Environmental Biotechnology
Prof. Pinaki Sar
Department of Biotechnology
Indian Institute of Technology, Kharagpur

Lecture – 49
Carbon Capture**, Carbon Sequestration and Utilization**

Welcome to the 49th lecture of our course and in this particular lecture, we are going to talk about the carbon capture, sequestration and utilization processes and the role of environmental biotechnology and scope of environmental biotechnology in that.

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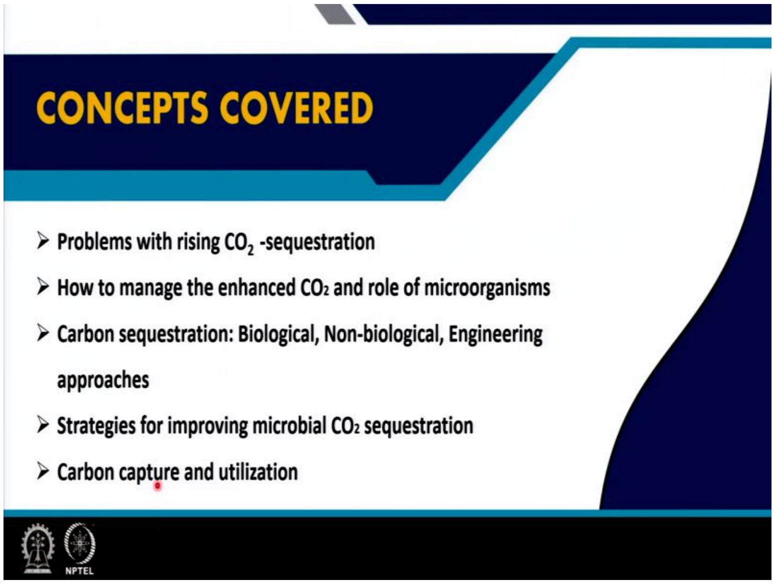

So, these are the following concepts which will be covered we will briefly discuss about the problem of rising CO concentration and then CO 2 sequestration and the carbon sequestration processes, particularly the biological one, will be highlighted. And strategies for improving the microbial CO 2 sequestration will be discussed in details and followed by these are the carbon capture and utilization processes will be are highlighted.

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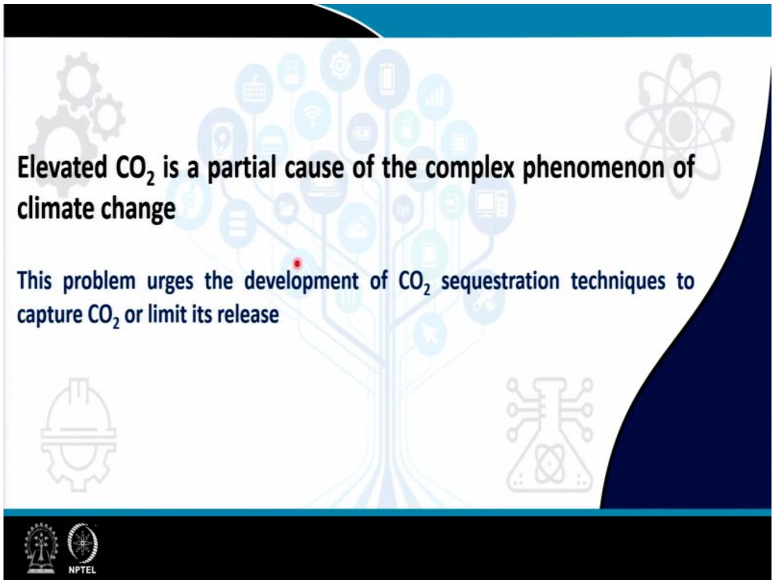

Now elevated carbon dioxide is a partial cause of the complex phenomenon of climate change and these elevated CO 2 concentration is urging all of us towards the development of CO 2 sequestration techniques to capture the CO 2 from the atmosphere ought to reduce its release.

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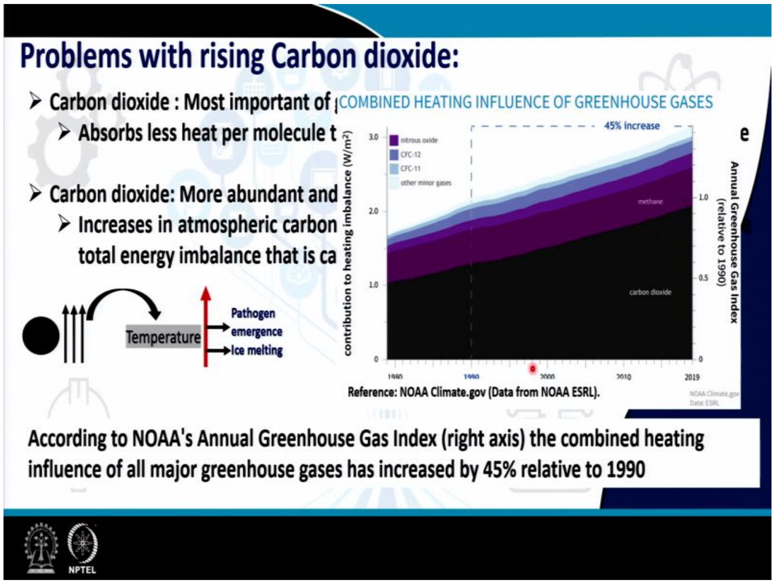

Now the problem with the rising carbon dioxide is multidimensional. It is considered to be one of the most important greenhouse gas it absorbs less heat part molecule than the greenhouse gases methane or nitrous oxide but it is more abundant and stays in the atmosphere a much longer. Increases in atmospheric carbon dioxide are considered to be responsible for about 2 thirds of the total energy imbalance that is causing the art temperature to rise and essentially, if you look at the data that is available for the for the NOAA's Annual Greenhouse Gas index.

The the combined hitting influence of all major greenhouse gases can be seen and we can identify that the role of carbon dioxide is pivotal.

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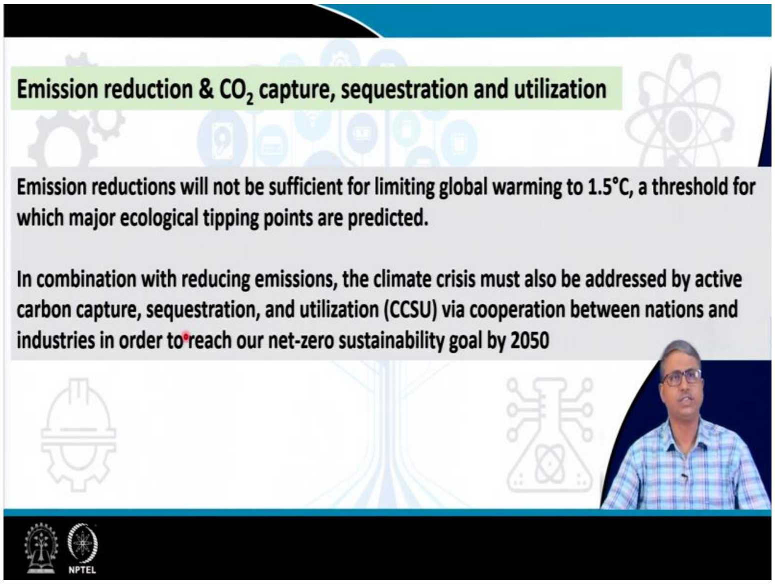

Now the emission reduction and show to capture sequestration and utilization is considered to be one of the priority areas of environmental biotechnology. Though physical and chemical methods are also developed, and in practice for mitigating this high carbon dioxide concentration presented the atmosphere. Now the emission reductions, who had mostly the physical and chemical technologies are more prominent.

It is found that these emissions reductions will not be sufficient for limiting the global warming to one point five degrees centigrade. A threshold which is considered and for a major ecological tipping point that is predicted. In combination with reducing emissions from the major industries who are releasing the carbon dioxide as part of their industrial processes, the climate crisis emerged due to this, rising carbon dioxide concentration must also be addressed by active carbon capture sequestration and its utilize by the cooperation between nations and industries in order to reach out to innate zero sustainability goal, which is said for the year 2050.

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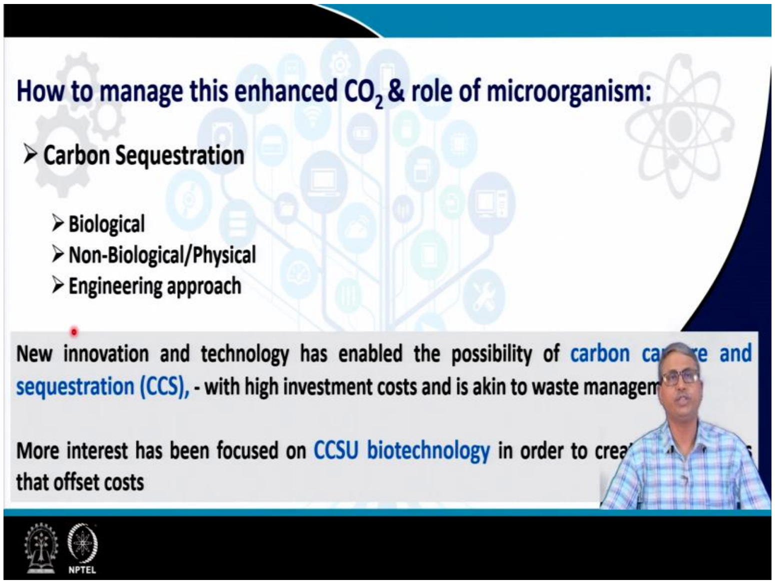

Now how to manage this enhanced CO 2. So, one idea is to reduce the emission that we talked about, that the industries are trying to develop technologies to reduce the emission, but at the at the other hand, we have the prospects are we have the opportunities to use technologies or develop technologies. Particularly using the micro organisms that sequestered or remove the atmospheric carbon dioxide and convert into a form which is safe and in the sequesters form a long period of time and more to that, if we can convert that carbon dioxide through biological systems, microorganisms in particular into valuable products.

So, carbon sequestration basically can be done either by biological or by physical approach or non biological approaches, and also using different tools technologies of engineering concepts. New innovation and technology which are being developed has enabled the possibility of carbon capture and sequestration, which is conventionally abbreviated as CCS with high investment cost and is akin to waste management.

That is that is considered to be one of the drawbacks of the non-biological processes because investment cost and also the waste management with each are likely to be generated from that. So, more interest has been focused CCSU biotechnology. Now U comes because of the utilization part. So, carbon capture and sequestration CCS and then U utilization, so, it is not only sequestering the carbon, but also converting the sequestered cardboard into some form, which is useful for the humankind or for our industry or other purposes.

So, there biotechnology plays a big role, and that actually is considered to be creating a value a chain from the from the carbon which is being captured.

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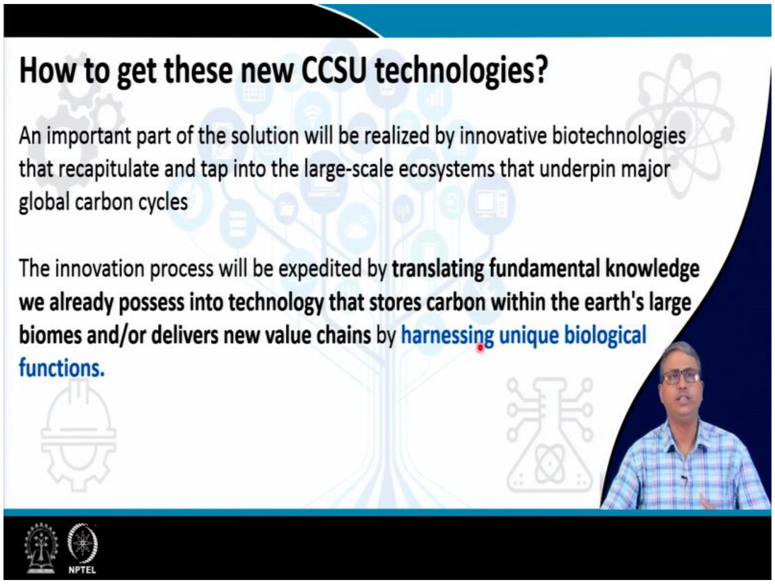

Now how to get these new CCSU technologies: An important part of the solution will be realized by innovative biotechnologies that recapitulate and tap the large scale ecosystem that underpin major global carbon cycle. Now, it is important to understand that these large scale ecosystems like the soil like the ocean, like the deep earth crust they have been cycling carbon for billion years. From the very beginning of this art or the planet, they are cycling or their their their the house or there, the place where the carbon is being constant being recycled from different solid phase or rock hosted carbon to the the atmospheric carbon.

So, it is important that biotechnologist, particularly the environmental biology try to look back and see how these large scale ecosystems are functioning and what we can learn from them, the global carbon cycles and then implement those in developing the CCSU. The innovation process will also be expedited by translating the fundamental knowledge we already deposit because we have lots of knowledge information about the cardboard cycling, which are taking place in these large ecosystems.

And we need to actually translate this knowledge into technology that store carbon within the art large biomes are delivered to new valuation like, for example soil, soil carbon cycle is known pretty well known, but if we want to develop a technology. We need to look into the soil carbon cycle into that aspect. So, that the carbon which is which is naturally sequestered within the within the soil system can be developed as a process to mitigate this high carbon dioxide into the atmosphere.

And not only that we need to also develop technology from our knowledge base. So, that is sequester carbon maybe from soil itself is converted to some kind of valuable products and for that we need to harness the unique biological functions.

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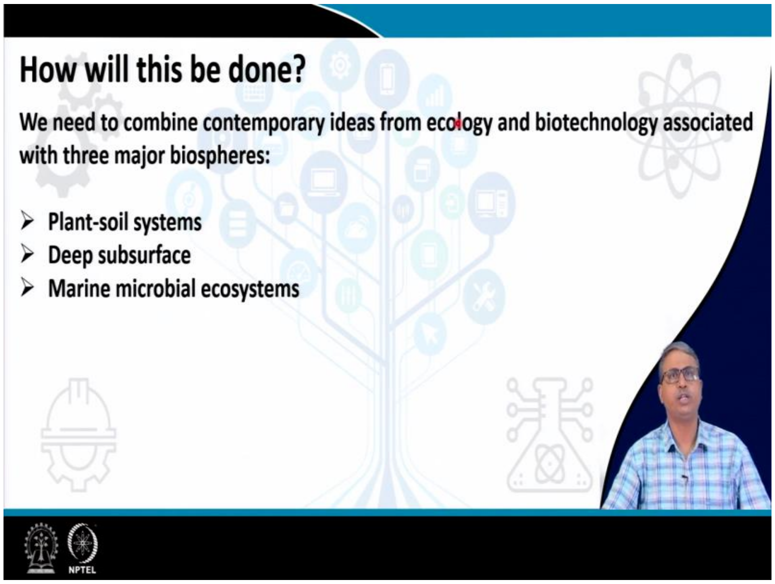

Now how will this be done. So, we need to combine the contemporary ideas from the ecology and biotechnology, which are basically the core of the environmental biotechnology and which are associated with three major biosphere plant soil systems, deep subsurface and marine microbial ecosystems,. So, these three systems are identified because these are representing the largest ecosystems where natural carbon cycles are going on.

And so, far, we have partly understood, at least with respect to some of these systems, like a planned soil system for example to some extent the marine microbial ecosystem. Deep subsurface, however is not very well understood by the scientists, but once we identify that, that, that, that can be a large repository of the global carbon. Increased attention has been paid in last

2 decades, at least to understand the deep subsurface carbon cycling processes.

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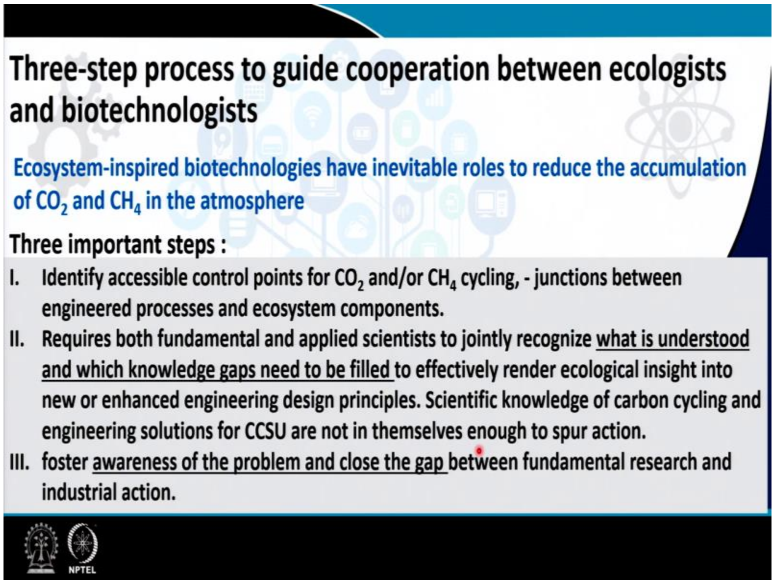

Now there is a three step process identified to guide the cooperation between the ecologist and the biotechnologist, more specifically for the environmental biotechnologist. So, we will see what are these three step processes? These are called ecosystem inspired by technologies, and these have inevitable roles to reduce the accumulation of CO 2 and methane in the atmosphere. So, what are these steps? The first step is to identify the accessible control points are for the CO 2 and our methane cycling.

Because we know that within the soil system, this carbon and submitted are being cycled. Rather the carbon is cycled through this carbon dioxide and methane. Now what are the accessible control point what are the junctions between the engineered processes and ecosystem component and that requires possibly the fundamental and applied scientists to work jointly and recognize what is already understood and which knowledge gaps need to be filled to effectively render the ecological insights into new or enhanced engineering design principles.

So, that is something which help which will help us to translate the knowledge that we have about the carbon cycling into an effective technology. Now the scientific knowledge of carbon cycling and engineering solution for CCSU are not in themselves, enough to spark the action knowledge is not enough we have to actually get the the knowledge gaps identified and work together so, that we can feel these gaps and developed the technologies and translate technology into effective technologies.

And this also requires the third step is fostering the awareness of the problem and close the gap between the fundamental research and industrial action.

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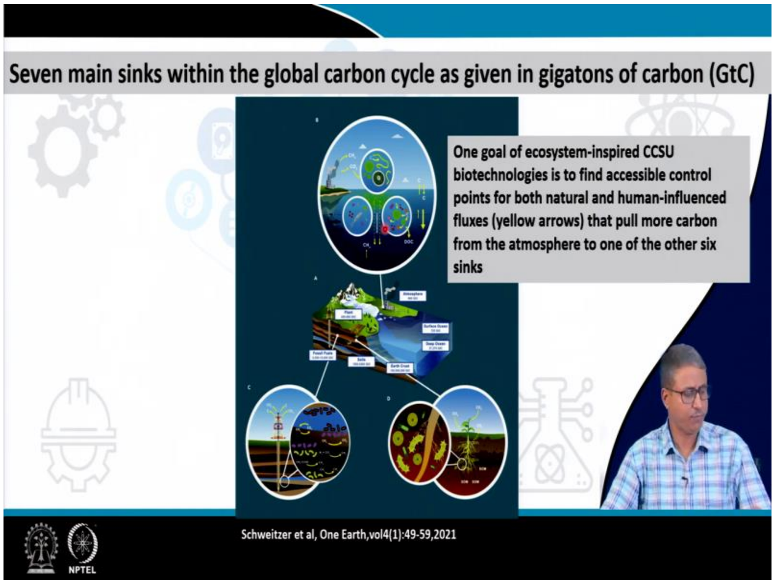

So, it has been clearly identified in a very recent paper in one earth. So, the references cited here is all, and also we have placed the references back of the end of the presentation that seven men sinks are there within the global carbon site. So, this has been this has been known for decades, but if we want to look very critically that the seven sinks are very well delineated like the atmosphere in the plant in the the problem of the fossil fuels and the soil in art craft in deep ocean and in the surface motion.

So, these are the seven things identified. Now one goal of ecosystem inspired CCSU related biotechnologies is to find the control points. Control points in order to party both natural and human influenced fluxes. So, how natural carbon flux, like the yellow arrows are indicating the carbon movement how the entrepreneurial activities and how the natural activities are responsible for controlling the carbon fluxes within the seven sink.

And that possibly will be important to identify the point that pulls more carbon from the atmosphere to one of the other six sinks. So, one is the atmosphere, but the other six sinks are there where the carbon can be sequestered and possibly they can be converted to useful product also. Now the points of control are very important.

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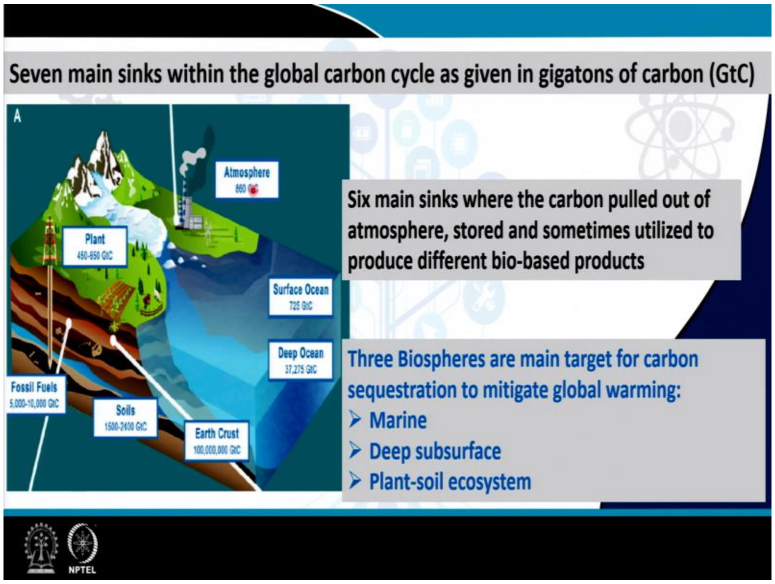

Now these are the six sinks that could be potentially utilized except the seventh one that is the atmospheric one because we want carbon to move from atmosphere to rest of the six sinks. Now these six main sinks where the carbon pulled out atmosphere stored, and sometimes it can be utilized to produce defined bio based products the second interesting aspect of the entire story of the environmental biotechnology based carbon sequestration.

Because there we think of the the circular economy or maybe halogen system that we convert the carbon not only remove the carbon, but also try to convert the carbon into some valuable products and the three biosphere,. So, these six things together, we can actually converge, we can think of converging them into three biospheres, which are considered to be the main targets for carbon sequestration to mitigate the global warming.

And these are the marine system that is, oceanic both the surface ocean and the deep ocean deep subsurface of the terrestrial crust or or the earth crust, plant soil ecosystem which is where the entire soil is found to be the major part of the biome where the carbon can be sequestered and can be utilized or can be converted to sample now.

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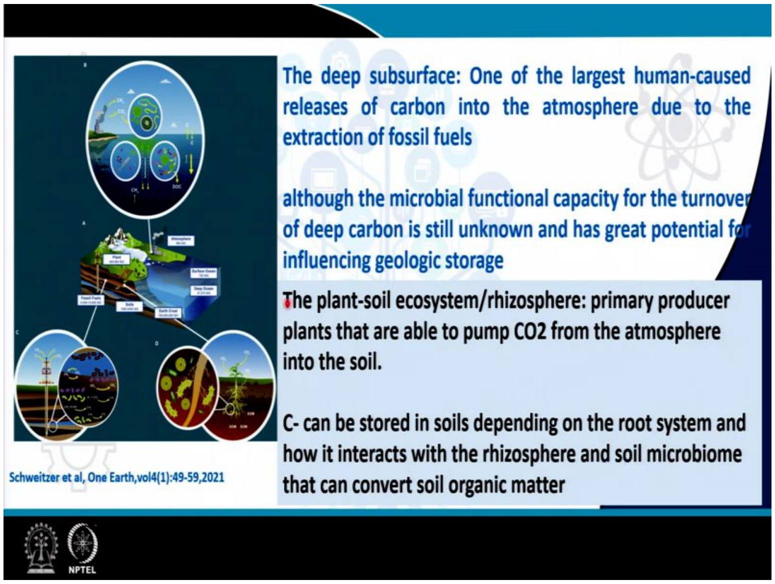

Let us see these parts in little more details. Now the deep subsurface, particularly, is less known but in recent past, as I mentioned last 2 decades, we see very, very interesting observations are coming and people are gaining interest in this particular domain of the earth that this is considered to be one of the largest human caused releases of carbon into the atmosphere due to the instruction of fossil fuel.

So, we have been continuously dragging the fossil fuels from these deep subsurface, but how about returning this carbon dioxide back to this deep subsurface, because naturally, we the call the fossil fuel, the natural gases, these are the source of all the carbons that we are using today. And most of the carbon dioxide present in the atmosphere is actually coming from the particularly the anthropogenic release component.

But how about this, that developing technologies particularly biotechnologies; where the microbial functional capacity can be enhanced. So, that the turnover of the deep carbon can be reversed so, that the carbon can be stored instead of the carbon is lost as a gaseous form. And it is interesting that this microbial functional capacity within the deep subsurface of the earth crust remain largely unknown and it has shown great potential for influencing with the geological carbon storage.

The second aspect is the the plant soil ecosystem or the we conventionally call the rhizospheric region because the primary producer are the plants who are naturally able to capture the atmospheric carbon dioxide and during their photosynthetic convert this carbon dioxide into complex organic molecule. And part of these molecules are being continuously pumped into the soil system because the plants are having profuse route system and through the routes, they release a large amount of carbon.

Now carbon can be stored in soil depending on the root system and how it interacts with the rhizosphere that the root associated soil zone and the soil microbiome. So, there are actually three components one is the plant root system, another is the plant root root system associated soil system, and then the rhizospheric and the soil bulk microbiome, which are actually responsible for controlling the fate of the organic matter, which is being released or produced by these green plants within this soil. So, this needs to be looked into in detail.

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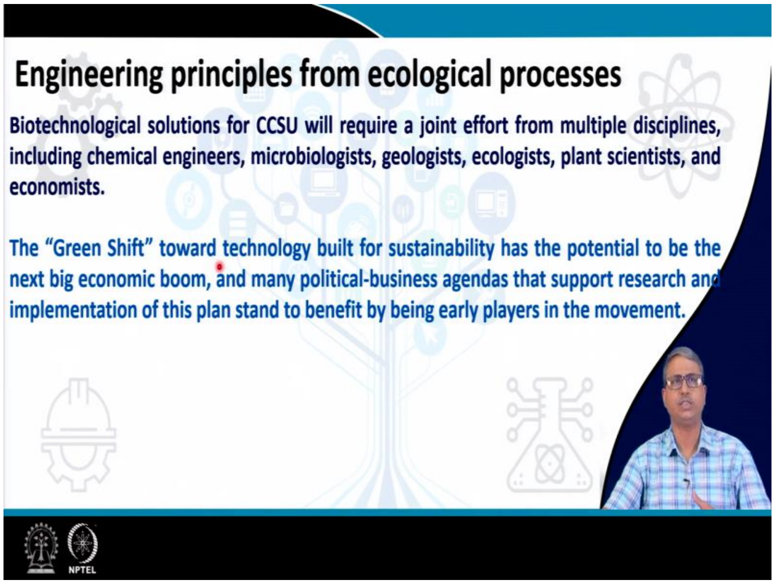

Now with respect to the engineering principle from ecological processes, the biotechnological solutions for CCSU will require the joint effort from multiple disciplines, including the chemical engineers, microbiologist. geologist, ecologist, plant scientist and also economist. And the green shift concept has emerged, which is basically green sipped we call towards technology built for sustainability that has shown the potential to be the next big economic boom.

And many political business agendas that support research and implementation of this plan stand to benefit by being early players in the movement.

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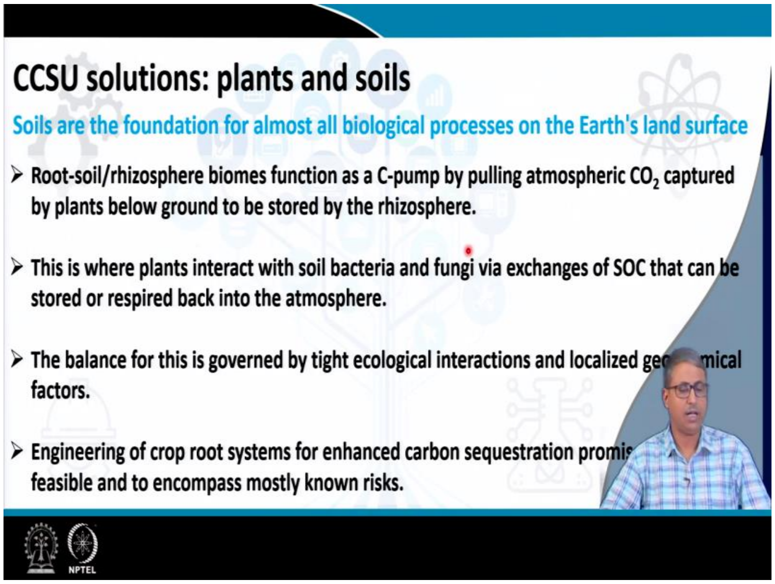

Now first, we will see the plants and soil soils are the foundation, as I mentioned. for almost all biological processes on the earth land and root soil rizhosphere function as a carbon pump by pulling the atmospheric carbon dioxide captured by the plants and then below the ground, transferred it and stored in the rizhospheric region and in this region. The plants interact with soil bacteria and fungi via the exchange of SOC that is, the soil organic carbon that can be stored or respired back into the atmosphere.

So, basically the root system is delivering the carbon which is originally fixed from the atmospheric carbon, and then they are releasing the SOC’s. These SOC’s are being metabolized by the organisms, presenting the rizhosphere in the carbon dioxide, and this SOC organic carbon is getting converted into carbon dioxide and the carbon dioxide or methane it is been coming out into the atmosphere.

Now the balance for this, that how much carbon will be assimilated by the plant and released into the soil as a SOC and then how much SOC will be oxidized by just file microorganisms, and they will be converting them into gaseous form. So, there must be a balance, and this balance for adequate carbon sequestration is governed by the tight ecological interactions and localized geochemical factors.

The engineering of the crop root systems for enhanced carbon sequestration promise basically to be to be feasible and to encompass mostly known risk.

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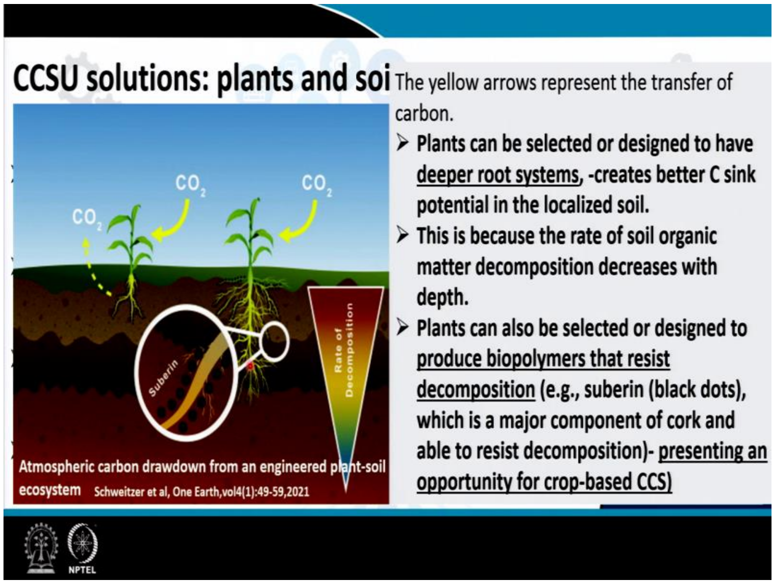

Now in case of plant system with a league, see there are actually 2 aspects. One aspect is the plants can be selected to design having a very deep root system, creating the better carbon sink potential in the localised soil. So, the deposit route, more carbon will be sequestered in the soil zone because the rate of soil organic matter decomposition decreases with get deeper, it will be less will be the oxygen level available, and the activity of the aerobic heterotrophic microorganisms oxidizing the organic card, would it be less.

Plants can also be selected or designed to produce biopolymers that resist the composition, for example, the suberin type of molecules, which are represented here as the which is a major component of cork and able to resist decomposition. So, so plants can be selected who are able to naturally produce more suberin type of molecules, and these molecules will stop the ready decomposition of this organic material that would possibly present an opportunity for crop based CCS.

So, on the above ground we can grow the crop harvest the fruits, vegetables, flowers, leaves, etcetera, but at the same time, we can allow more carbon to be sequestered safely within the soil.

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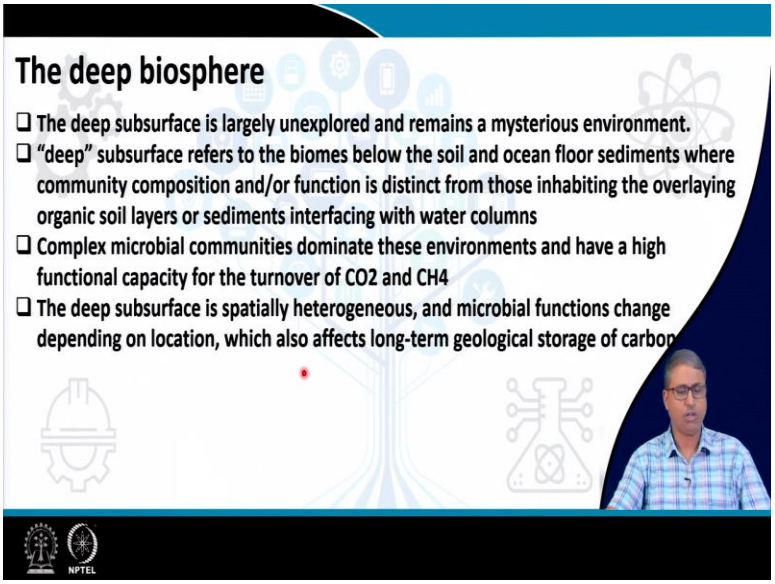

Second is the deep biosphere, the deep subsurface is largely unexplored and remains a mysterious environment. And when we say it is a deep surface, it is a few meters below the top surface and it is referring to the biomes below soil ocean floor sediment where community composition, microbial community composition and the functions microbial community functions and are found to be different from those inhabiting the overlying organic soil layer or sediment interfacing the water columns in place of the the oceanic system.

So, the both oceanic deep subsurface and the terrestrial deep sub surfaces are found to play very important role in sequestering the carbon. Complex microbial communities are found to dominate these environments both the oceanic crust, as well as the terrestrial crust and these organisms, as I mentioned, are not very well characterized, but they show potential high functional capacity for the turnover of carbon dioxide and methane.

Deep subsurface is specially heterogeneous from place to place because of the composition of the rock crust and microbial functions also will change depending upon the data, depending upon the location, availability of different substrate, etcetera which also affects long term geological storage of the carbon.

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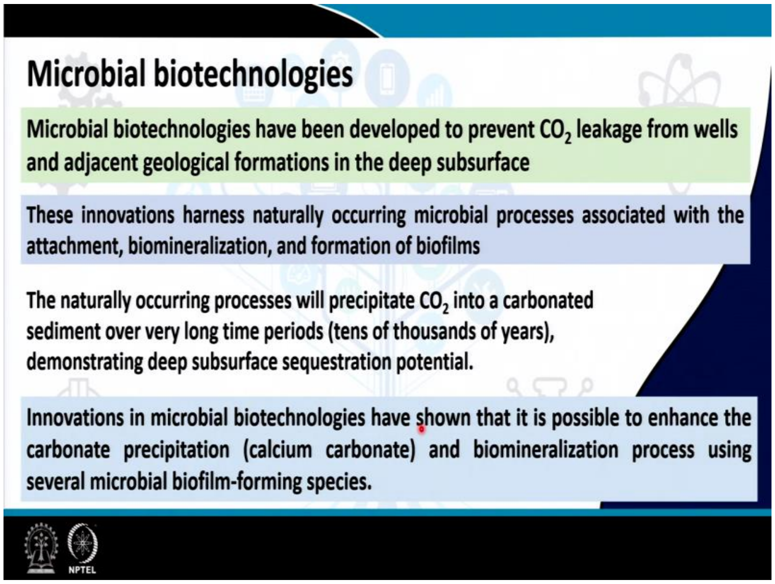

One of the approaches was the injection of the carbon in the basaltic crust, where you can see that there are several efforts are being internationally done where we can see that the water and carbon dioxide is injected into the basaltic rock crust so, that long term storage of carbonate minerals can be achieved. So, this is how to be an attractive strategy, it is called geo sequestration of carbon dioxide, particularly in the basaltic crust.

Because the technology for injecting something into the underground system is already existed because of the microbial enhanced oil recovery or something similar, and it has already been applied for for example, the oil recovery although geologic CO 2 sequestration has a key role to play in managing atmospheric carbon dioxide. And already, as I mentioned, being practiced in several countries and several places, many current technologies are viable only for temporary storage.

Meaning; that more innovation is required to fully understand the carbon dioxide sequestration and long term storage of the carbon, particularly considering the leakage factor. Hence, while the deep subsurface represent a major scene for CO 2 more knowledge need to be gained or you should understand the resident microorganisms present in the this geogenetic geological startup where the carbon dioxide is stored.

So, that we can enhance or limit the long term storage maybe the leakage can be controlled or the enhanced CO 2 carbonate formation or mineralization can be far formed. Now microbial biotechnologies have been developed to prevent CO 2 leakage from example from the oils and adjusted geology formation in the deep subsurface. These innovations harnessed naturally occurring microbes microbial process associated with the attachment, bio, mineralization. and formation of biofuel underground where the CO 2 is being injected.

The naturally occurring process will precipitate CO 2 into the carbonate or carbonated sediment over a very long period of time tens of thousands of years, demonstrating deep surface sequestration potential. However, innovations in microbial biotechnology has to be done more has to be done because we have seen that it is possible to enhance the carbonate precipitation and by mineralization, but more research and development of technologies are required.

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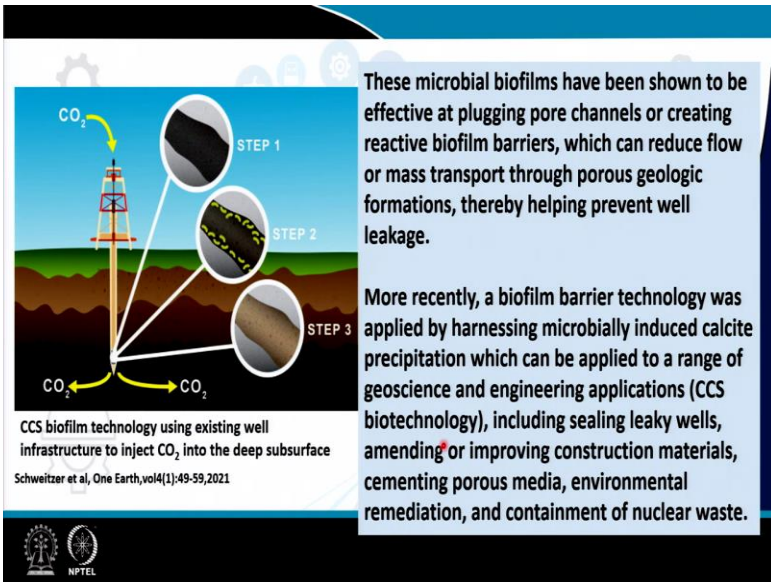

So, some of the aspects like the CCS biofilm technology, which helped in three steps like the microbial biofilm can actually allow in in effective plugging up the pore channels over there.

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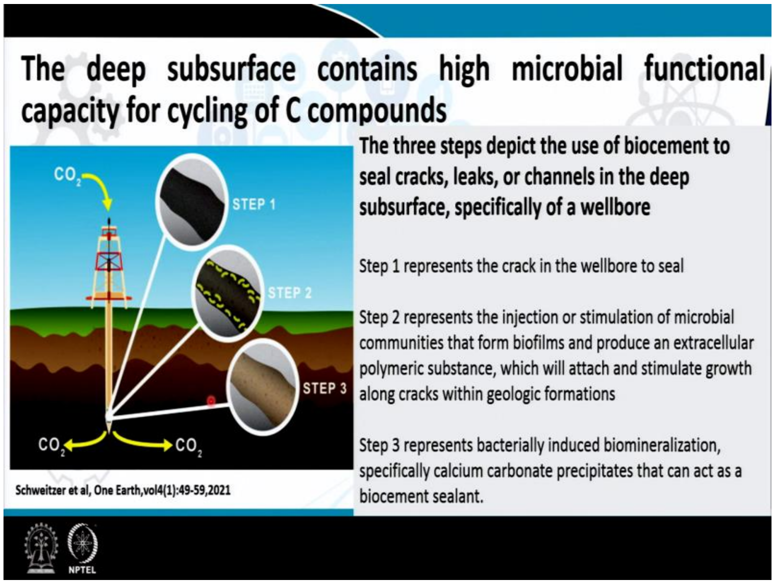

And we can see that there are definite advantages for this. The deep subsurface contains high microbial functional capacity for cycling carbon compound. And biotechnologies that seal the wellbore to reduce the leaking of CO 2 or methane are being developed to manage the carbon storage. Now there are three steps into this. These three steps are used to biopsy meant the seal cracks, leaks or channels in the deep surface specifically of the well bore.

Step one in this case represent the crack in the wellbore to seal. So, the microbes form by a film and help in selling this wellbore. Crack in the wellbore. The second step is injection or stimulation of the natural microbial committee that form biofilm and produce an extracellular polymeric substance EPS material, which will attach and stimulate growth along the cracks within the geologic formation.

So that is the step 2 and in step three bacteria bio mineralization process can be induced, specifically the carbon calcium carbonate precipitation that can act as a bio cement or sealant to seal the leakage, thereby allowing the long term of sequestration and innovating the leakage of the carbon dioxide underground of mosquito studying startup.

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Similarly, the marine microbiomes and microbial biotechnology are also gaining importance because the photosynthetic microbes specifically, the algae and cyanobacteria, they have shown enormous potential marine phytoplankton, benthic microalgae, the atoms they are showing huge potential because they can contribute to the 20% of the global primary productivity, for example, and despite the favorable biomass productivities it is still widely understood that economic feasibility limits the application of industrial scale algal CCSU.

It new values value and socioeconomic drivers for these technologies are emerging, which includes the food, feed and sustainable bioproducts, particularly from the marine organisms. And multiple industrial and pilot scale efforts are in operation, particularly with respect to the marine carbon sequestration and utilization, including Europe, North America and Asia.

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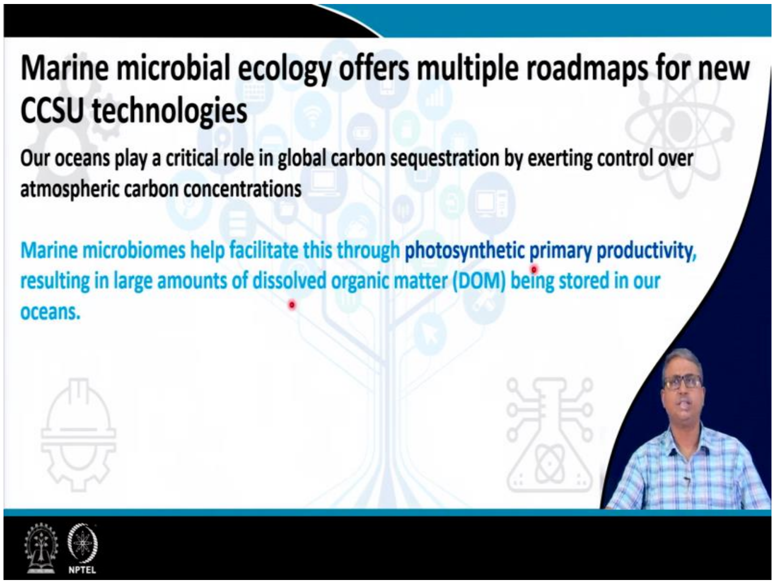

A marine microbial ecology offers actually multiple roadmaps for new CCSU technology because our oceans play critical role in global carbon sequestration particularly, the many microbiomes help facilitate to the photosynthetic primary productivity and resulting in large amount of dissolved organic matter DOM being stored in our ocean.

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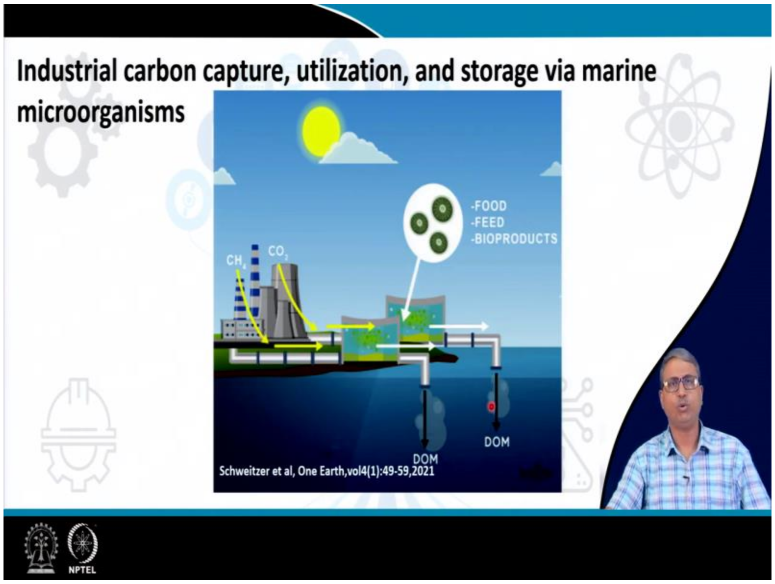

So, this this can be harnessed, so, that the more and more carbon dioxide can be converted into DOM by the microorganisms, which are present in the ocean.

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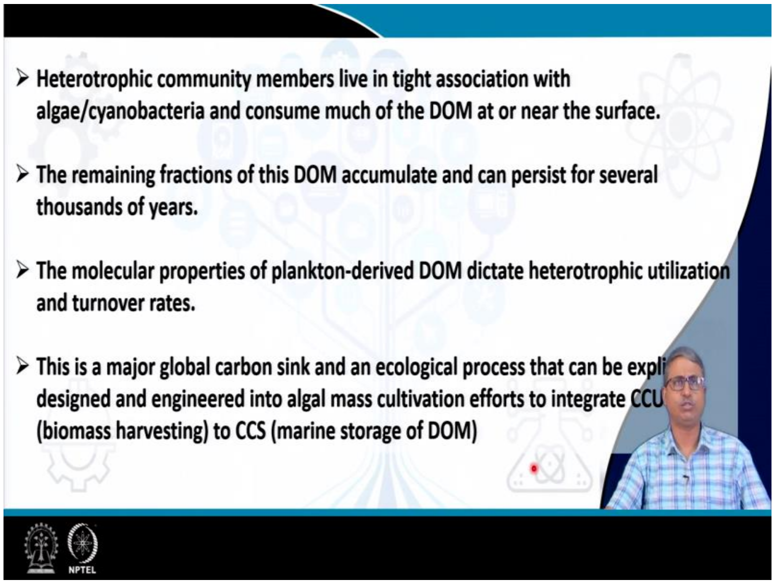

It could be by the heterotrophic community member, the remaining fraction of the DOM accumulates because heterotopic community leave in tight association with the algae and consume much of the DOM produced. And the remaining fraction of the DOM basically accumulates and persists for several thousands of years. The molecular properties of this plankton derived DOM dictate the heterotrophic utilization and turnover rates and it is found to be a global carbon sink.

And an ecological process that can be explicitly designed and engineered into algal mass cultivation effort to integrate the CCUS that is, the biomass harvesting to CCS that is, the marine storage of dissolved organic matter. And both the algae and other organisms can be utilized for that.

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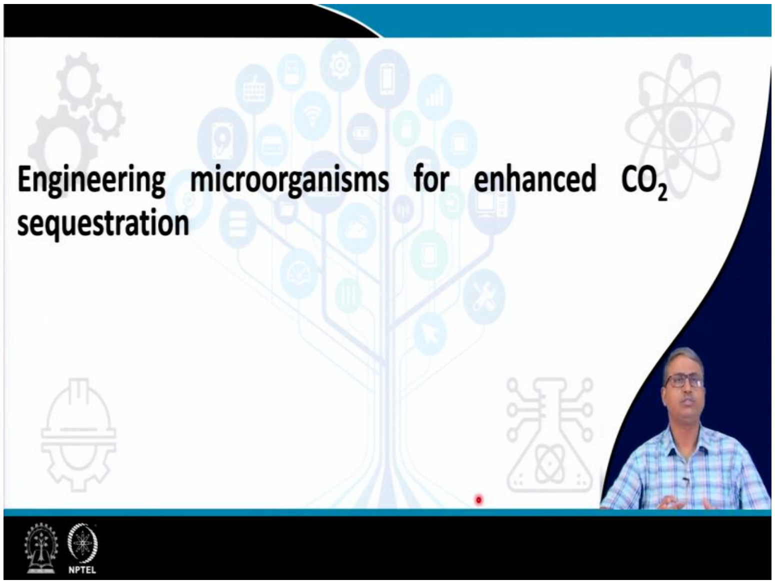

Now in the second part of this we will talk briefly about the engineering the microorganism specifically to enhance the CO 2 sequestration because we can understand that the microorganisms, whether they are in the soil. Whether they are in a deep terrestrial crust or oceanic crust or in the marine micro environment marine environment, they play huge role in sequestered in the carbon dioxide.

So, enhanced research interest increased research interest has been shown to engineer the microorganism for enhance your 2 sequences.

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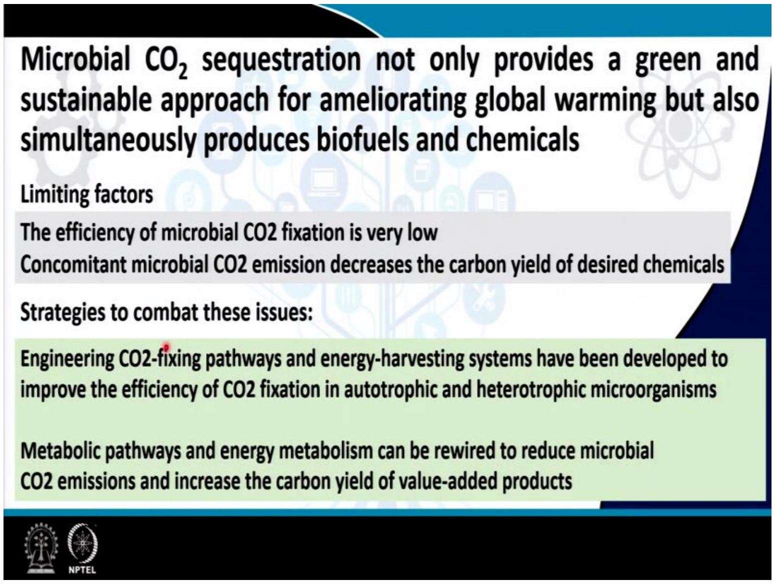

Now, because microbial CO 2 sequestration is one part which not only provides the green and sustainable approach for mitigating this globe climate challenge but also it provides the opportunity to produce useful molecule ID, biofuels and chemicals. however, it is facing some challenges and these factors challenging factors are the efficiency of microbial CO 2 fixation is found to be quite low and concomitant microbial CO 2 emissions decreases the carbon yield of desired chemical.

And therefore, the strategies are identified to combat these issues. So, one aspect is engineering the CO 2 fixation pattern and energy harvesting systems have been developed to improve the efficiency of shelter fixation in both autotrophic and heterotrophic microorganisms. On the other hand, metabolic pathways and energy metabolism engineered can be reviewed to reduce the microbial CO 2 emission and increasing the carbon yield of the value added products.

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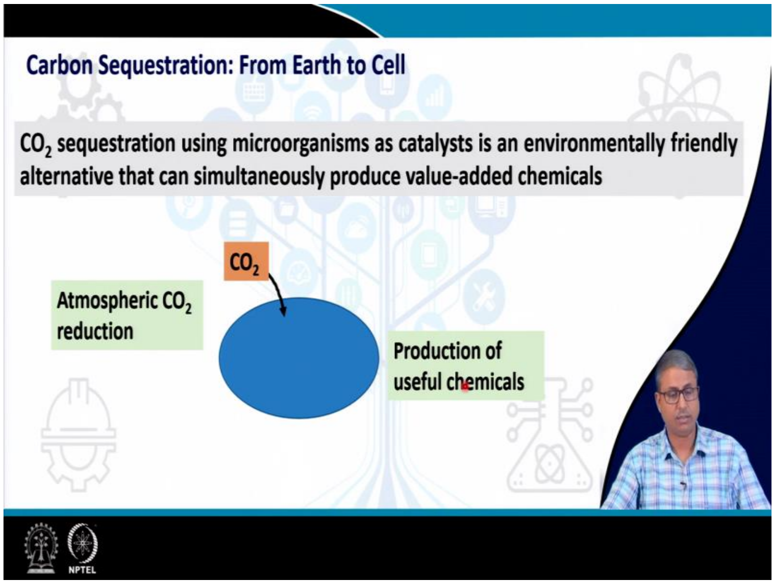

Now carbon sequestration from earth to sell is catalyzed by these microorganisms, where microbes can actually remove the carbon from the atmosphere and can simultaneously converted into the valuable useful chemicals and some of them can be resources as good as to be used in bioenergy.

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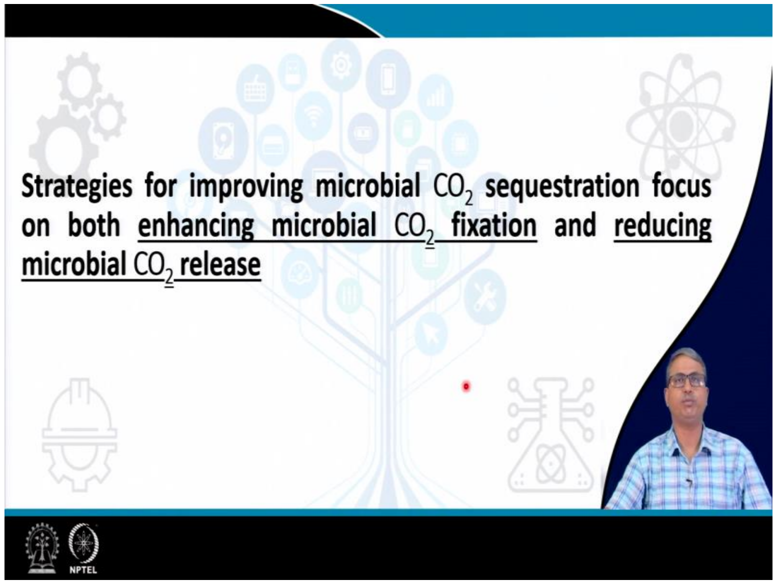

Now strategies for improving the microbial CO 2 sequestration focus therefore, on both aspect. One is enhancing the microbial CO 2 fixation and second is the reducing CO release. So, we will look into these 2 aspects briefly.

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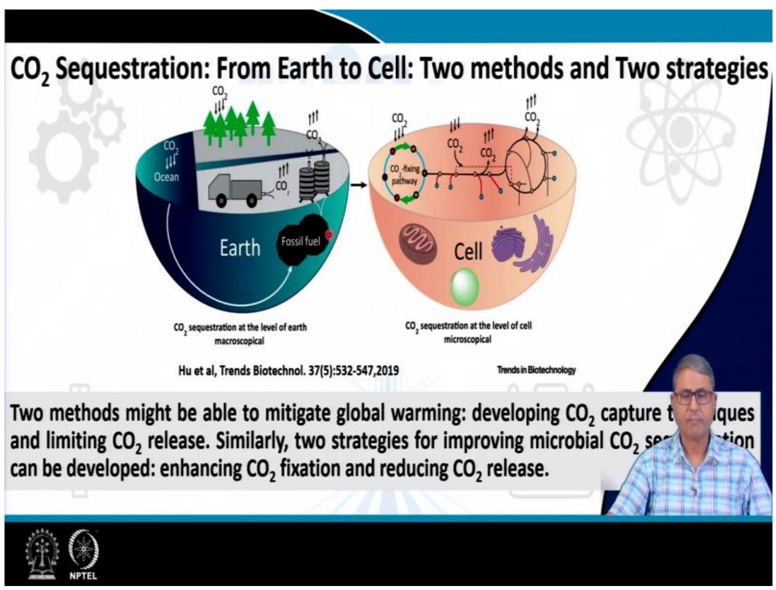

So, one aspect is that 2 methods up there and 2 strategies up there. So, what are these methods and strategies? 2 methods might be able to; so one is reduce the emission another is convert the carbon dioxide into valuable products. The 2 methods might be able to mitigate the global warming, developing CO 2 capture technology and limiting CO 2 release. And the strategies would be improving the microbial CO 2 sequestration and enhancing through enhancing the CO 2 fixation and reducing the CO 2 release.

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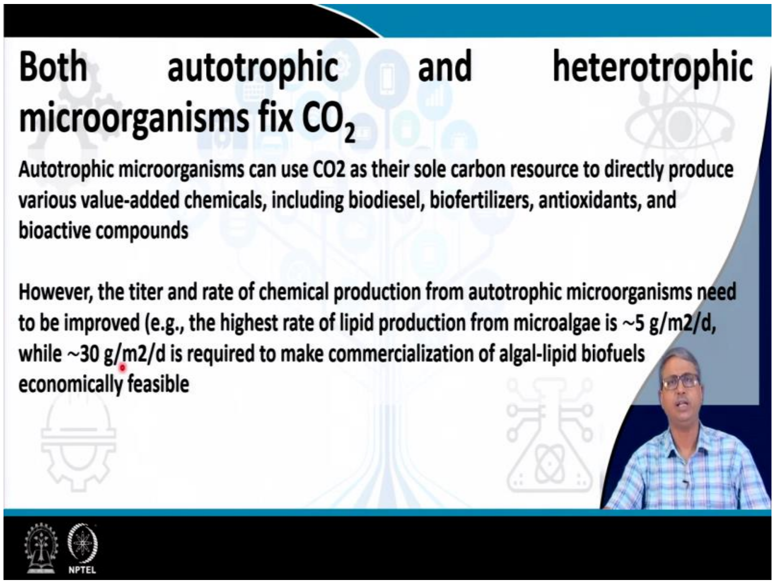

And as I mentioned, both automatic and natural traffic microorganisms, they can fix carbon dioxide. Autotrophic microbes they use the CO 2 have the sole carbon source to directly produce the various value added chemicals. So, they convert zero to value added chemicals the molecules which are useful in biodiesel production, bio fertilizer production. antioxidants, and bioactive compounds. On the other hand, the title and the rate of these chemicals, which are produced out of the carbon dioxide which is fixed by these autotrophic organisms need to be improved.

That is, for example, the highest rate of lipid production from microalgae is around 5 gram per meter score per day, while it is 30 gram parameters of our day is required to make commercialization of the algal lipid biofuel which is considered to be economically feasible.

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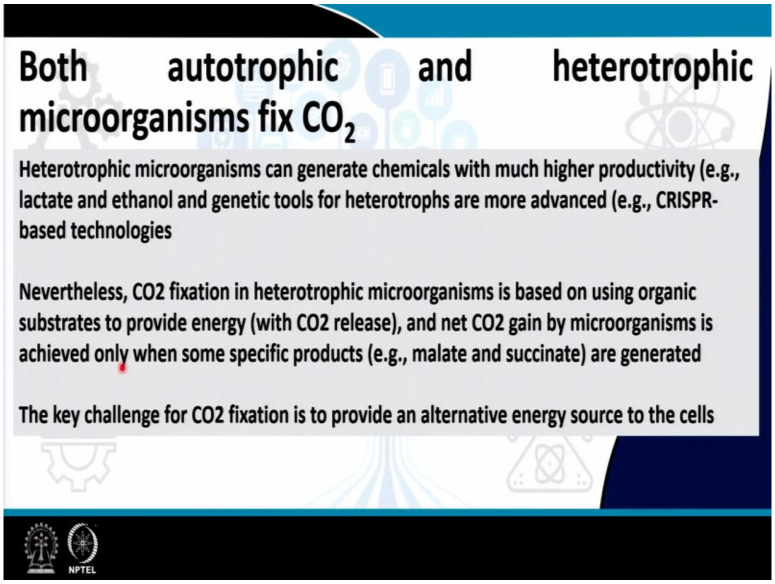

On the other end the heterotrophic microorganisms they can also generate chemicals with much higher productivity, for example lackted ethanol and genetic tools for heterotrophic organisms are more advanced, including decreased per gas systems. Nevertheless, this year to fixation in heterotopic organisms is based on using organic subjects to provide the energy, which actually leads to a release of carbon dioxide.

And net CO 2 gain by microbes is achieved only when some specific products like mallet or succinate are generated, otherwise, there will be a substantial CO 2 release. Now the key challenge for CO 2 fixation in case of heterotrophic organism is to provide an alternative energy source to the cells.

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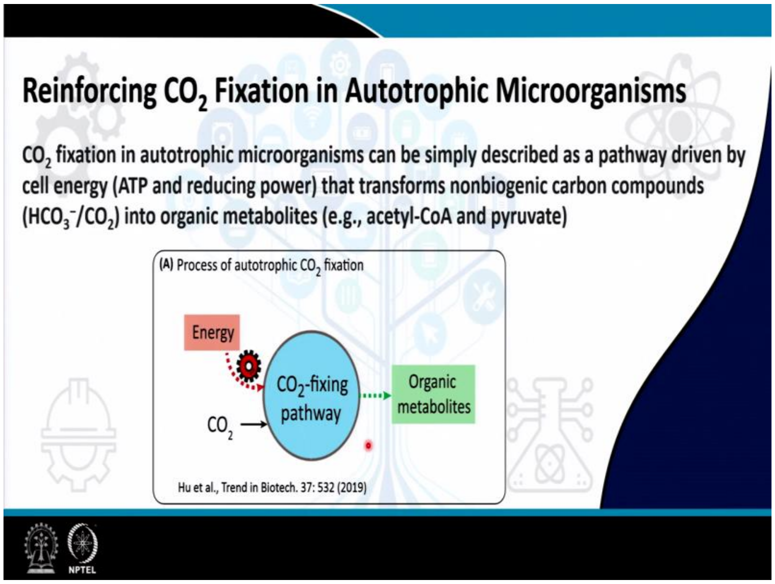

Now the reinforcing the CO 2 fiction by autotrophic microorganism, as I mentioned the CO 2 fixation in autotrophic microbes can be simply described as a pathway which is driven by cellular energy by the ATP and the reducing power and that transform non biogenic carbon, carbon dioxide into some kind of a complex organic molecules through the CO 2 or the bicarbonate which is taken in the cell is converted into acetyl-CoA and pyruvata.

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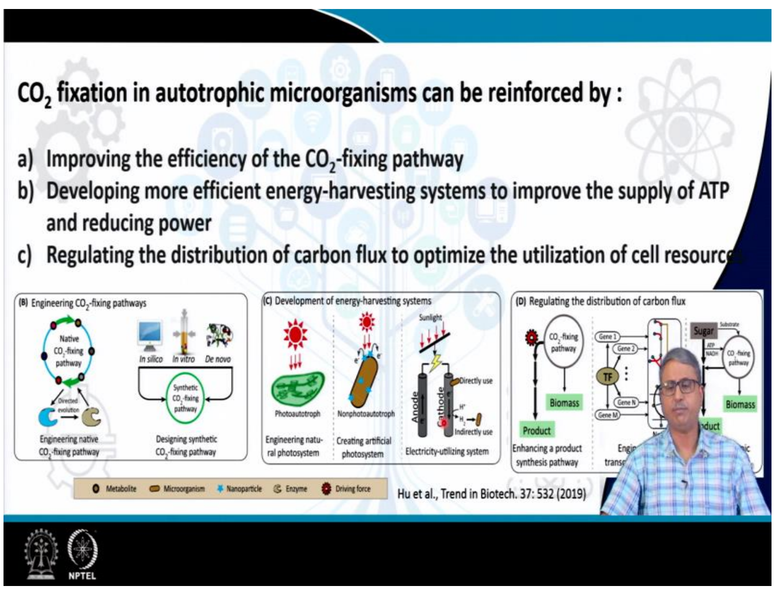

Now, CO 2 fixation can be reinforced by improving the efficiency of this CO 2 fixation pathway. The way this CO 2 fixation pathway operate, we can increase their efficiency by different engineering approaches developing through developing more effective energy harvesting system that improves the supply of ATP and reducing power and also regulating the distribution of carbon fluxes to optimize the utilization of cell resources.

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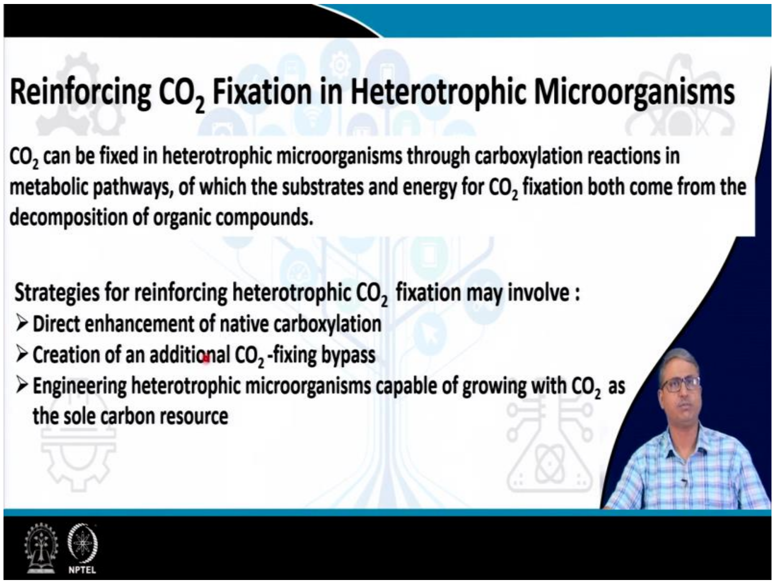

On the other hand, the reinforcement of the CO 2 fixation in heterotrophic organism can also be done through carboxylation reaction in metabolic pathway, in which the substantial energy for CO 2 fixation both come from the decomposition of the organic compound. And the strategies for reinforcing the heterotrophic you to fixation may involve direct enhancement of native carboxylation creation of an additional CO 2 fixation bypass and engineering the heterotrophic microorganisms we are capable of growing with CO 2 as the sole carbon source.

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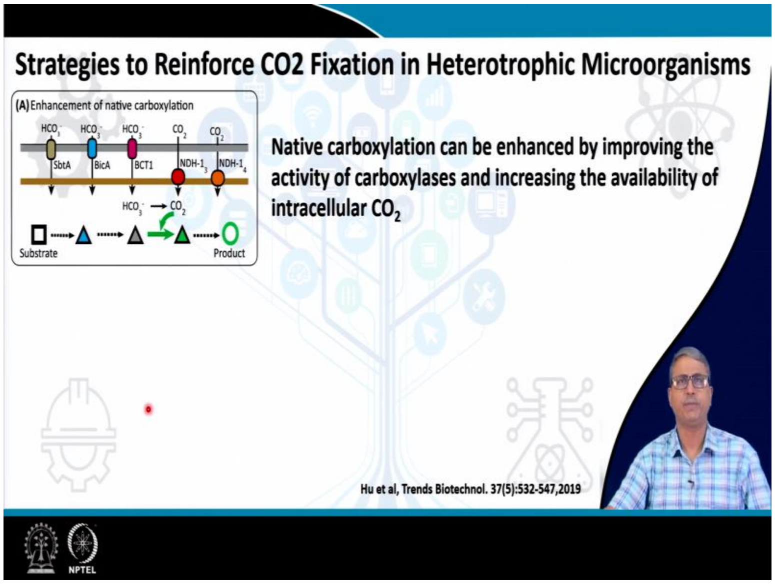

Now these are the strategies one strategy could be the native carboxylation, which can be enhanced by improving the activity of carboxylase and increasing the availability of the intera cellular CO 2.

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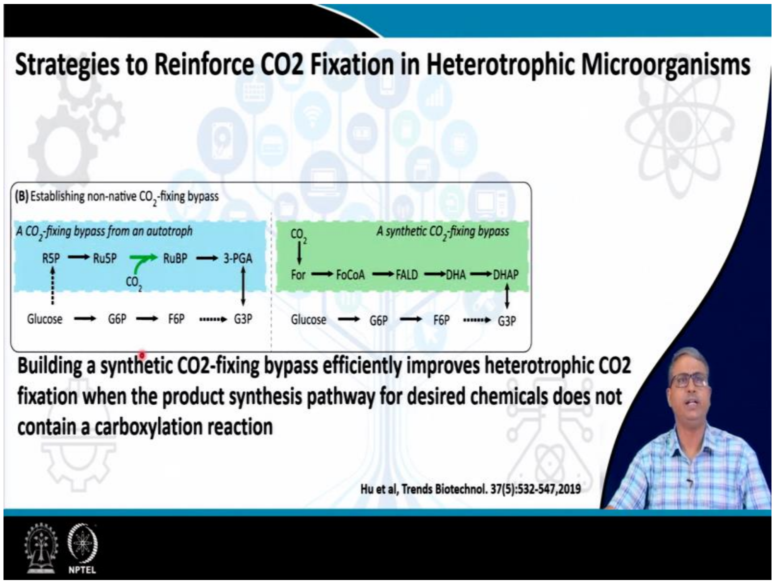

And the other could be building CO 2 fixing bypass efficiently that will improve the hydrotropic CO 2 fixation.

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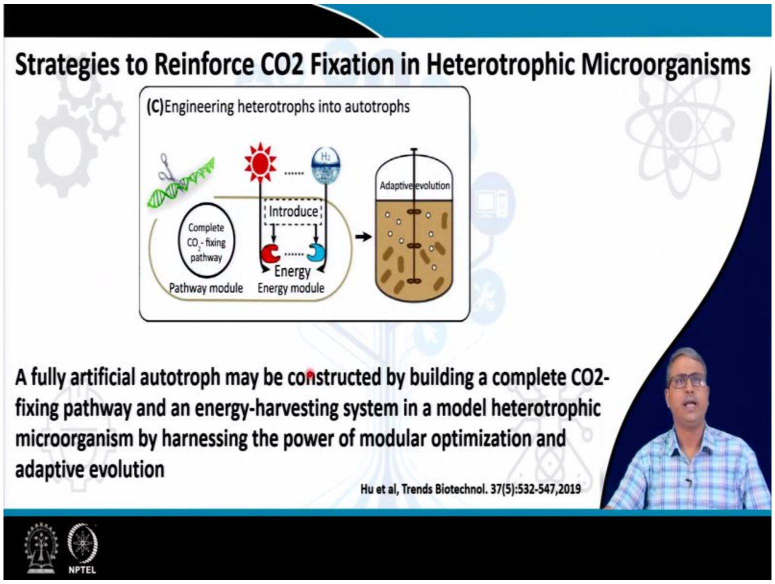

And the other one is a fully artificial autotrophy may be constructed by building a concrete CO 2 fixation pathway and an energy harvesting system in a model hydrotherapy E.coli by harnessing the power of modular optimization, adaptive evolution and other approaches of metabolic engineering and synthetic biologist.

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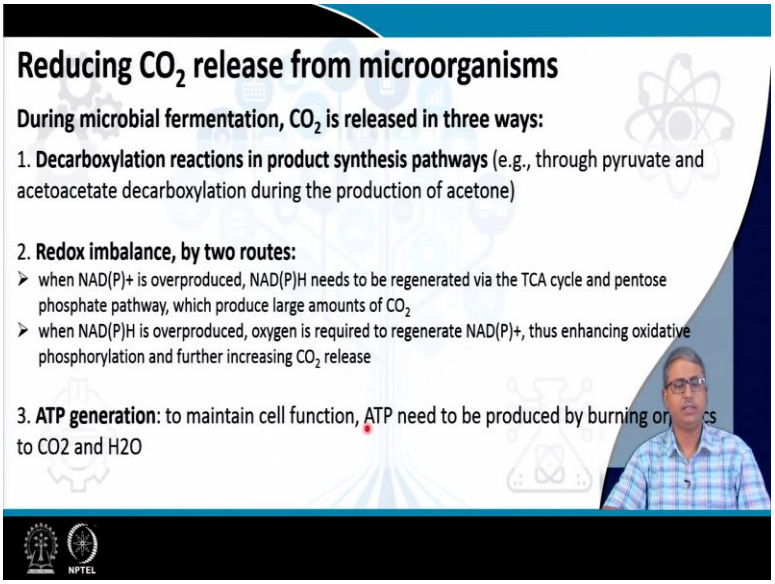

The last one is the reducing CO 2 release from the microorganisms. Now during microbial metabolism CO 2 releases are there because of the decarboxylation reaction because of the redox imbalance and also because of the ATP generation to maintain the cell function.

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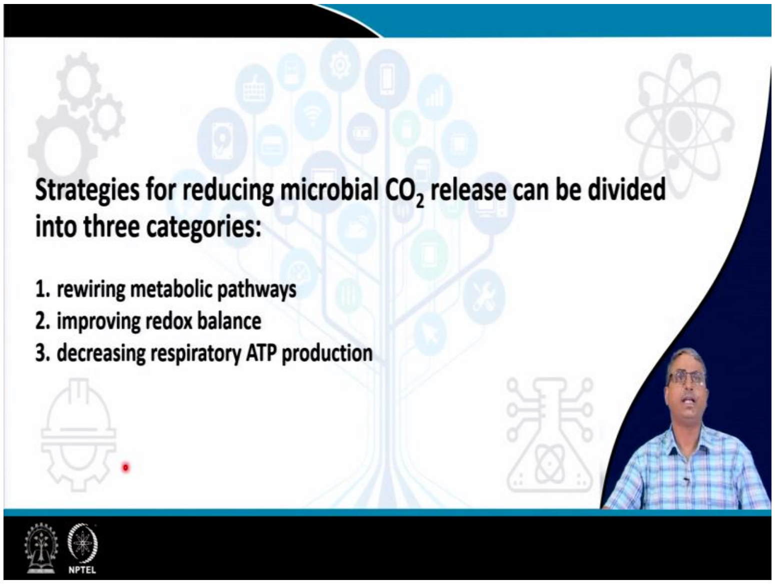

There have been defined processes or strategies through which the microbial metabolism derived CO 2, which is which is actually releasing CO 2 into the atmosphere can also be controlled, and this can be done using three categories. One is the rewiring of metabolic pathways improving the redox balance and decreasing the respiratory ATP production.

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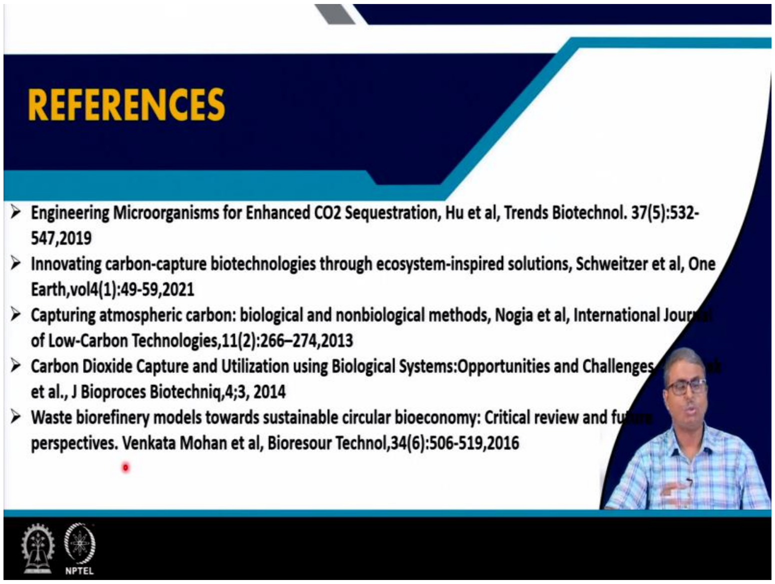

So, overall, for these 2 aspects of the carbon sequestration that the first one was a general aspect of the sequestration capture utilization, and the third one more like how do we engineer or what are the options to engineer microorganisms for better CO 2 fixation and reduced CO 2 emissions. These are the references.

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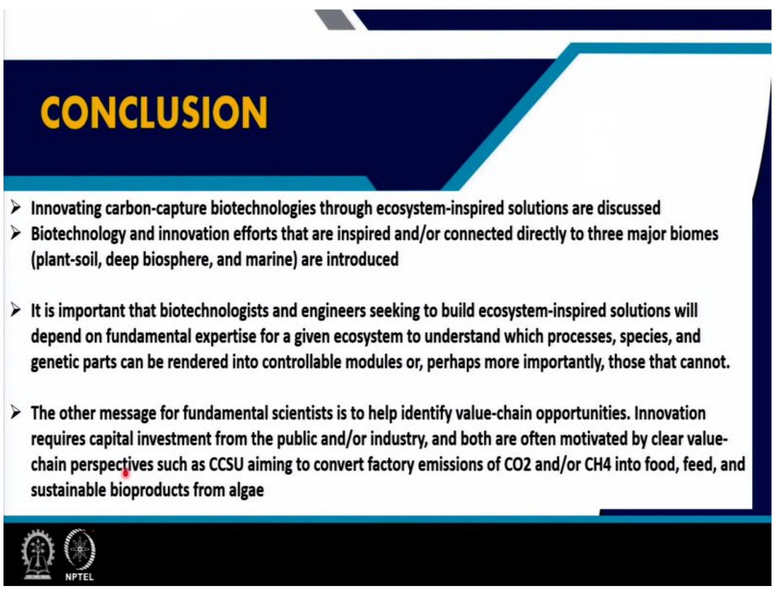

And in conclusion the innovating carbon captures of our technologies to ecosystem inspired solutions are discussed, and biotechnology innovation efforts that inspired and are connected directly to the three major biomes are introduced. It is important that biotechnologists and engineers seeking to build ecosystem inspired solutions will depend on fundamental expertise for a given ecosystem to understand which process species genetic parts can be rendered into controllable module perhaps more importantly those that cannot.

The other message of the fundamental scientists is to help identify the value and opportunities. How do we convert identify the roots through which the products can be synthesized. And again, in a deeper understanding of these processes, biologically catalyzed processes into carbon cycling will guide towards innovation industrial developments. It must be emphasized that better communication and cross disciplinary innovation will motivate future investments into science and industrial action to consider the benefit of ecosystem in the CCSU.

Microbial CO 2 sequestration is a promising approach for closing this carbon cycle of earth using current particle legal strategies, the efficiency of CO 2 fixation in autotrophic and heterographic, organisms can be increased, and the problem of microbial CO 2 release can be partly sought. Finally, the improvements of microbial CO 2 sequestration often result in a higher level of chemical production, which emulates the energy and resource shortage simultaneously. Thank you.