Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning(NPTEL)

Course Title
Bioenergy

Lecture -16
Efficiency Calculation of Photosynthesis Process

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Welcome back to the lecture series in bio energy so when we concluded the last class we concluded with the formation of fructose 6-phosphate which is the first key molecule or sugar molecule and I concluded to the fact that in the next class we will talk about how the two major molecules called the starch or the sucrose our form because these two formation of these two molecules is essential about what is the raw material we are getting to transform these kind of energy-rich molecules to alcohol or whatever other energy rich products.

So the efficiency or the growth or with what rate these molecules are formed and what is the energy requirement for a plant to produce per unit starch or sucrose or all these energy-rich molecules is what determines that how much benefits we can harness from a bio fuel or from the whole process will it be cheaper because think of for a minute we went through so we started the class with the energy dynamics we talked about the basic energy and then we moved on to the by energy.

Then we move to the bio resource where from there on we started talking about the whole scheme of biomass production and in that process we have explored the light and dark cycle of photosynthesis and in the dark cycle by the time we leave the last class we talked about the Calvin cycle where the formation of sugar takes place, so now this in this whole process of thing you need solar energy which leads to excitation of the chlorophyll molecules at for the system 1 and photo system 2then that generates very strong reluctant like NADPH and weak as well as weak oxidant as well as we created reluctant like ATP as well as oxygen as a by-product okay and in that process we realize that this whole thing what all input in terms of the solar energy interms of ATP in terms of NADPH and how much carbon dioxide is getting transformed so there has to be a kind of energy map that what is your input what is your output and what is the cost involved.

Because whenever we are growing plant now to add a few other things suppose you are growing a plot or a curse or hectares of land with some plant which you believe that you can transform it into you can transform the biomass of it into some kind of a very rich bio film so what you have to take into account is for example.

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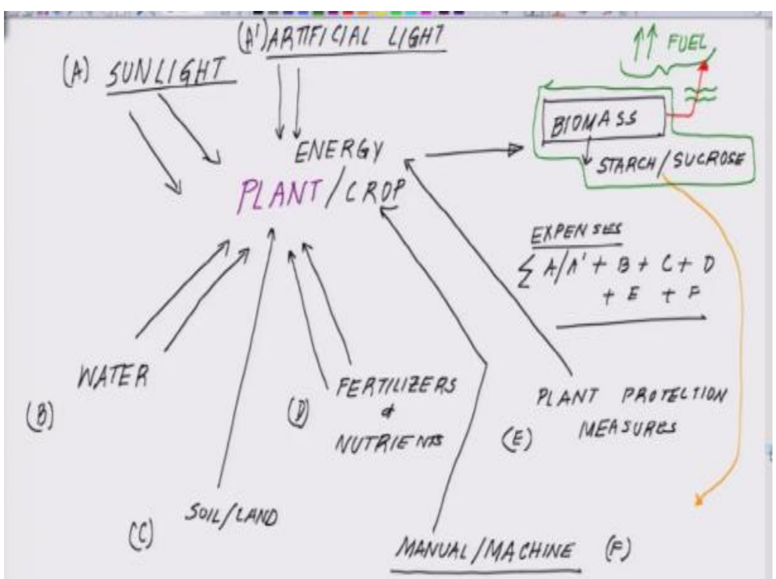

So what you have to take account is that particular plant what is certain things which you are getting free of cost out here the input why's your free of cost input is sunlight provided you are staying in a sunlight rich area but then water it is a commodity there are places on our to where it is cheaper yet there are places on earth where it varies then you need in terms of growing the plan or the crop / crops floating okay.

I am just putting energy rich energy plant or energy crop valuing the fertilizers and nutrients fertilizers and nutrients now even if the sunlight there may be a situation you may do may have to do it in door so you need different kind of setup in terms of say if you have to use artificial light okay as well as so after this you need to spend on plant protection measures in terms of attack from pathogen and other microbes.

After all these things what is the output what you are getting is in the form of a biomass so these are your of course if you are going it in someone else's land then you have to give the soil or the land charges so if you order add all these things say for example A if I represented by a or a prime if it is an artificial light source B which is water see which is set Soil and land then d this expenditure and of course for many of the e then there is an involvement of manual or machine labor in terms of how big is the form size.

So that is your f okay so these are all your expenses so if I have to put the expenses so these are your expenses, expenses include a or / a prime plus B plus C which is soil and land Plus D+ e which is plant protection measured then you have the f at least now what you are producing is biomass what is the form of biomass you are getting that is what we are going to discuss today either it will be starch or some form of other simple carbohydrates like sucrose okay.

Now come the next phase of it which is transforming them so either at this stage of two options either you can directly use them for burning swell okay or you convert them into high-end so before we move into this part how you the conversion which will be the next part which will be taking probably after couple of classes at this stage we will talk about what is the currency of biomass in form of in terms of the starts and the sucrose. If you see the last class where we end it this is where we stay.

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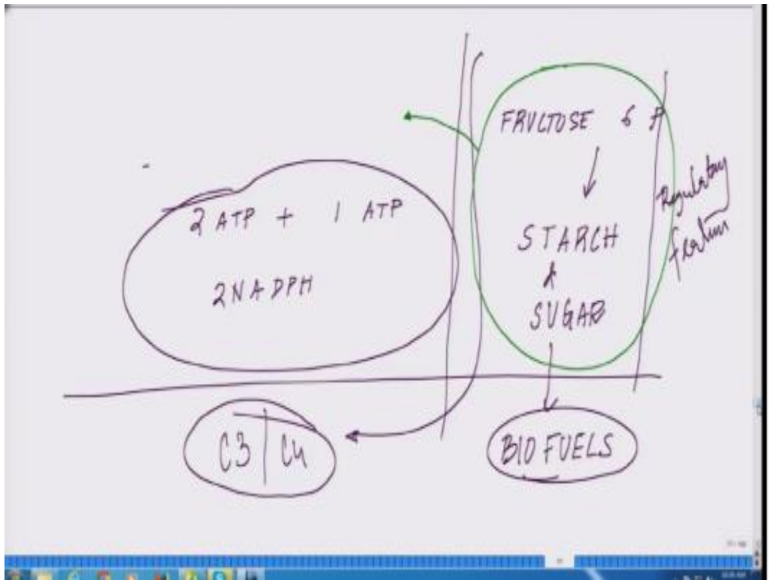

So the fructose to starch and the sugar and in that process what is the expenditure of ATP ADP and the light so today our job will be at this stage we will talk about we will not.

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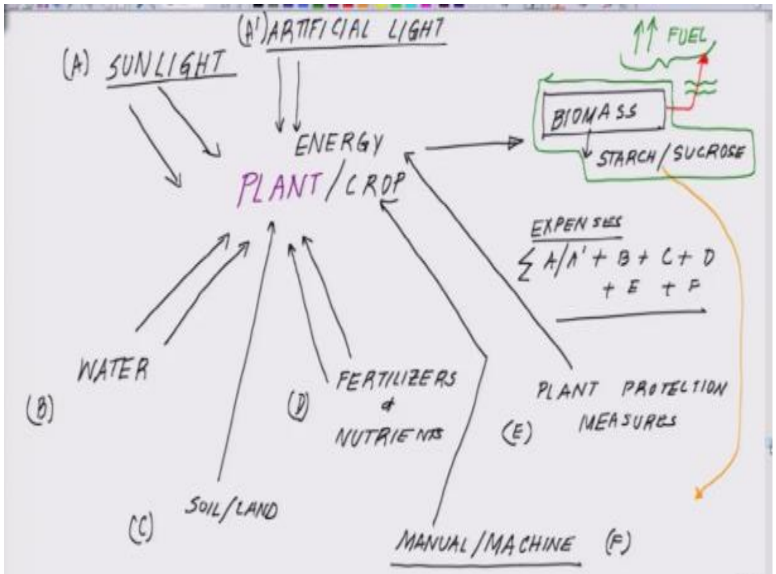

So we will talk about what is the light expenditure you need it how much light it will be needing for this kind of situation how many photons what are we are not dealing fertilizers and nutrients is crock to crop basis we are not going to deal with this so I will and land also we are not dealing we'll definitely talk about how many water molecules on an average will be needing to make one heck soul or 16 sugar six-carbon sugar and plant protection measures we are not taking here.

Because that that also varies from plant to plant and this is also we are not taking so essentially what we will be dealing today will we talk about what is the water expenses what you are having what is the light in terms of the photons and in this process what all ATP and NADPH is involved to convert Co2 to six carbon starch or sucrose okay.

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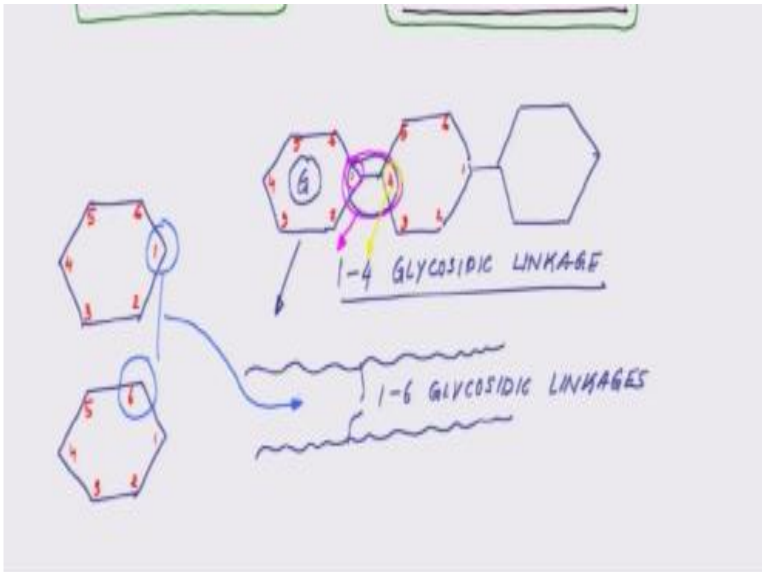

So let us move on so if we talk about the starch and the sucrose so the starch is nothing but those of you just recollect back when we explained about the structure about the glucose so you can represent glucose something like this okay it is a six carbon so something like this someone suck right okay so now these glucose molecules is this is an individual glucose I am NOT adding all the functional groups or anything out there.

So if each one of these glucose molecules ERG represent glucose okay each of these glucose molecules are attached to each other like this in linear chain, so there are two ways it can join one is called say for example it is linearly attached like this something like this which is called 1-4 glycosidic linkage okay this is one of the ways how this linkage take this which is a linear-linear chain long linear chains of molecules yet there is another way it can form that forms between two different chains.

Say for example this is if I represent this as one single chain like this and there is another chain like this and between the two chains there are linkages which are called 16 glycosidic linkages what does that one and four means is so if you start numbering them this is1, 2, 3, 4, 5, 6 okay similarly here if I number them 1 2 3 4 5 6 if you see the bond which is forming here it is forming between carbon 1 and carbon 4 that is what represent one of this one to the first one this one and the four of the second one this one okay.

So that means that makes it 1-4 glycosidic because both of them are glucose molecule like pathetic linkage so see for example there is a bond which forms between if is not let me again right to glucose molecule say this is one glucose molecule sitting here and let us number them 1 2 3 4 5 6 okay so another glucose molecule somewhere out here. With one two three four five six so if there is a bond which is formed between this one and this one then those are called 16 microcytic linkages.

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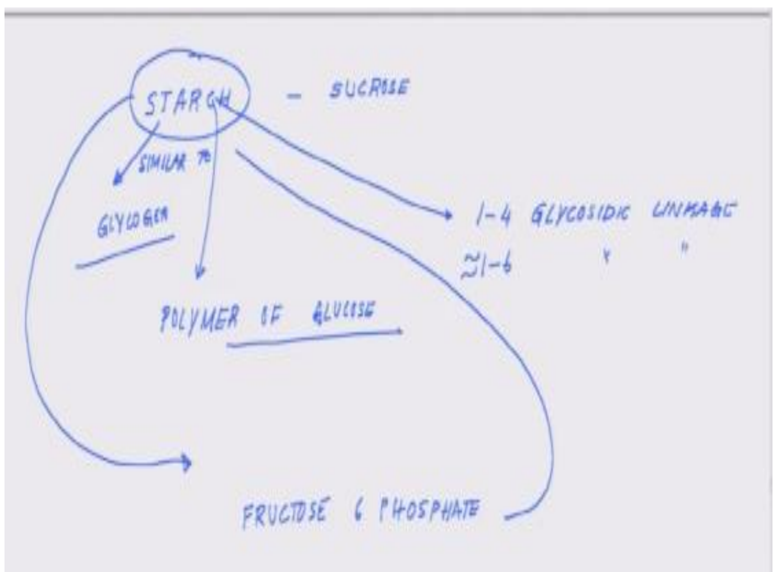

So if we look at what we are essentially doing plant contains two major storage forms which we have already talked about one is the starch and the other one is the sucrose okay, now if we talk about the starch, starch is basically stored in the form of starch is like glycogen very similar to other similar to glycogen and it is basically you can call this as a polymer of glucose and most of this polymeric chain of sucrose consists of1-4 glycosidic linkages and there is a small fraction small fraction of 16glycosidic linkages.

Which are present in them so this is synthesized and stored in the chloroplast so all this starts molecule what you see so this the genesis of all these things is from fructose 6-phosphate to starch Kelvin cycle fructose 6-phosphate.

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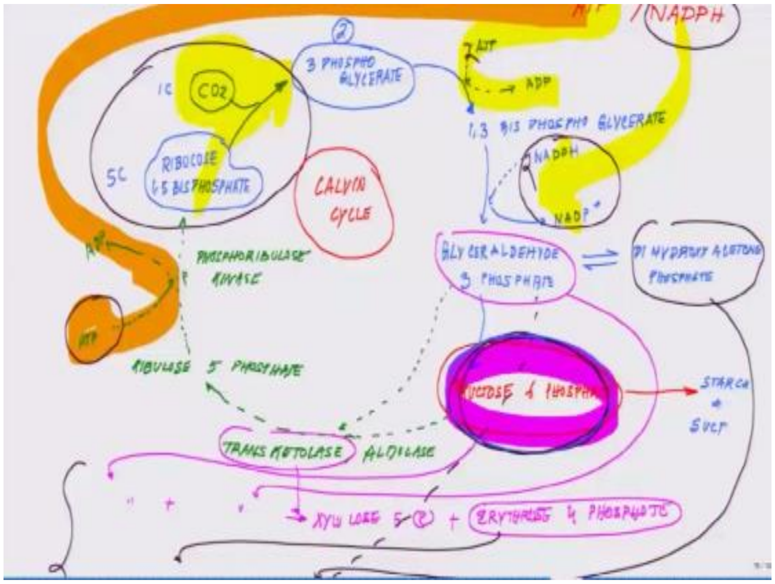

Look at this molecule so this is converted into starch or and sucrose.

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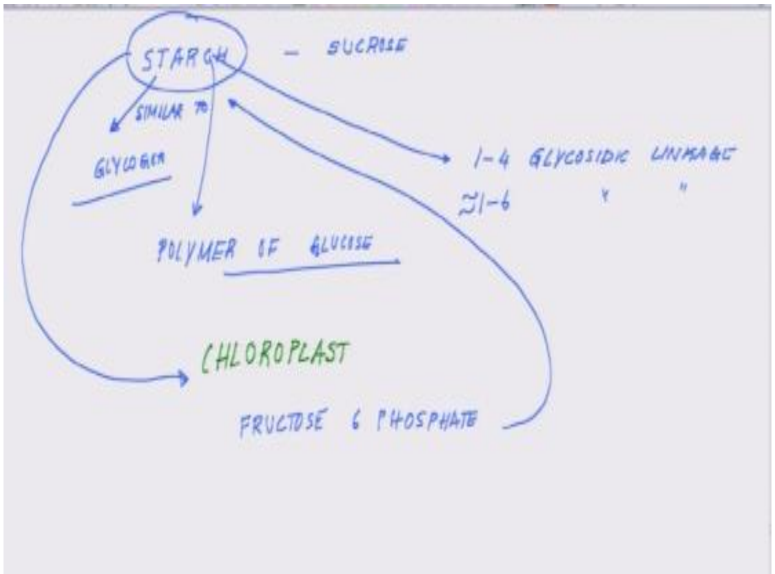

This is a starch is store in a chloroplasts now there is a second molecule which is form which is called sucrose, sucrose is a much more simpler molecule it consists of two units to six carbon chain six carbon ring okay so we talked about how they sucrose molecule is from and it is readily usable sugar okay.

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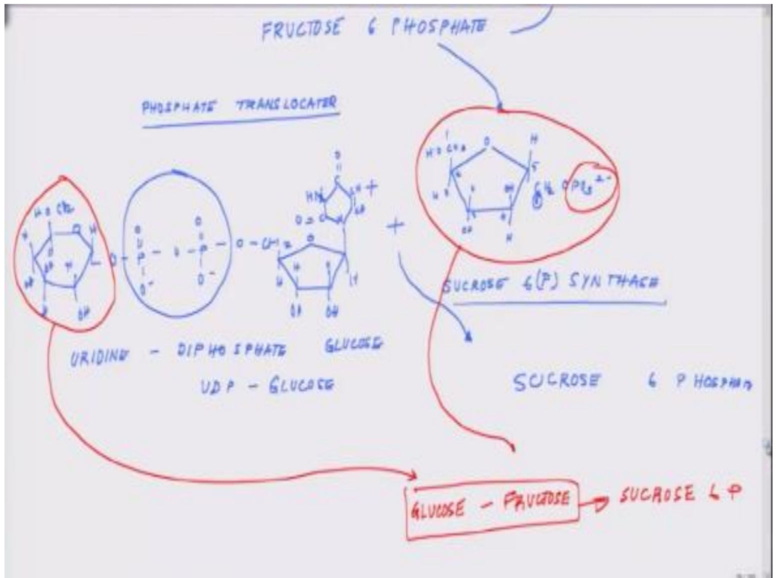

Coming back to the slide so you have this crypto6-phosphate so if you see the structure of the fructose 6-phosphate now let us start from there so photo 6 phosphate is nothing like this suffice one chain so the oxygen out here you have hydrogen here which is the fifth carbon and you have the sixth carbon out here CH $_2$ 0 Cl_3 minus this is the phosphate group this is the sixth carbon okay and have you hydroxyl group and this is your fourth carbon now you are on the third carbon hydroxyl group pointing out of the plane.

And here you have hydroxyl group and you have another hydroxyl group attached to this carbon which is the carbon one so this is your fructose6-phosphate fructose 6-phosphate is using an abundant phosphate cross locator we needed a phosphate cross located the phosphate trans located I am adding now, phosphate, trans locator so this phosphate trans located is molecule like this and this phosphate class locators are fairly rich in the chloroplast okay.

This oxygen out here out here then you have OC here sorry OCH_2 H is another five member ring out here which is H-H-H-OH and okay there is a nitrogen CH- CH with O at the NH here sorry this is NH and yet the top and this is called your let me just finish this molecule the oxygen out here hydrogen and you have a hydrogen OH-OH-H and H-OH okay so this is called a phosphate trans locator it is called URIDINE this URIDINE group attached di-phosphate glucose this is also called UDP.

So you have the di-phosphate out here di- phosphate glucose and this URIDINE attached to it so when this two molecules react with each other in the presence of sucrose 6-phosphatesynthetase sucrose 6-phosphatesynthetase is the enzyme which is involved in it what you essentially get out of it a is sucrose 6-phosphate sucrose 6-phosphate is nothing but this molecule this is what you see the fructose and you have this part which is the glucose.

So what you are we have glucose and have a fructose which makes you the sucrose, sucrose 6 phosphate so phosphate look like this which comes as it is if you see the structure, structure will be like this.

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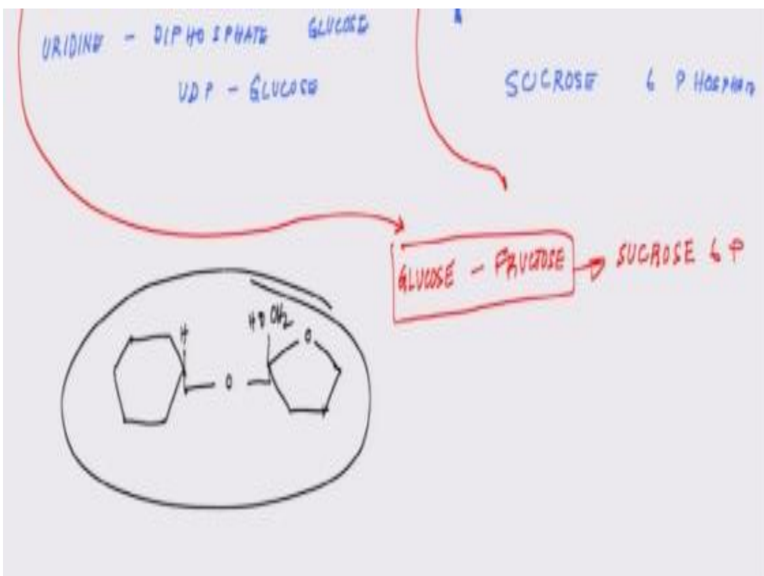

Let me just draw the structure and of course it will be left with a UDP which is the original phosphate I am NOT drawing that again so it will be something like this H-O and here you have OH $-CH_2$ so only for you guys to complete this whole structure I wish you to complete this part of the structure okay.

That is kind of your assignment to look at how these things are formed so just now what we concluded is in this whole process we landed up with long-chain starch which consists mostly of 1-4 glycosidic linkages and few or handful of 16 glycosidic linkages these are long chain apart from it we what we get is sucrose molecule of 15 carbon ring off and one six carbon ring of glucose and fructose they attached together and form what we call as sucrose so these two are the majors molecules so now coming back to our first light of today.

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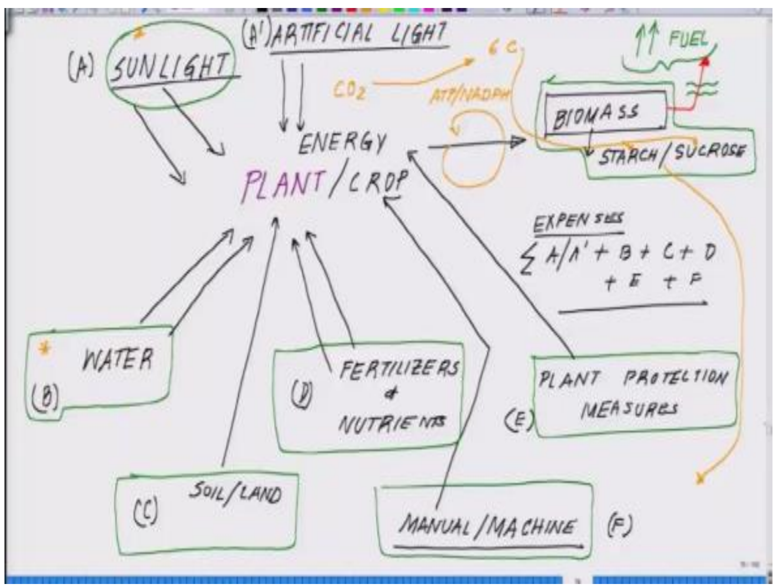

So these two molecules what we talked about is what will dictate that what is the efficiency of this process but before we get into the efficiency now let's take a count of how much NADP and NADPH has been involved in this process so coming back to the NADP and NADPH a so if you remember we started the reaction like this.

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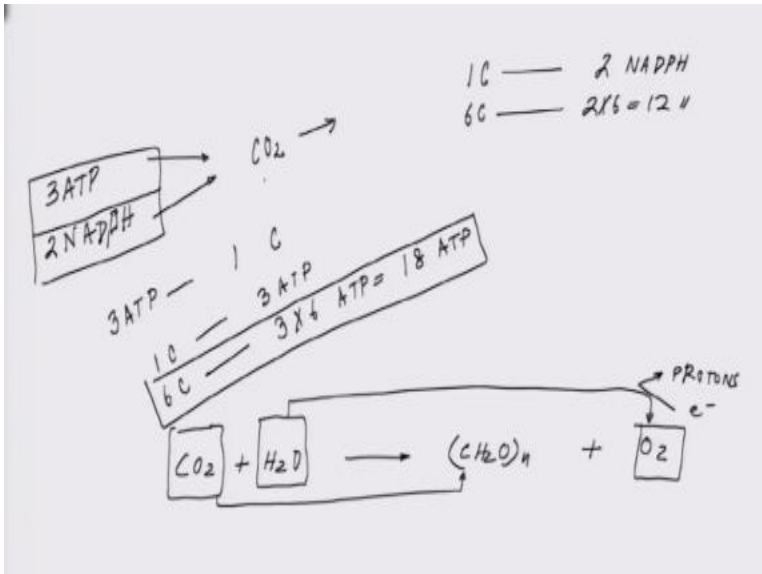

$CO_2 + H_2O$ forming CH_2O and plus oxygen this is the first reaction what we started when we say it carbon dioxide is getting reduced to carbohydrates okay, where as water is getting a split into proton electron and oxygen you know protons, protons electrons and oxygen now in this process we realize so if you go back to the cycle we saw there are involvement of ATP is out here there are two ATP's we got involved.

And there is another ATP which got so the first two ATP will got involved was when 3-phosphoglycerate is converted into 13 bits phospholipid you have two NADPH making NADP and you have another ATP molecule converted to a DP by donating that phosphorus group in the conversion of glyceraldehyde 3-phosphate or three below 65 of say to Reba lows 15bisphosphate so Reba lows 5-phosphate a single phosphate and 15 bi-phosphate is having two phosphate moieties okay.

So if you see so in one cycle there is two ATP plus 13 ATP right so this is one ATP to here and one here 22 plus 13 ATP are involved whereas you see at the NADPH there are two NAD PA consume okay so now let us add up this to the cycle so we talked about 3ADP + 2 NADPH so this is what is needed to convert one co_2 molecule to add one co_2 molecule so for 6 you will be needing six time of this so essentially what will happen 3ATP for one carbon so rather 141 carbon unit three ATP.

So for six carbon you will be needing three x 6ATP so which is essentially 18 ATP molecule will be needed similarly if this is one the other instances NADPH ok, so for attaching one carbon you need two NADPH so attaching six carbon you will be needing to x 6 12 NADPH now this is what we are going to add into this equation what we have put forward in the beginning to start our journey of photosynthesis.

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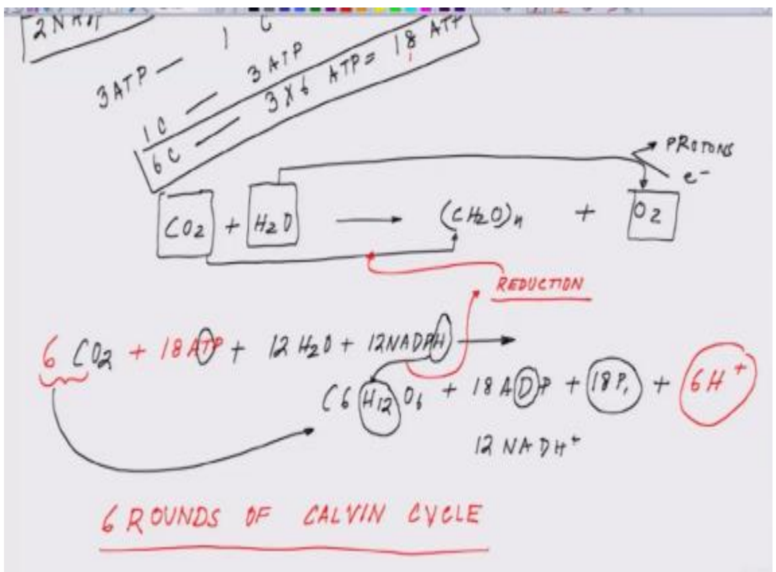

Now we are revising the reaction you have co_2 which is a single carbon so now we make it six now I am adding $6co_2$ because we need six carbon sugar plus we have talked about 18 ATP plus you will be needing to h_2o so you will be needing 12 water molecules one point of time plus we have talked about we will be needing 12 NADPH okay and what you are getting out of it is c $_6$ okay 6 carbon H-12 O-6 plus it has donated 18 phosphorus moieties.

So we are left with18ADP di-phosphate here you have the tri-phosphate just compared okay + 18 phosphorus molecule which is can come out from try to dyad I ok plus 12 in ADP plus because it has donated these hydrogen to out here which makes it h $_{12}$ so this is that critical reduction process what we have been talking all along or this reaction essentially okay plus we talked about there will be a proton 6 H^+ those protons which are left.

So what we see out here if we see what is the energy expenditure of synthesizing a X0's so if you go through six rounds of Calvin cycle this is what you expect so this is the sum total of the energy expenditure of a six round of Calvin cycle when you go through it this is what you will be obtained okay.

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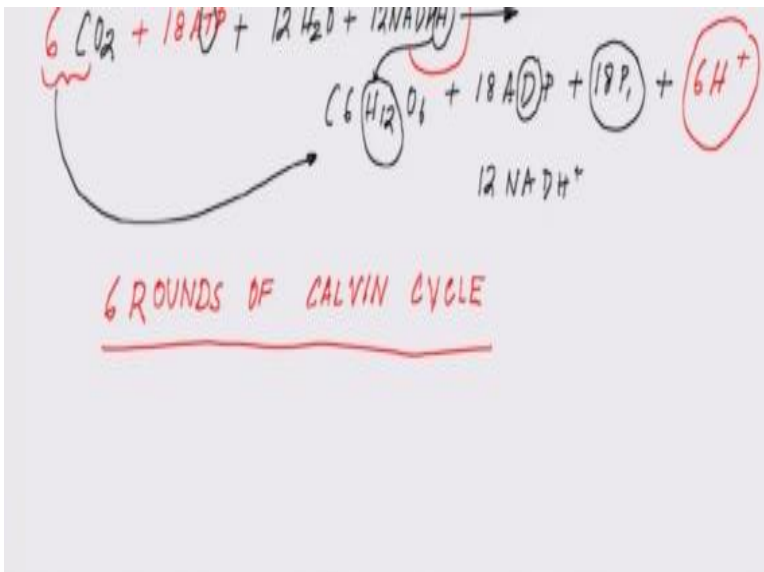

Now we will add 2, 3 more things before I conclude this part.

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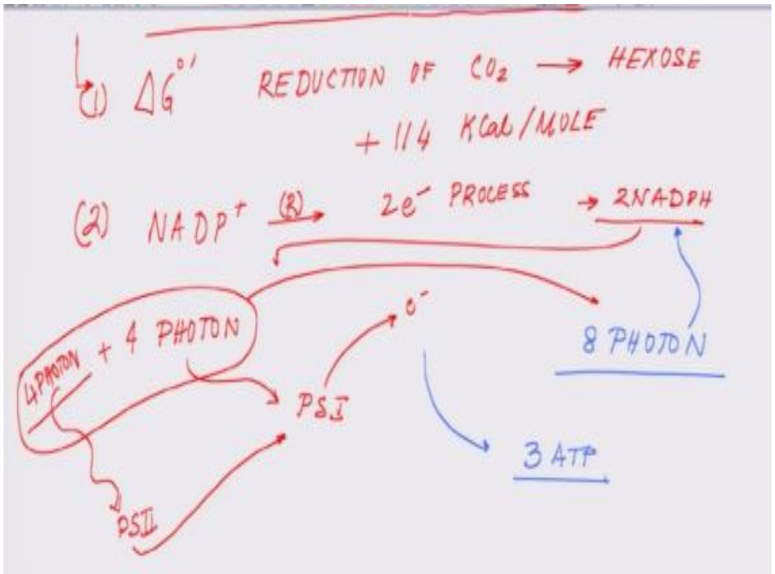

Is what is the efficiency of photosynthesis how it is being evaluated okay so if you have to see the efficiency because this will be very relevant to our next topic where we will be talking about the c_3 and the c_4 plants and how the Rubisco oxygen is activity is be encountered in high temperature where because of the high temperature the photo respiration increases so the Delta G the first thing is the Delta G zero prime for the reduction of co_2 2 hexose.

Which is a fixed carbon is plus 114 kilo calorie per mole step one second so the reduction of NADP to NADPH NADP+ this reduction process is two electron process okay hence the formation of two NADPH requires the pumping off so if you want to NADPH molecules to be formed so this required this part is very critical just evaluate it carefully this requires pumping up for photon to photo system 1.

So four photon to photo system 1 so this is the light expenditure we are talking about the electron given up by four system one so it is giving out electrons in that process if we replenished by 40 system to now for the system to replenished those electrons which are given out we instead of absorb equal number of photons so automatically this also need equal number of photon into play.

Hence sum total of photons which are needed is if you add these two what you are getting is it will be needing eight photon which is the energy expenditure in terms of the photons so what you are getting is an eight photon are needed to generate the required NADPH molecule okay the proton gradient generated in producing two NADPH is more than sufficient to drive the synthesis off so in that process there is a proton gradient synthesis of three ATP molecules for mark my word again the proton gradient generated in producing two NADPH.

Is more than sufficient to drive the synthesis of three ATP molecule and the third and the final aspect is that.

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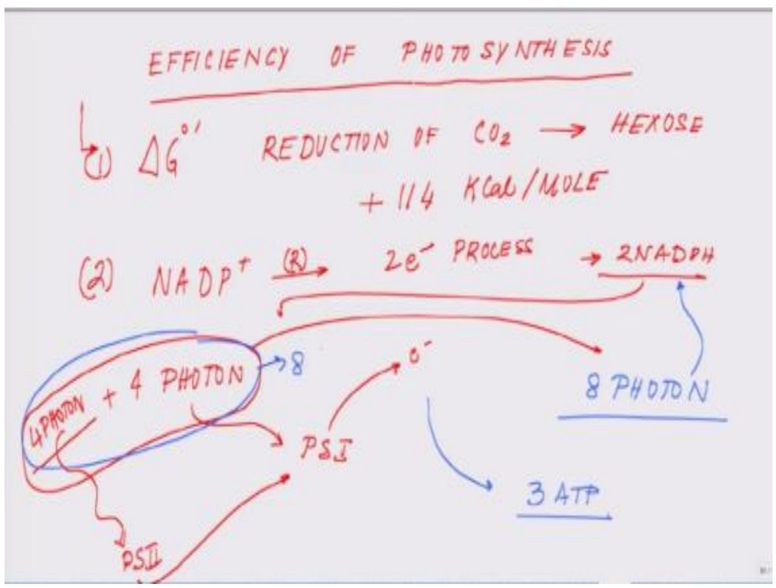

A mole of 600 nanometer photon has an energy content of 47.6 kilocalorie so remember this part a mole of 600 nanometer once again 600 nanometer photon has an energy of 47.6 kilo calorie and so the energy input of 8 moles so the energy input of 8 moles of photon will be equal to 3 81 kilo calorie why 8 moles, from where this eight mole is coming? So she will little further up see the four photon and for photon eight.

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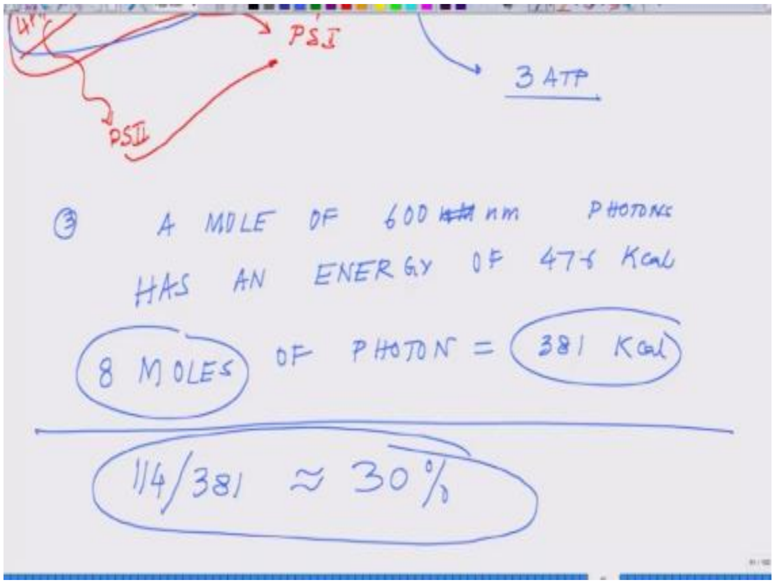

So this is from where this eight moles of photonics 381 kilo calorie this brings us to the concluding part of this lecture thus the overall efficiency of for synthesis and the standard condition is 381 which is approximately thirteen percent so from where 114 is coming 114 is coming with vh1 you know from where it is come one is coming from here and 114 is coming from here.

The Delta G of conversion so when you divide 114 by 381 x 100 so efficiency of photosynthesis on the floor of Earth is thirty percent so this is how the whole energy dynamics so if you look at look in the first slide what I showed you in the beginning of the class to start off with.

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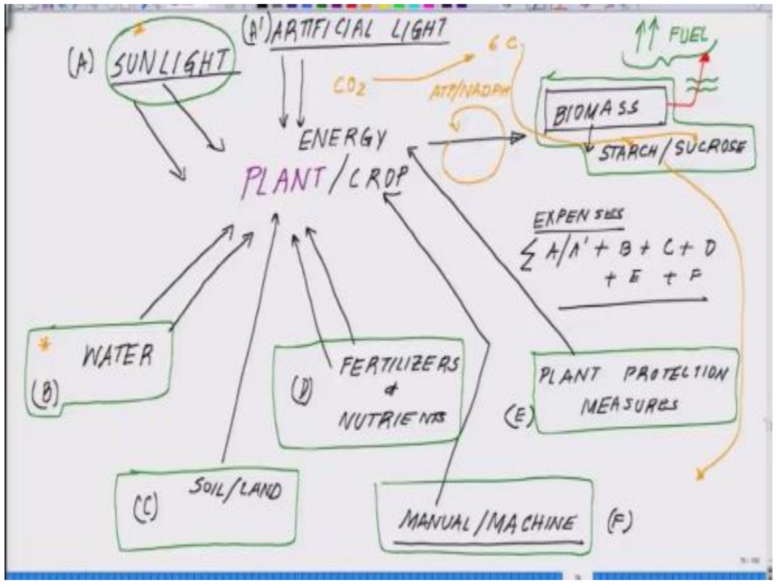

So this is we talked about their formation of the starch and the sucrose right followed by we talked about that ATP and NADPH and the whole expenses of course barring a site we did not talk about this one we did not talk about this one we did not talk about this one we did not occur this one what we talked about is the water sunlight which is involved in the form of photons and the energy needed to convert this reaction co_2 to 6 carbon and what we are getting out here is let me come back okay.

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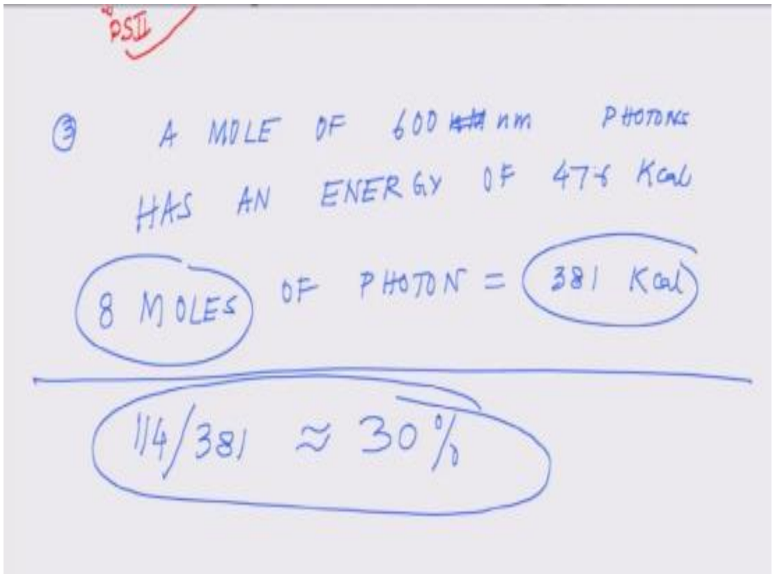

So the take-home message for you triple is this part a mole of this much amount of light which is 380 kilocalorie which is 381 kilo calorie what is needed to convert one hexose molecule which is 114 and it is that what you are getting is we are talking about thirty percent efficiency so overall photosynthesis is thirty percent efficient now from here keeping this in mind and talk keeping in mind the problems Rubisco faces it has oxygenates as well as carboxylates activity and there is always a tug-of-war there is a very interesting thing as a temperature increases specially added semi-arid tropics of the world where the temperature is really high.

In those places the oxygen binding capacity of Rubisco increases in other words photorespiration increases your consuming oxygen how the plan get around it because this is very important because if you remember the very first lectures what I was giving you I told you that if we have to get our huge bio mass we have to ensure it is not the cost of environment because if the system itself is consuming a lot of oxygen it is not going to help us so what nature has developed this will take us to one of the very unknown study made by one Russian followed by an Australian scientist hatch and slack.

And how they discovered something called c4 plants from here we'll move on to something now you know the efficiency overall officials which is thirty percent we have talked about that drawbacks of Rubisco and we have also talked about why lot of mutagenesis of studies of you know manipulating the Rubisco molecule as of now it is not really successful because Rubisco is a peculiar enzyme sitting out there so what nature has devised to ensure that the Rubisco efficiency is maintained at high temperature where otherwise Rubisco will behave more for further expression then for utilizing the carbon dioxide.

So we will close in here will resume our next class where we will talk about c3and c4 plants and that will kind of bring us to the point the how these bio first set of bio cells are formed by nature from there we will take up how the conversion is going to take place and what are the basic paradigm how these starch sugars cellulose bunch of glycans and everything which are formed how to convert them and how much energy has to be consumed to convert them as of now we have talked about how much energy is needed to make them by nature itself next ways we will talk about once we are done with the c3 c4.

We will talk about how much energy man has to put to convert this too much more usable skills so this is how the whole bio energy landscape will run through what we have a fairly good idea or a grip on the system about what is happening in nature and the form of photosynthesis photorespiration group disco light reaction dark reaction formation of starch and sugar molecules and from there we will move up how we can convert them once we harvest all that okay thank you.

Acknowledgement

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