Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Bioenergy

Lecture – 17
C3 & C4 Plant Structure and Photosynthesis Process

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Welcome back to the lecture series in bio energy so in the last class we finished with the Calvin cycle and we talked about the energy expenditure and we concluded the class with the fact that for synthetic efficiencies 30-person we talked about how many ATP molecules are required how many NADP features required how many water molecules and how many carbon dioxide and what is the end product of six carbon glucose or starch molecules okay start your sucrose molecule.

So today what we will do is if you guys remember that at some point I was telling you about the Rubisco and the problems with Rubisco so today's lecture will be about C3 and C4 plants but the way I will move is that first o fall I will give you an idea exactly where is the significance of this so actually Rubisco as per the evolutionary chemist or evolutionary biologist Rubisco possibly evolved in an environment in a distant past at some point which was rich in carbon dioxide Rubisco as an enzyme was never really made by nature or a no engineered by nature to handle a situation of high oxygen.

And as we have already discussed that Rubisco has both ways of binding it can bind to oxygen it can bind to carbon dioxide okay so now it has been observed that at higher temperature if the main temperature goes up say for example somewhere in the tropics or semiarid tropics where the temperature during the summer goes to like a 45 degree centigrade or at least even 42 or you know however between 45 to 50 degree centigrade it has been observed with the increase in

temperature Rubisco affinity for oxygen increases what does that mean that means Rubisco which was supposed to bind to carbon dioxide and promote carbon dioxide sequestration or carbon capture instead utilizes the oxygen that means instead of synthesizing it is now utilizing oxygen.

So there is no evolved divorcing of oxygen instead it is consuming oxygen a process which is also called photorespiration so now if you just think let us do not go to the details first of all try to get the philosophy of it if you think that an enzyme which is so critical for the plant to carryout photosynthesis is now involved in consuming oxygen so what we have talked about the thirty percent efficiency of photosynthesis is going to go down because part of the energy is we consume the respiration process and that thing whole thing or photo expression and this that whole thing will continue till the temperature comes down.

But then how in all these semiarid tropics and tropical areas or the places on the earth where there is huge amount of incoming solar radiation how the plants grow there are several crawfish growth okay interestingly meaning of those plants many of those crop plants have developed or devised a very interesting technique to compensate for it how they do so before we get into the detail of water there is those mechanisms and everything let us talk about a little bit about the anatomy of the leaf.

So if you see a leaf suppose this is a lead okay you are doing so on top surface if we take a microscope and you take a section of the leaf you will see there are very small structure called stomata okay.

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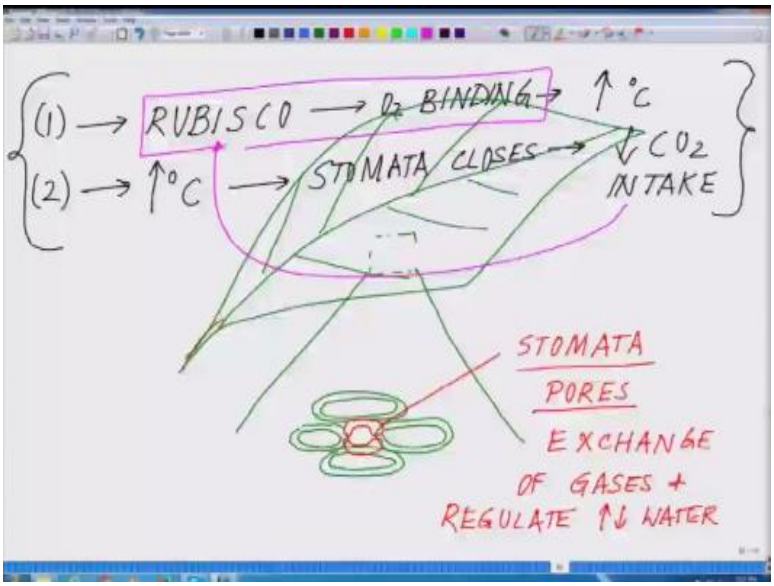

So it looks something like this coming back to the slide you see a structure of the leaf something like this okay so if you take a cross-section of it so if I take a cross section like this so in the cross section what will you see there are cells like this these are the plant cells with the cell wall like this and in between these are all the plant cells what I am drawing you see certain structures like this okay something like this these are essentially the one which I drown in red color these are essentially called the estimator so these are called stomata so stomata are small pores which regulates exchange of gases and regulate movement of water regulate and just train movement of water I am just showing by arrow in the moment okay.

So now if this is structure regulated a moment of water certain high temperature this is stomata spores closes because it cannot afford to lose water now think of situation if this stomata closes at a higher temperature automatically gaseous exchange is kind of now prevented because I told you the Kiska matter has two functions one function is that it allows the gas to slide in slide out glass molecule diffuses through the stomata and the water molecules moves out in the form of vapor and some of the water molecules will come inside through that okay.

Now at a high temperature what is happening is this stomata spores is shut down so automatically carbon dioxide which is supposed for the plant is supposed to know trap the carbon dioxide does not happen so now correlate the two situation first let me put it together the first point what I mentioned to you was the Rubisco the first the beginning so Rubisco become more oxygen binding okay when the temperature is higher right point one point two when the temperature is higher the stomata closes okay.

And in this stomata closes so automatically there will be fall in CO_2 intake so essentially these two situations where the CO_2 intake is reduced and this stomata is closed and the Rubisco this essentially promotes in a way something like this where the Rubisco is binding to oxygen now what is the strategy the plant kingdom developed in order to ensure that Rubisco functions so one strategy could be if some way or other some way or other in that local vicinity just underneath the stomata spores it somewhere or other they could tap a lot of carbon dioxide.

So it means you have a store of carbon dioxide which you are holding out there okay if you could trap those carbon dioxide and transform them obviously just think of it you cannot track car with because there is no cylinder there okay there is no so you have to transform carbon dioxide into some other form there if you have a mechanism by virtue of which say for example CO_2 is transform into a product X and then that X product you have some way or other again make it CO_2.

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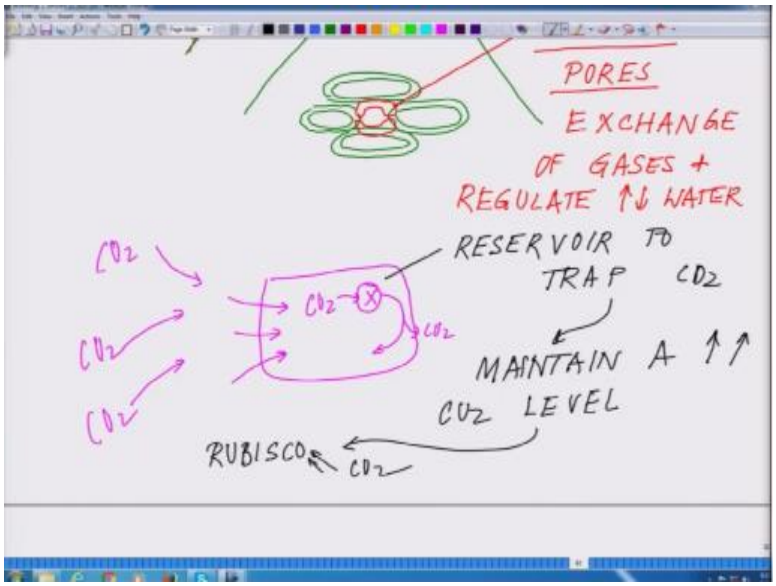

Now say something I strategy like this so there is lot of ambient CO_2 okay so this CO_2 is being picked up suppose this is the plant cell it is picking up this $CO_2$and concentrating it at one point and this CO_2it is converting into an x compound which by another process could again release CO_2 okay something like this so in other words this vessels what I have drawn here is acting as a kind of reservoir to trap $CO_2$and the idea is to maintain a high CO_2 level such that the Rubisco is more affinity has more affinity for CO_2 okay.

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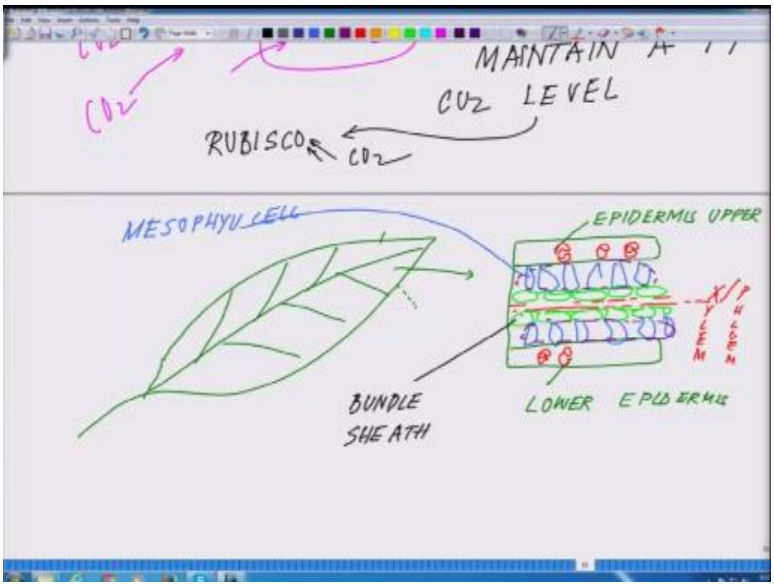

So this is the strategy then how the plant does it here comes a catch let us say for example if this is the leaf and so we are taking the cross section so if you see the cross section it has an upper layer and it has a lower layer okay so now the upper in the lower layer is filled with us so we will call the epidermis okay something like this these are called the epidermal layers upper epidermis which is the top of the plant okay.

And this is the so this is up epidermis upper epidermis and you have the lower epidermis okay and in the center of it here the xylem phloem vessels which are rolling through okay so this is the xylem flame X and P that is essentially for xylem and phloem vessels around that now I will show in light green are a series of cell where most of the Calvin cycle is happening okay those are called is the name from called bundle sheath cells okay and between the bundle sheath cells and the epidermis and by the way on the epidermis layer you are having those stomata and all those things which are sitting out there which is in direct contact with the air underneath this now put a blue color or there are cells which are arranged something like this these are called the mesophyll cells or mesophyll cell okay.

So the cross section if you look at it so you have the upper layer of epidermis underneath you on the epidermis you are having these estimator underneath you are having the mesophyll cells lining or mesophyll cells underneath you are have the vascular cheat layer and then underneath you are having the xylem flame again that repeats further in the same pattern okay now coming back to the slide so the catch line out here in this layer this layer what you see I am just putting it the one which I am talking now in the mesophyll layer.

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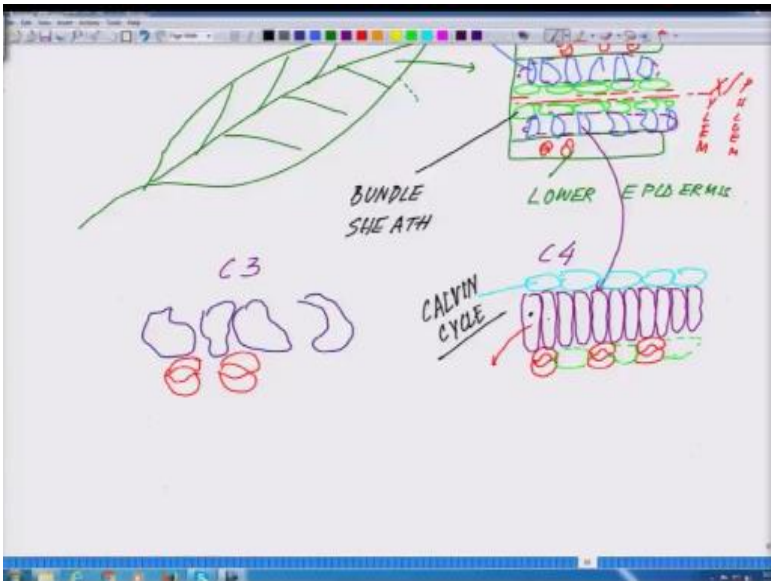

So there are two categories of plants I will explain it why they are called one is called C3 plants the other one is called C4 plants and in a C3 and C4 plant that different lies in that mesophyll layer these mesophyll layers are very intensely packed in C4 plants like this okay almost like as if like a cylinder they are standing out there so this is how they are packed so instead of these blue you have to replace it by a and they are in very close proximity with on the epidermal layer the estimator like this okay something like this and some of them even are in direct contact with air.

And you are having the epidermal lining like this which is I am putting in the light green color okay whereas on the country these mesophyll lining is something like this crinkle shape like this

and underneath you are having the stomata like something like this once again okay first emitter is like okay so now what happens by specialization lies in this layer of the mesophyll cells these mesophyll cells what they do is that they are direct contact with air or through the stomata this is that reservoir what just coming back to the slide these mesophyll cells for the C4 plant.

If this reservoir like this that CO_2reservoir so what is happening inside these mesophyll cells because it is underneath the mesophyll cells you're having the layer of bundle sheath cells which are sitting here is where all the Calvin cycle is taking place okay I am coming to the camp pathway after this okay so an out here so this is the reserve voice where something is happening and what is happening in that mesophyll point.

So in that reservoir is CO_2 is getting accumulated and transformed into certain 4 carbon molecules called mallets okay and there is a series of transformation let me put it down on the slide it will make more sense.

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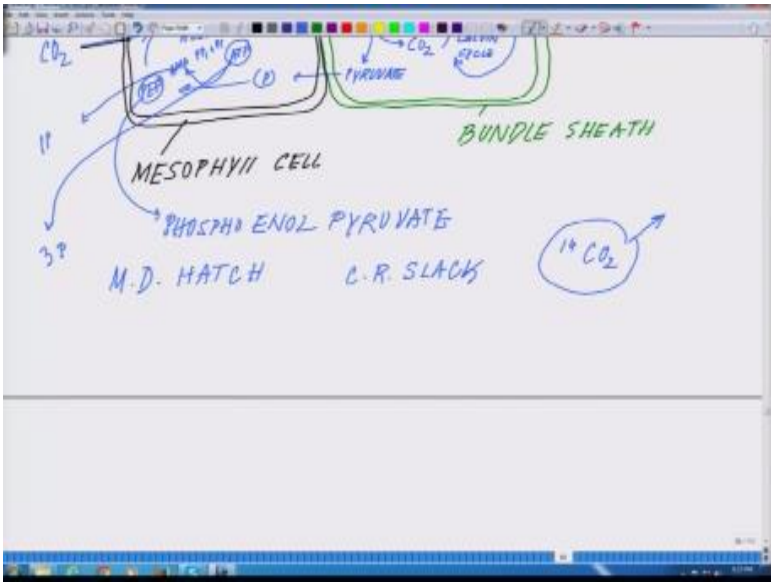

What is happening inside this now we are into the C4 plants in the C4 plants so let us put the two cell layer so this is the mesophyll cell layer out here and I am just drawing it horizontally there I

drew it vertically now I am drawing it horizontally and adjutant to it you are having the bundle sheath layer which is in closed touch with it so this is the bundle sheath layer bundle sheath cells where the Calvin cycle is happening okay so this is why Calvin cycle is happening and this is the bundle sheath so this is the bundle sheath cells whereas out here you're having these are the mesophyll cells.

Okay so in the midst of yourself they are in direct contact with the air so here one second if you are having CO_2 coming from outside so this is the environment either okay so CO_2 is entering a fall entering the CO_2 is converted into something called oxolao acetate okay from oxolo acetate it forms molecule called malate okay and this malate is transferred or transported into the bundle sheath cells where Malate transform into a Pyruvate and in that process it releases the carbon dioxide.

And this carbon dioxide eventually takes part in to the Calvin cycle okay Calvin cycle whereas this pyruvate which is formed here is brought back transported back here I am just putting P by the weight this fire weight goes to a very intricate reaction which I am not getting into detail where it is consuming so this is where it consuming a lot of ATP molecules and transformed it into ANP this is the interesting part is that adenosine triphosphate so this has three phosphate groups and ANP it has the one phosphate group so in other word it is losing two phosphate in that process okay TI plus TI okay it goes through to transition and form phosphoe in all pyruvate PEP phospho in all pyruvate okay and this phospho pyruvate again transform into auxiliary acetate and again this whole reaction continues now interestingly the first clue of the existence of such cycle or something different was given by a Russian scientist okay.

Followed by that there this was further so coming back to the flight this was further back in nineteen sixty this idea was thrown that there is something different is happening after that two scientist explored this pathway which is called or rather discovered this pathway one is name is hatch and the other one is CR slack and that is what is this also called hatch slack pathway what they said is that Celvin side the first clue of the existence CO_2 transport mechanism came from studies showing that the radioactivity from a pulse 14 co2 remember what we have talked in beginning 14 co2 appeared initial in oxolo acetate and malate and other 4 carbon.

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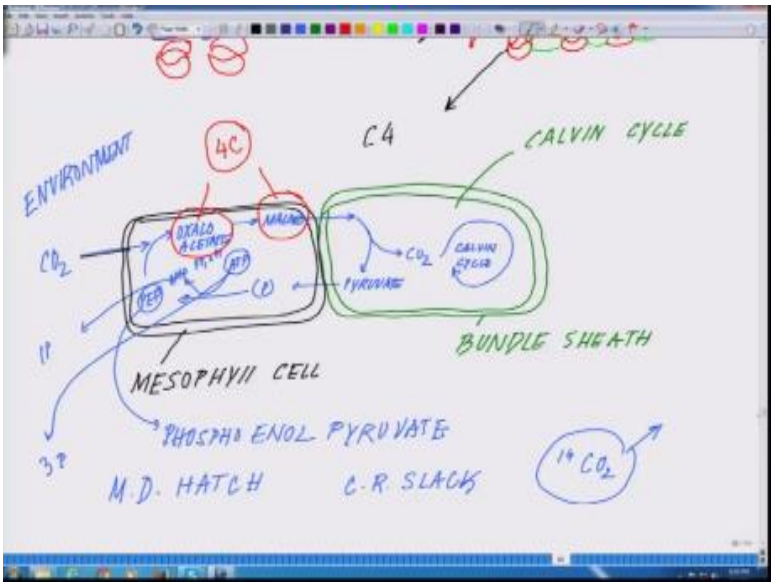

So what you see here that will see here this is oxolo acetate malate these are all four carbon chains okay and you remember in the previous situation we talked about three carbons which was starting the process so what you are getting is starting point here is the four carbon okay.

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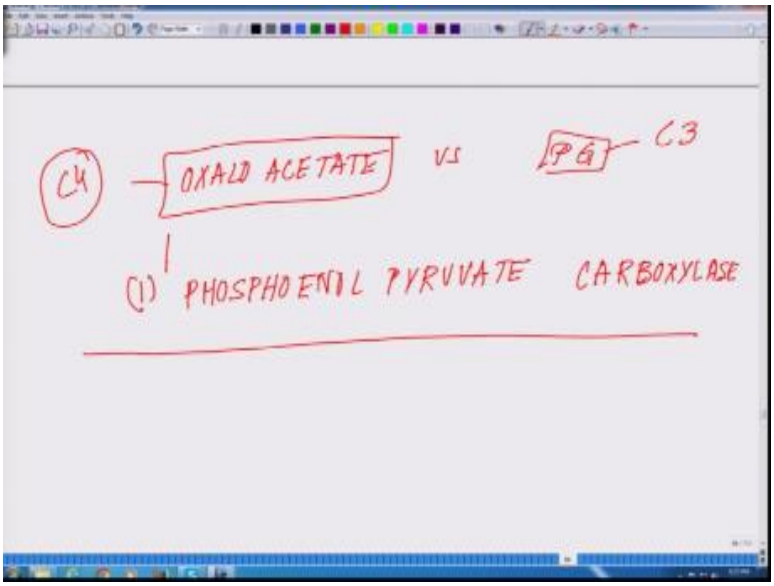

So comparison here is that oxalo acetate verses phosphoglycerate this is where C3 and oxalo acetate being C4 to the starting point these are called C4 plants okay and there is a decarboxylation of the C4 compound in the burned cheap cell maintains the high concentration of basically of the CO_2 at the site of Calvin cycle and theC3 compounds returned to the mesophyll cellsanother round of carboxylation so this whole thing continued and enzymes which are involved in this process one of them is called phosphoenol pyruvate carboxylase and there are few other which are not really significant at this point but what is important for you people to understand is what is exactly happening here.

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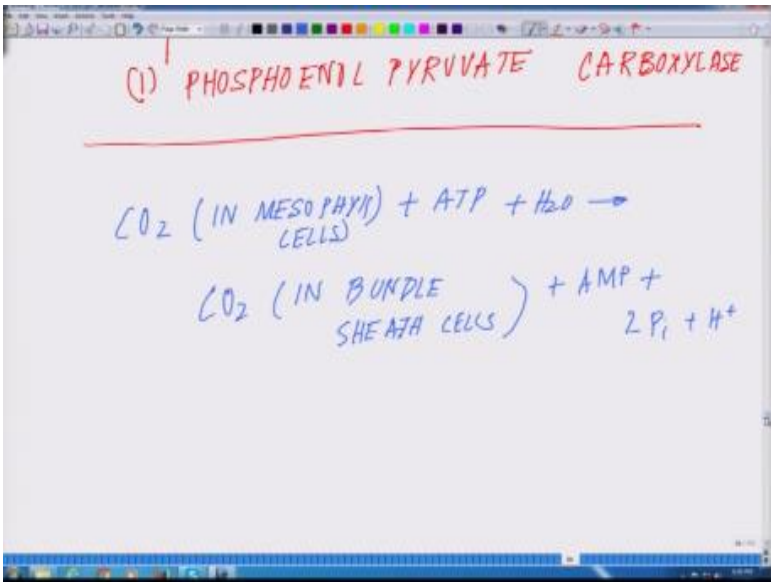

The reaction is something like this I am just putting down the reaction so you have co2 in mesophyll cells okay plus ATP remember that I told you that there is a consumption of ATP plus water which is making it CO_2 in bundle sheath cells and plus AMP I told you ATP gives away two phosphate and becoming in 2Pi because those two phosphate serving lost and a proton and two high energy phosphate bonds are consumed in transporting CO_2 to the chloroplast of the bundle sheath cells okay.

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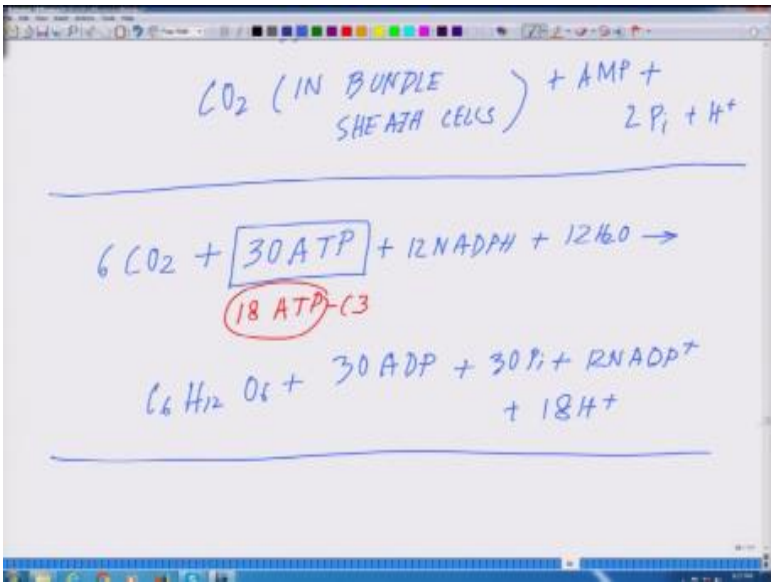

Now what we will do after talking about this basic pathway of C4 cells let us talk about the what is the total consumption of energy in this whole process so now $6C0_2$ now this is that comparison +30 ATP now here you see the difference is 30 ATP as compared to where you are using if you talk about the C3 pathway you are using18 ATP so you are needing more energy for 33 okay it is 43 you need less energy whereas here you need more energy now coming back next twelve NADPH +12 H_2O giving away $C_6H_{12}O_6$ +30 ADP because you know process having lost the 30 Pi that is phosphate 12 in ADP + 18 proton moieties which are coming out of it.

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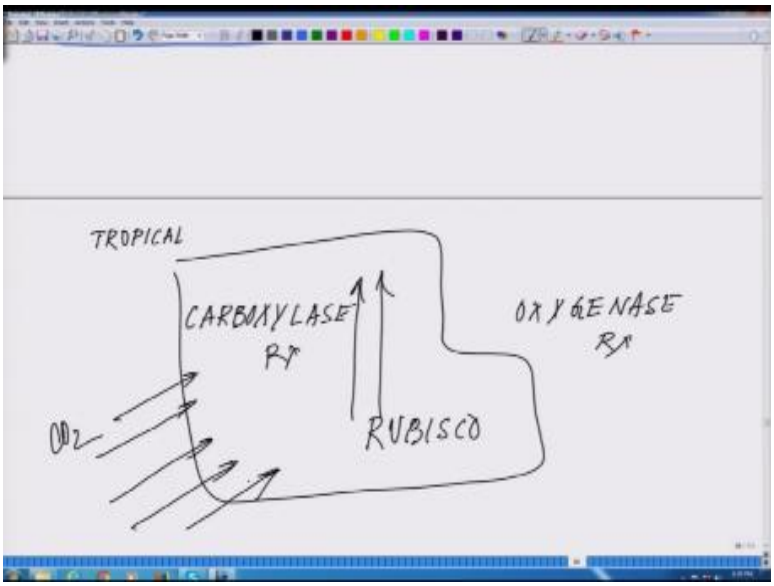

So in other word to put it summarize this whole thing does this mean the tropical plants with C4 pathway do little for photorespiration because it has a high concentration of CO_2 in the bundle sheath cells and accelerate the carboxylase reaction related to the oxygenase reaction so this is the challenge carboxylase and oxygenase reaction of Rubisco so by this process you are increasing the carboxylase reaction because you are trapping more co2 making this environment in spite of having high temperature you are making this environment more and local concentration of co2 is much more higher.

So there are plants like sugarcane in most common plant which follows a C4 pathway and I request you to look for what are the other C4 so one of the objectives of a lot of bio energy research directed towards plant genetic engineering is that if we could have more and more plants with C4 plackets think of it philosophically what does that that means we will be sequestering more carbon dioxide because they have a mechanism of kind of a cylinder where they can trap it.

There are lot of efforts happening across the world how the plant could have more co2 so that they can transform them into hexose sugar so this is where all the way from the basic reaction of

photosynthesis we reach to the C3 and C4 and this is where we will be concluding the photosynthesis part where how old is different bio energy resources are being produced so what we see.

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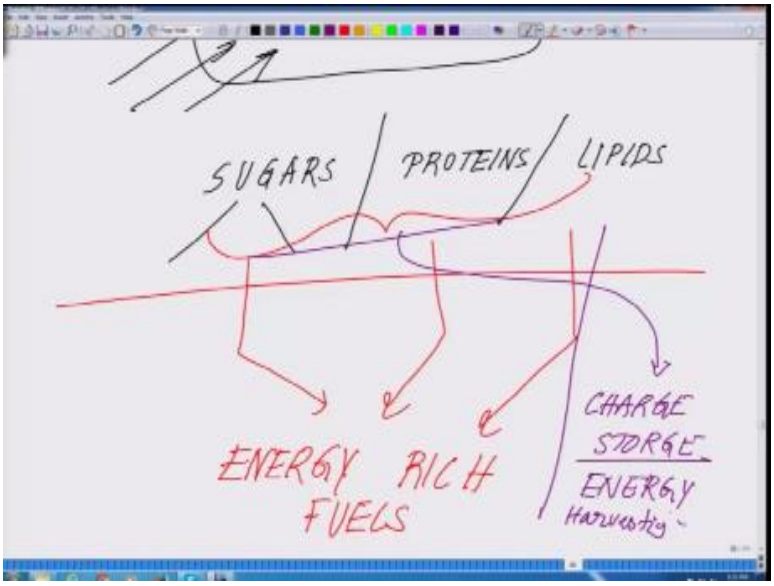

Now this is the driving force for producing wide range of sugars driving the whole machinery of the plant and with having lot of protein and lipids and all sorts of complex sugar long-chain sugar shortchange sugars likewise series of them so low they can non cellulosic starch and all that stuff so now since we know pretty much with all these lectures as of now that this is how the biology is producing all over the world whatever vegetation you see which are dependent on light we are not talking about the hydrothermal where there is no like light.

Light independent system produces it biomass through this whole chain of photosynthesis using light synthesizing a series of molecules on next our goal is in the next class what will be starting is that how again these could be transformed from here to energy rich well one aspect what we will be dealing with and the second thing how these materials could be utilized for making charge storage or energy harvesting directly okay which will be our advanced topics and we will talk about all this.

So to conclude this journey of photosynthesis or the most fundamental mechanism by virtue of which the light-dependent synthesis of these molecules are happening we started with basic architecture then we talked about for system one and system two we talked about water splitting cluster where the part of the reaction $CO_2 + H_2O$ making CH_2ON which is the carbohydrate plus oxygen.

So H_2O 42 which is essentially the water splitting which is happening underneath for system to in the manganese cluster is taking care of that from there that electron which is the infinite source of electron in the form of water is supplying electron to the for system two in order to bring it back to its ground state where because of the four photon electron is being ejected out from the chlorophyll molecules that chlorophyll molecule which is devoid of the electron is brought back to its ground state than the electron hops to for system 2 for system 1 for system 2 for system1 simultaneously as series of chlorophyll molecules which are devoid of electron.

Because we have ejected out electron is balanced out they are being brought back to their ground state and that electron which is donated by the for system one then supplies fun of that electron to NADP to make it NADPH which is a very strong reductant and then once that how that NADPH takes care of using C3 carbons how the whole glucose moieties are being formed and now today we concluded that that is not the only one route there is another route where C4 carbons are being there so in other words there are nana cylinders in the form of mesophyll cells in the plan which has this ability to you know trap and carbon dioxide and transform them into four carbon molecules which could release again carbon dioxide and which was being funneled into the Calvin cycle.

So this is the whole summary of photosynthesis encoding what I just forget to mention in this whole thing all the redox potential and how the electrons are hopping through so again please go through so this was quite an intensive photosynthesis part what we covered so next we will be all the processing of all this plant product which are formed now in the form of sugars proteins and lipids and what all the technologies the next class see you back in the next class with the phase 2 of X where we will be doing all the processing of generating energy rich flues and some of the

very interesting energy harvesting as well as energy storage products made from biological sources thank you.

Acknowledgement

Ministry of Human Resource & Development

Prof. Satyaki Roy

Co-ordinator, NPTEL IIT Kanpur

NPTEL Team

Sanjay Pal

Ashish Singh

Badal Pradhan

Tapobrata Das

Ram Chandra

Dilip Tripathi

Manoj Shrivastava

Padam Shukla

Sanjay Mishra

Shubham Rawat

Shikha Gupta

K. K. Mishra

Aradhana Singh

Sweta

Ashutosh Gairola

Dilip Katiyar

Sharwan

Hari Ram

Bhadra Rao

Puneet Kumar Bajpai

Lalty Dutta

Ajay Kanaujia
Shivendra Kumar Tiwari

an IIT Kanpur Production