 Porous organic polymers (POPs)

(POPs) which are also known with the name of porous organic polymers, are catching the attention of the world because of their carbon capture potential. POPs have very high specific surface area, nanoscale porosity and magnificent chemical stability due to these properties, POPs are susceptible for CO2 capture and storage. POPs also contain reactive groups in their monomers which can manipulated to synthesize varieties of distinct POPs with different CO2 capture ability (Bhanja, Modak et al. 2019). POPs are versatile in nature as their porosity, specific surface area and other parameters can be tuned according to the needs which makes them excellent contenders for CO2 capture.

High BET surface area is the most important property of POPs as it is directly related with CO_2 (Modak, Jana et al. 2018). Surface area of the specific POPs can be increased like PAF-301 shows highest CO_2 uptake capacity by (Modak, Jana et al. 2019), which had very small pores indicating that the smaller the pores are the greater the potential for CO_2 capture there is. Also, (Shao, Li et al. 2018) have carried out the synthesis of N-enhanced porous carbons which are made from the triazine compound based POPs which are inexpensive, showed better CO_2 uptake ability along with enhanced CO_2/N_2 selectivity also. Ionic POPs have also gained attention recently owing to their charge, which appears to be valuable parameter in context to CO_2 capture (Liu, Han et al. 2019). POPs have functional groups, a property which has been exploited to enhance the carbon capturing potential like amino groups which have been identified as brilliant candidates for carbon capture, have been modified by various researchers like (Wang, Zhou et al. 2017), which have modified the amino groups and observed that the modification of amino groups causes drastic decrease in the BET surface area but increases the CO_2 capture significantly. Another modification is done by (Wang, Guo et al. 2020), in which melamine has been embedded into functionalised POPs which resulted in high Brunauer-Emmett-Teller (BET) surface area and has also increased the pore volume which directly relates to higher CO_2 capture.

3.2 Metal Organic Frameworks (MOFs)

Metal organic frameworks (MOFs) have gained remarkable attention from the last two decades owing to their unique properties. MOFs are expensive and the process in which they are synthesized is costly which means they are economically usable at a large scale, but this limitation is overcome by their very high efficiency in the carbon capture (Elhenawy, Khraisheh et al. 2020). These high-cost restraints of the MOFs can be solved by the synthesis of biological MOFs (Bio-MOFs), which are prepared from inexpensive biomolecules like amin acids, proteins and peptides, which can be manufactured to adsorb CO2 (Zulys, Yulia et al. 2020). MOFs are made of metal ions in association with organic ligands to from dense networks. MOFs have extraordinary properties when it comes to CO2 capture such as high surface area, high porosity and also the organic ligands can be chemically modified to adsorb CO2 (Mohamedali, Nath et al. 2016). Mg-MOF-74 which has been used to adsorb CO2 at 298 K adsorbs 47 kJ mole^{-1} as shown by (Caskey, Wong-Foy et al. 2008). Most advance technologies which are aiming to reduce the CO2 emissions are incorporating MOFs by controlling their crystalline and pore properties to capture CO2 (Mukherjee, Kumar et al. 2019). MOFs play their role majorly in the post combustion emissions in which after the combustion process in the industries the emissions are passed through chamber of MOFs which selectively adsorb high amounts of CO2 which otherwise would be released as it is in the atmosphere (Simmons, Wu et al. 2011). MOFs provide excellent framework stability and a high BET surface area which ultimately leads to the higher CO2 adsorption. Activated HNUST-9 (Liu, Zhou et al. 2021) which shows very high CO2 adsorption and also very specific CO2 distinctive ability from the mixture of gases, shown by (Liao, Zeng et al. 2020). Association of ligands with the MOFs is very crucial for the CO2 uptake activity like amines are bridged with MOFs as ligands which overall provides a net positive charge and all the CO2 is captured via C-N bonds (Pettinari, Tombesi et al. 2020).

Table 2. indicating array of MOFs used to adsorb CO2.

Name	Operating Temp.(K)	Qst(CO2)(kJ /mol)	Reference

UPG-1	298	24	(Taddei, Costantino et al. 2014)
NU-111	298	23	(Peng, Srinivas et al. 2013)
UTSA-62a	298	16	(He, Furukawa et al. 2013)
(Taddei, Costantino et al. 2014)n	298	19.1	(Yang, Santana et al. 2014)
Basolite® C 300	318	18	(Deniz, Karadas et al. 2013)
DMOF	298	20	(Burtch, Jasuja et al. 2013)
MIL-100	304	62	(Li, Liu et al. 2020)
MIL-101	304	44	(Li, Liu et al. 2020)
MOF-74	305	42	(Gautam and Cole 2020)
JLU-Liu22	298	30	(Wang, Liu et al. 2015)
Zn-DABCO	298	22.4	(Chaemchuen, Zhou et al. 2015)

3.3 Zeolite imidazolate frameworks (ZIFs)

Zeolites are used extensively in the adsorption of CO_2 around the globe for their microporous structure which aids in the carbon capture. Zeolites are basically crystalline structure based network of holes or cavities which contain channels (Singh, Lee et al. 2020. ZIFs are suitable for carbon capture because of tunable functional groups, high chemical and thermal stability and large versatile volumes {Yang, 2020 #88. ZIFs are suitable for carbon capture because of tunable functional groups, high chemical and thermal stability and large versatile volumes {Yang, 2020 #88, Yang, Shi et al. 2020). More than 30 different topologies of ZIFs have been reported (He, Yao et al. 2013). With the aid of temperature and pressure changes the framework of ZIFs can be modulated according to the need of the experiment (Noguera-Díaz, Villarroel-Rocha et al. 2019). These flexible ZIFs are gaining attention of the researchers due to the fact that they possess inducible gas separation and sensor technology applications (Noguera-Díaz, Villarroel-Rocha et al. 2019). Not long ago, it has been demonstrated that the ZIFs retain their porosity and all chemical properties when these ZIFs are melted, which sums up that the ZIFs can exist in liquid state also (Gaillac, Pullumbi et al. 2017). Benzimidazole linkers form two small cavities in a six membered ring of Zn atoms into which CO_2 gets adsorbed, which in turn will rotate and open the cavities so that more CO_2 molecules can be accommodated (Zhao, Lampronti et al. 2014). ZIF-7 has been extensively used for experimentation of phase changes in which temperature first induces the phase change in ZIF-7 which in turn changes the narrow pore size to a broader pore size for more CO_2 molecules to adsorb (Zhao, Lampronti et al. 2014). In the further study of ZIF-7, it showed higher CO_2 adsorption at higher pressures which was associated with the CO_2 adsorption in the large pore phase (Du, Wooler et al. 2015). ZIFs are subclass of MOFs itself but they are categorized separately because of the enormous potential they themselves have for carbon capture. ZIFs combine the advantageous properties of MOFs and zeolites like high BET surface area, porosity, tunable functional groups and great thermal and chemical stability (Tzialla, Veziri et al. 2013). This high versatility of ZIFs provides large scope for the production of original products and a great leap towards carbon capture strategy. The ZIFs can be modulated as done by some researchers which have reported composite membrane manufactured by filling the intercrystalline gaps of ZIF-69 which have been made to selectively adsorb CO_2 (Tzialla, Veziri et al. 2013). ZIFs have extraordinary ability to distinguish and adsorb CO_2 from the adverse gaseous mixture of gases (Izzaouihda, Abou El Makarim et al. 2017). Various researches have been done which explains the interaction of CO_2 and ZIFs as scaling up of CO_2 adsorption by ZIFs at an industrial scale is encountering various halts. It has been reported that during the adsorption process in ZIFs, there is no distortion in the chemical structure of CO_2 which is a huge advantage (Izzaouihda, Abou El Makarim et al. 2017).

4. Carbon capture and storage

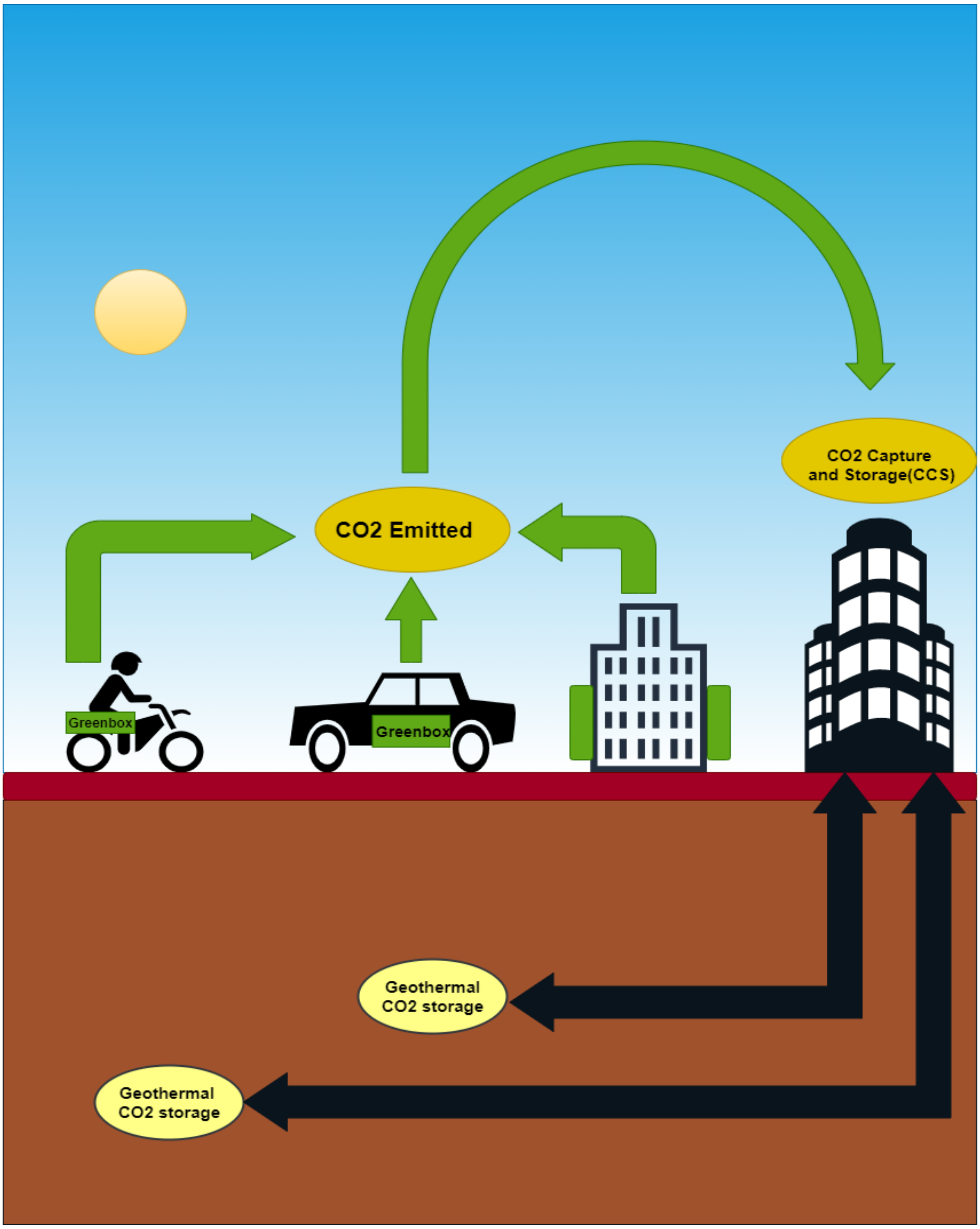

Fig. Representation of CO_2 capture and storage

(Gopinath, Rajagopal et al. 2021) Carbon capture and its storage is basically a process of capturing (Gopinath, Rajagopal et al. 2021)the emitted carbon dioxide and relocating or transporting to a local storage hub of carbon dioxide in a town or a city which now will not enter the environment or atmosphere and will not cause any kind of pollution or harm to the environment. Carbon capture from large factories like cement factories and Biomass power plant is possible with the help of a green box which contain carbon dioxide adsorbing compounds. After its capture the carbon dioxide is stored in underground level in the form of geo thermal carbon storage. By this way the large quantities of carbon dioxide are not released directly into the atmosphere and do not cause any kind of pollution and will not lead to the climate change. By storing the carbon dioxide buy geothermal way it can lead to the fulfilment of various purposes like enhanced oil recovery and many other ways. Researchers of Wales have found a tremendous way of capturing the carbon dioxide by implementing the green box to generate biodiesel production. Green box is basically a removable device which is installed in the vehicle. In the place or near to exhaust system. It is quite small in size and do not take up large space which can cause manufacturing defects it is small enough to fit in a exhaust of a car. Basically, the concept is based on vehicle exhaust system and also on the fuel. Whenever a car refuels which is containing this green box at a fuel station the Stored green box is replaced with a new one which is empty. This stored carbon dioxide can be used to culture carbon dioxide convert in bacteria and also will lead to the formation of biodiesel. The capture rate of this green box is between 85 to 95%. Not only this green box captures the carbon dioxide emissions from the vehicles but it can also be installed in the factories or Industries at a larger scale and all the emissions or major emissions can be captured and transported back to the carbon dioxide storage hub of a city. The green box contains adsorbent of carbon dioxide which includes metal organic frameworks, porous organic polymers and zeolite imidazole framework. Is fully equipped with a green box with all the functionality running it can trap up to 95% of the greenhouse gases which includes carbon dioxide and nitrous oxide also. Now whenever a car is low in fuel it goes to a fuel station from there the green box is replaced with a new one which is empty. The metal organic frameworks in the green box provide network or a system which is perfectly suitable for capturing the carbon dioxide and as well as nitrous oxide which are both devastating for our environment and are currently leading members for the climate change.

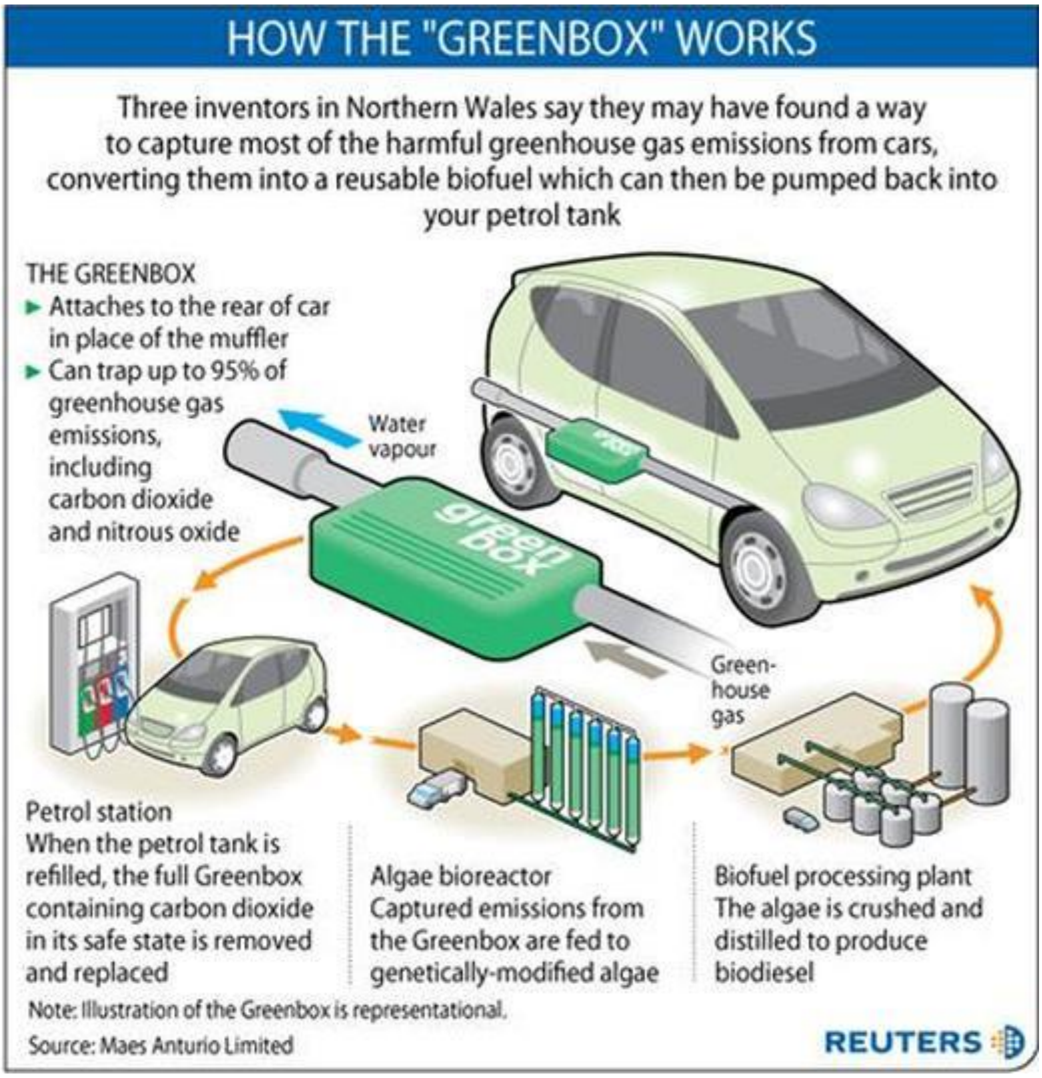

Fig. the working of greenbox demonstrated by REUTERS.

CO2 is one of the fundamental ozone harming substances that causes a dangerous atmospheric devation, prompting a worldwide impeding effect on the climate, economy, and society overall. Carbon catch is viewed as a significant and viable way to deal with diminishing CO2 outflows. This report basically tries to put light on two significant parts of CO2 catch: carbon catch advancements and carbon catch for modern applications. Three diverse carbon catch strategies, including post combustion, oxy-combustion, and precombustion, will be introduced. The development, benefits, weaknesses, and economy of the three carbon catch strategies will be looked at. What's more, different modern utilizations of carbon catch in various zones, for example, concrete and clinker creation, the iron and steel industry, water desalination, petroleum treatment facility, and the gas-to-fluid cycle will be talked about. Carbon catch can be conveyed on modern and nuclear energy stations to decrease their natural effect. By coordinating this with biomass, a lower carbon power fuel, it is feasible to accomplish net-negative discharges. Bioenergy with carbon capture and its storage (BECCS) can be cultivated in an assortment of ways, utilizing postcombustion, oxy-fuel, and precombustion alternatives. As of now, dissolvable based postcombustion catch is the most developed and accordingly will be the fundamental core interest. Key difficulties will be featured—in particular, statement, molecule vestige, and molecule enhancement—alongside the examination roads that require further examination to guarantee BECCS is deployable, at scale and in a productive and financially savvy way. To close, proof-based suggestions are made to advise strategy creators on the administrative structures essential for the effective combination of BECCS into the future energy framework. Carbon dioxide (CO2) is one of the major reasons of global warming which is still increasing repidally. CO2 capture and its conversion into valued added products has gained much attention of researchers in last decade. Conversion of CO2 into polymers such as Polyhydroxyalkanoates (PHA), Polyhydroxybutyrate (PHB), Polyurethane (PUR) and many other polycarbonates which are of industrial use. Various nano-porous materials such as nanotubes, nanosheets, nanoparticles, metal organic frames (MOFs) and porous organic polymers (POPs) have been used as absorbent for CO2 capture. By using ring opening co-polymerization, this captured CO2 can be converted into sustainable polymers and hydrocarbon-based fuels. CO2 can also be converted by photocatalytic reduction which is also known as artificial photosynthesis. Normally, this method is utilized to convert captured CO2 to value-added products by utilizing sun-based vitality, for example, light or laser. Polyesters like poly lactic acid, poly glycolic acid and polyhydroxyalkanoates are produced by using CO2 as a raw material. PHAs have also been used in the biomedical applications because of their low toxicity, biocompatibility and biodegradability. These methods can be used in the industrial scale and hence can lower the CO2 levels in the atmosphere. Capturing carbon dioxide and then utilising it into value added products is a very attractive as it not only aims to reduce the CO_2 emitted but also production of useful compounds like polymers. The main objective is to reduce overall emitted CO_2 and also to check whether the products generated from it are viable or useful in the market or not. Polymers can be prepared from CO_2 by ring opening copolymerization of CO_2 and epoxides with the help of high value catalysts. The products which are obtained from this are aliphatic polycarbonates. At low molecular weights these polymers are suitable replacements for petrochemical polyols used in polyurethane manufacturing.. The process is basically dependent on the selection of the catalyst, with a wide range of very promising heterogeneous and homogeneous catalysts have been reported recently. C k Williams et.al have shown that dinuclear metal catalysts are tolerant to a wide range of impurities found in captured carbon dioxide, including nitrogen, oxygen, oxides of carbon and NO and SO. In the study C K Williams et. Al have done, the carbon dioxide captured from a UK power station was applied and showed near-equivalent performance compared to pure carbon dioxide. They have reported a series of homogeneous catalysts for CO_2/epoxide copolymerization, based on dinuclear complexes of zinc, magnesium, CO and Fe. C K Williams et. al have used dizinc catalyst ie. $LZn_2(O_2CCf_3)_2$ in the copolymerization of cyclohexene oxide (CHO) or vinyl cyclohexene oxide (vCHO) and carbon dioxide. This catalyst has lead to the production of polymers that have molecular weights, determined by size exclusion chromatography. They have found that the polymerizations appear to be occurring under immortal conditions, whereby chains are rapidly being exchanged or transferred between the catalyst and a chain transfer agent (alcohol). PCHC or poly cyclo hexene carbonate which was formed ny this polymerization reaction was isolated by size exclusion chromatography (SEC).

Permeable materials have arisen as possible contender for this reason in view of their particular physico-synthetic attributes with high solidness and property, and astounding ozone harming substance photoreduction exhibitions (Yadav, Seidi et al. 2019). Normally, a photocatalytic ozone harming substance decrease framework incorporates a light-gathering specialist that may change over apparent radiation into energy by the age of electron–opening sets that drive the response reactions (Yadav, Seidi et al. 2019) .300 Semiconductors square measure the first unexceptionally used materials for photocatalytic ozone harming substance transformation

5. Role of microbes and biocatalytic conversion of CO2 into bio-polymers.

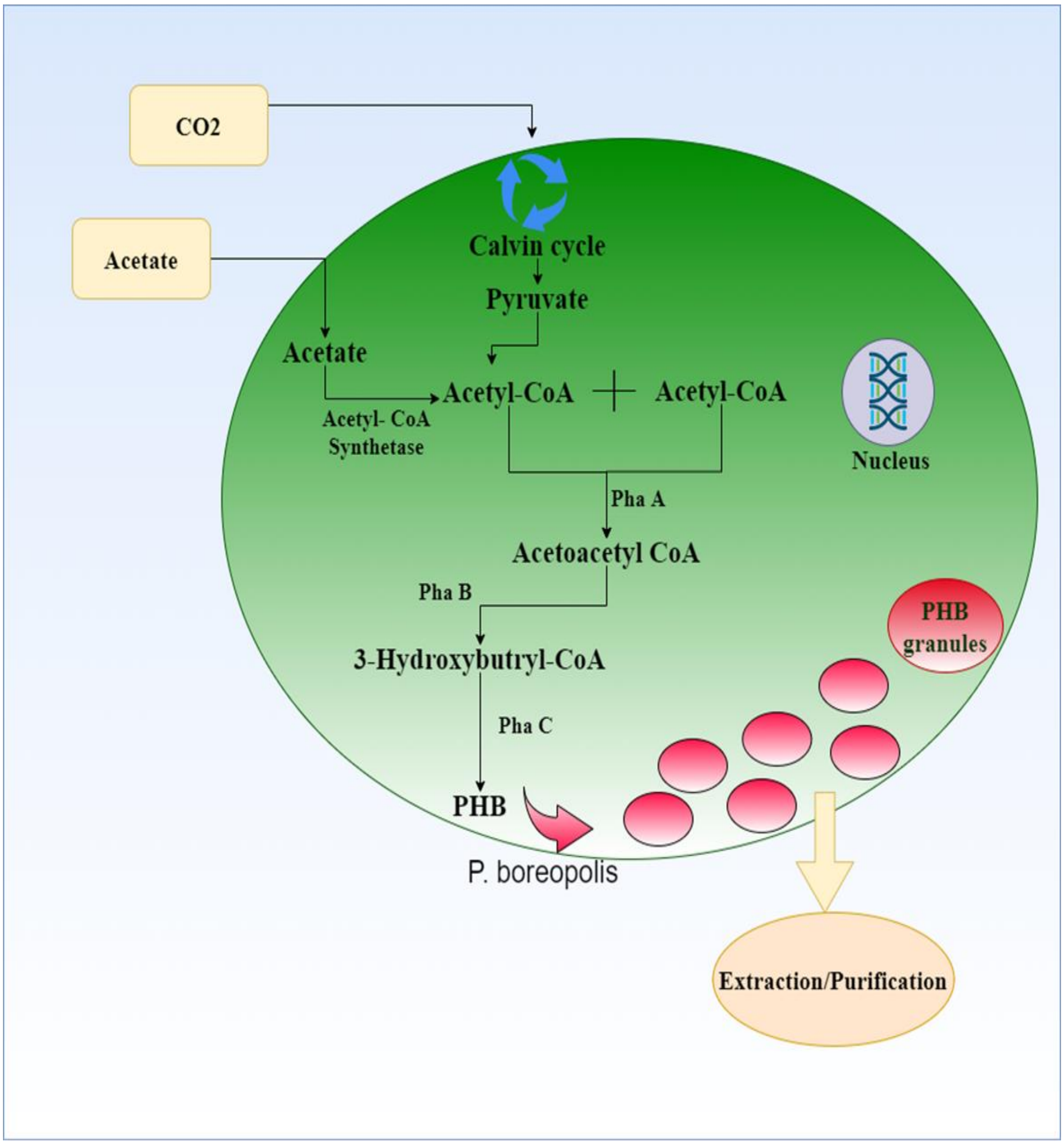

Fig. Mechanism of production of PHB granules inside P. boreopolis.

The methodology which follows is that, the CO2 is captured by porous organic polymers (POPs), Metal organic frameworks (MOFs), and various other carbon dioxide adsorbents like zeolite imidazole frameworks (ZIFs). The carbon dioxide captured is basically stored in the local storage hub of the area, and large bio-reactors are inoculated with CO2 converting bacteria like pseudomonas borepolis, Synechocystis sp. PCC6803 and various bacillus strains and these carbon dioxide converting bacteria are grown in the optimum conditions and then sudden change in their nutrient requirement is done along with the supply of the carbon dioxide to trigger the production of PHA/PHB inside the cells in the form of granules. Cyanobacteria accumulates significant amounts of PHB inside as a product of unusual metabolism. Genetic engineering also plays a very crucial role as there is heterologous transformation of the genes which are involved in the PHB production. In these bacteria the PHB is source of carbon and is produced via intermediate biosynthetic pathway of PHA. Addition of acetate can increase the PHB content and acetate will be used and converted into Acetyl-coA.The expanding effect of plastic materials on the climate is a developing worldwide concern. With respect to the present situation, it is a significant test to discover new hotspots for the creation of bioplastics. Poly-β-hydroxybutyrate (PHB) is described by fascinating highlights that draw consideration for exploration and business adventures. Surely, PHB is eco-accommodating, biodegradable, and biocompatible. Bacterial maturation measures are a realized course to create PHB. Be that as it may, the creation of PHB through the chemoheterotrophic bacterial framework is extravagant because of the significant expenses of the carbon hotspot for the development of the living being. Unexpectedly, the creation of PHB through the photoautotrophic cyanobacterium framework is viewed as an appealing option for a minimal expense PHB creation due to the modest feedstock (CO2 and light). This paper respects the assessment of four free techniques to improve the PHB creation by cyanobacteria the plan of the medium the hereditary designing to improve the PHB collection the advancement of strong models as a device to recognize the bottleneck(s) of the PHB creation to boost the creation; and the nonstop activity mode in a photobioreactor for PHB creation (Rajan, Thomas et al. 2019, Sangeetha, Thangadurai et al. 2019). The synergic impact of these methodologies could address the plan of the ideal PHB creation measure by cyanobacteria. A further restriction for the business creation of PHB through the biotechnological course are the high costs identified with the recuperation of PHB granules. Hence, a further test is to choose a minimal expense furthermore, harmless to the ecosystem cycle to recuperate PHB from cyanobacteria. Synechocystis sp. PCC6803 is used which is a strain of cyanobacteria (Gram negative). It is capable of using CO2 and sunlight to produce PHB. When nitrogen depletion conditions are employed, the bacteria induce drastic shifts in its metabolism. Generally, the polymers which are sold in the market or used in the manufacturing industries are petroleum-based polymers which are nonrenewable in nature. So, we need to make polymers in a sustainable way from renewable sources. Thus biosynthesis of poly beta hydroxybutarate(PHB) is a sustainable way of producing polymers by using CO_2 and microorganisms. The bioconversion of CO_2 into PHB contributes to the reduction of greenhouse gasses in the atmosphere. PHB is interesting because of its properties like thermoplastic processability, hydrophobicity, complete biodegradability and biocompatibility. Roberta Carpine et al have used an Algae based biomaterial production method for PHB as in this method no extra carbon source is necessary and the production systems can be easily developed. So, in context to this, Synechocystis sp. PCC6803 has been used by Roberta Carpine et al which is a strain of cyanobacteria (Gram negative), which can convert CO_2 and sunlight directly into PHB or our product of interest. Synechocystis sp. PCC6803 is quite interesting because it can induce drastic shifts in its central carbon metabolism, this property is exploited by the researchers like Anfelt et al and they have shown that under nitrogen depletion, the intracellular carbon metabolism is directed to the accumulation of PHB. Roberta Carpine et al have proposed a kinetic dynamic model which describes photoautotrophic PHB production by cyanobacteria in photobioreactors under a light/dark cycle. Two types of cells were considered in the models: growing cells and PHB producing cells. The carbon dioxide converting Bacteria is actually grown in in specific conditions or controlled conditions so that pha can be produced. Nitrogen deficient conditions are employed in the media which is already containing phosphates and other essential nutrients for the growth of bacteria which can convert carbon dioxide. Whenever nitrogen deficient conditions are employed the pha production is triggered and cell start accumulating the pha inside the cells in the form of granules. The entire mechanism is based on unusual metabolism of carbon dioxide converting bacteria which when grown under limiting nitrogen conditions can accumulate pha inside the cell. The carbon dioxide converting bacteria is grown in the culture medium which contains all the essential nutrients for its growth. Carbon dioxide which was captured from the green box and was transported to the local hub of the city for its geothermal storage, is now taken to cultivate the carbon dioxide converting bacteria. The carbon dioxide enters the cell and directly enters Calvin cycle which ultimately leads to the production of pyruvate. The pyruvate is converted into acetyl coa which is very crucial for the production of polyhydroxyalkanoates and polyhydroxy butyrate. We need excess acetyl coa inside the cell for this, the media is supplemented with acetate so that with the help of acetyl coa synthetase which is already present inside the cell can convert the Acetate which is provided from outside and convert it into another molecule of acetyl coa. We need this excess of of acetyl coa inside the cell because two molecules of acetyl coa a inside a cell of carbon dioxide converting bacteria give rise to to the formation of acetoacetyl coa with the help of of pha A enzyme which is also known as pha specific beta ketothiolase. Now this acetoacetyl coa is converted into 3 hydroxybutyrl coa with the help of phaB which is also known as acetoacetyl coa reductase. After this the final step remain which convert this 3 hydroxybutyrl coa into phb in the form of granules inside the cells. Now be then you can be subjected to Nile red staining which can screen the phb granules and at last extraction and purification and as well as characterization of phb granules can be done.

Cyanobacteria show every one of the benefits of microbes when contrasted with the chemoheterotrophs. Also, cyanobacteria are described by the possibility to misuse daylight energy and to change over CO_2-plentiful and not cutthroat carbon-based feedstock into a result of interest, like PHB. Two further benefits of the cyanobacterial framework are that they don't contend with the agro-food market for assets and they add to catch and to utilize the CO_2, diminishing the pressing factor of the ozone depleting substance discharge into the climate. Cyanobacteria—or blue green growth—are prokaryotic living beings that have end up being intriguing as a result of their likely commitment to the maintainable economy. They can perform photosynthesis catching free energy from (daylight for the union of ATP and NADPH. Significant items from CO_2, daylight, and water can be delivered by photosynthetic digestion. The range of expected uses of cyanobacteria or of their parts is extremely enormous. Cyanobacteria have been utilized as food and feed sources. Strains of Spirulina are plentiful in nutrients and proteins and are utilized as food supplement. One of the biggest mechanical utilizations of cyanobacteria is their capacity of being successful composts. Since cyanobacteria can fix nitrogen, they can offer help for plant development in rice fields Cyanobacteria were likewise explored to deliver hostile to parasitic, against bacterial, and hostile to disease specialists. The cyanophycin polymer, worked from aspartate what's more, arginine, can supplant polyacrylate (which is gotten from propylene and accordingly from oil) in paints and surface coatings.

6. Applications of PHA/PHB

PHB is basically used as a thermoplastic - which implies it unwind and condenses when warmed. It is insoluble in water, yet has powerless insurance from acids and bases and deteriorates in chlorinated solvents. Beside the high creation cost, the central issue with using PHB to make purchaser stock is its respectably poor mechanical properties. Inferable from the common segment by with PHB is made, it has an exceptionally standard plan - it is absolutely isotactic, which suggests that all of the side social events on the polymer chain point a comparative way. This makes the chains structure helical plans, with the side social events all pointing away from the point of convergence of the helix to restrict steric avoidance. The chains thus pack together successfully to shape valuable stones, and the clear thought of the polymer makes it delicate and firm. Another drawback is that it is difficult to gauge in a fluid state since it starts to ruin at temperatures almost no higher than the conditioning temperature of 175 degrees celsius to overcome a bit of these issues, the bacterial creation communication can be acclimated to convey PHB that is copolymerised with polyhydroxyvalerate, or PHV. This makes the development more erratic and likewise less clear and less delicate, yet simultaneously biodegradable. Copolymerisation also brings the melting temperature down to anything as low as 75 degrees Celsius , dependent upon the overall degrees of PHB and PHV, which makes the copolymer significantly easier to gauge. The degradation time depends upon the construction, similarly as the environment. It might be practically pretty much as little a few months, for example in a sewage works, where there are a lot of tiny creatures to eat up the polymer. In the sea, where there are less microorganisms, it requires fairly more, a few years, yet sitting on a rack, for example at home in your kitchen or bathroom, the plastic will continue to go for a significant long time. CO2 based polymers like Polyhydroxyalkanoates (PHA), Polyhydroxybutarate(PHB) and other polycarbonates are utilized in the electrical business like DVDs, Hard drives, SSDs and Bluray circles. Making polymers from CO2 (which produced by the businesses because of consuming of petroleum derivatives) helps in the assembling of polymers as well as lead to decrease of carbon impression. These polymers got from CO2 discovers applications, for example, Electrolyte parts in Li-particle batteries.Biomedical applications because of low poisonousness and biodegradability. Drug applications like medication conveyance and tumor imaging.

7. Conclusion and future objectives

Due to increasing human population, deforestation, industrialization, planet earth is suffering the loss of its natural resources (Wagner 2017). Increasing rates of burning of fossil fuels(Muneer, Rasul et al. 2020) and minerals have increased the climate change to a point where it is affecting every aspect of life (Abbasi 2020). Due to industrialization, the plastic production and its usage has gone off the charts as every product made nowadays uses plastic, for this very reason plastic accumulation in form of waste has become major concern because the plastic waste takes very long periods of time to degrade which is also affecting marine life (Ronkay, Molnar et al. 2021). There is a need for the sustainable synthesis of biodegradable polymers which can be used at an industrial scale and can be degraded quickly (Windsor, Durance et al. 2019). Biopolymers such as PHA, PHB and PLAs can be used to make bioplastics at n industrial scale, it is done by the action of biomass produced by suitable microbes which can be obtained from different sources (Hawas, El-Banna et al. 2016). microbes have enormous potential in producing industrial-grade polymers such as PHA and PHB as these microbes produce polymers owing to their unusual metabolism. PHA are basically polyesters produced by prokaryotic (Muneer, Rasul et al. 2020)microbes such as cyanobacteria in the form of granules (Sedlacek, Slaninova et al. 2019). These PHA granules are formed as a source energy inside the cells under limited supply of nutrients and excess of carbon sources. PHA has gained much attention by the researchers because these can be used as an alternative to the petroleum-based plastics (Sedlacek, Slaninova et al. 2019). Poly-β-hydroxybutyrate (PHB) is extraordinary compared to other biodegradable polymers among those proposed

as options in contrast to regular plastics. The photoautotrophic arrangement of cyanobacteria is thought of the arrangement of decision for a minimal expense creation of PHB. One of the difficulties is to deliver the PHB creation by cyanobacteria, a serious cycle, utilizing different procedures portrayed in this paper: (I) medium streamlining; (ii) hereditary designing methodology; (iii) tuning of numerical model for cyanobacterial development and coupled PHB creation; (iv) PHB creation utilizing ceaseless tasks. The synergic impact of the upgrades accomplished with these methodologies will allow the best opportunities to augment PHB creation by cyanobacteria. Up until this point, the fundamental downside of the business creation and utilization of PHB in the business is its high creation cost contrasted and ordinary plastics. The recuperation of PHB granules from cytoplasm altogether builds complete preparing costs. The other huge test of the PHB creation measure from cyanobacteria is to track down a minimal expense and harmless to the ecosystem methodology to recuperate it. Plastic materials began from petrochemicals cause genuine ecological issues because of their non-degradable nature. Such artificially delivered polymers are for the most part economical, however their perseverance has a critical natural effect. With the unavoidable non-renewable energy source emergency, the disturbing pace of petrol costs and ecological effect related with the items, the quest for choices is fundamental in diminishing humanity's conditions in non-inexhaustible assets. Biodegradable plastics offer the best answer for shield the climate from risks brought about by regular oil-based plastics as they are 'eco-accommodating' in nature. There are numerous kinds of biodegradable plastics with various levels of biodegradability. Among them polyhydroxybutyrate (PHBs) are the lone 100% biodegradable ones. PHBs are macromolecules integrated by microscopic organisms and are incorporation bodies gathered as hold material when the microorganisms develop under various pressure conditions. They are polymers having properties like different manufactured thermoplastic like polypropylene. This makes them valuable for broad applications and future business large scale manufacturing of biodegradable plastics that can supplant plastic materials at present got from oil bases. Nonetheless, a significant issue for broad creation and commercialization of PHBs is their high creation cost as contrasted and plastics got from petrochemicals. As of late, much exertion has been resolved to lessen the creation cost of PHB by utilizing methodologies, for example, creating productive bacterial strains, improving maturation and recuperation measures. Most reports in regards to the creation of PHB proposed that, the significant supporter of the generally PHB creation cost was carbon substrate cost. Thusly, the choice of proficient carbon substrate is a key angle, which confirms the absolute expense of the eventual outcome. The elective methodology is to pick sustainable, monetarily achievable and most promptly accessible carbon substrates for both microbial developments and proficient PHB creation. Thusly, the goal of the current investigation was to segregate PHB creating microorganisms and study its PHB creation from rural waste materials.

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