Energy Conversion Technologies (Biomass and Coal)

Prof. Vaibhav V. Goud

Department of Chemical Engineering

Indian Institute of Technology, Guwahati

Lecture 22

Bioethanol Production

Good morning everyone.

Welcome to the second lecture of module 5. In this lecture, we will discuss another biochemical conversion process that is alcoholic fermentation. In that, we will discuss about the comparison of biochemical and thermochemical routes, competitive production of alcohol, bioethanol production from edible sources and non-edible sources, process description, distillation, combined biogas and bioethanol production.

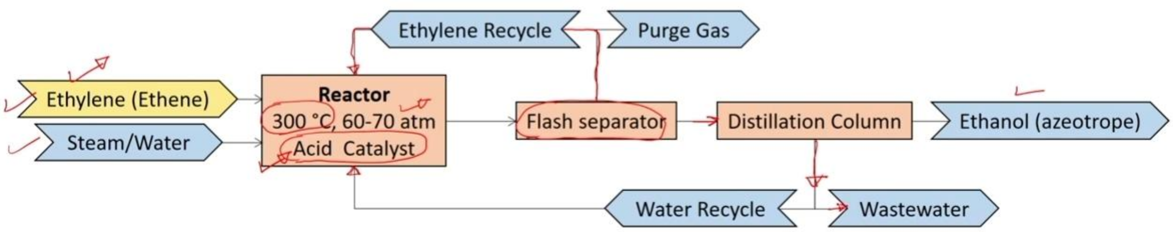
Refer slide time: 01:00

Ethanol

Ethanol is an important industrial chemical; it is used as a solvent, in the synthesis of other organic chemicals, and as a viable alternative to petroleum-based fuels.

- Ethanol can be produced by: (a) chemical process,
  (b) thermochemical process, and
  (c) biochemical process (Alcoholic Fermentation).

(a) **Chemical Synthesis of Ethanol**

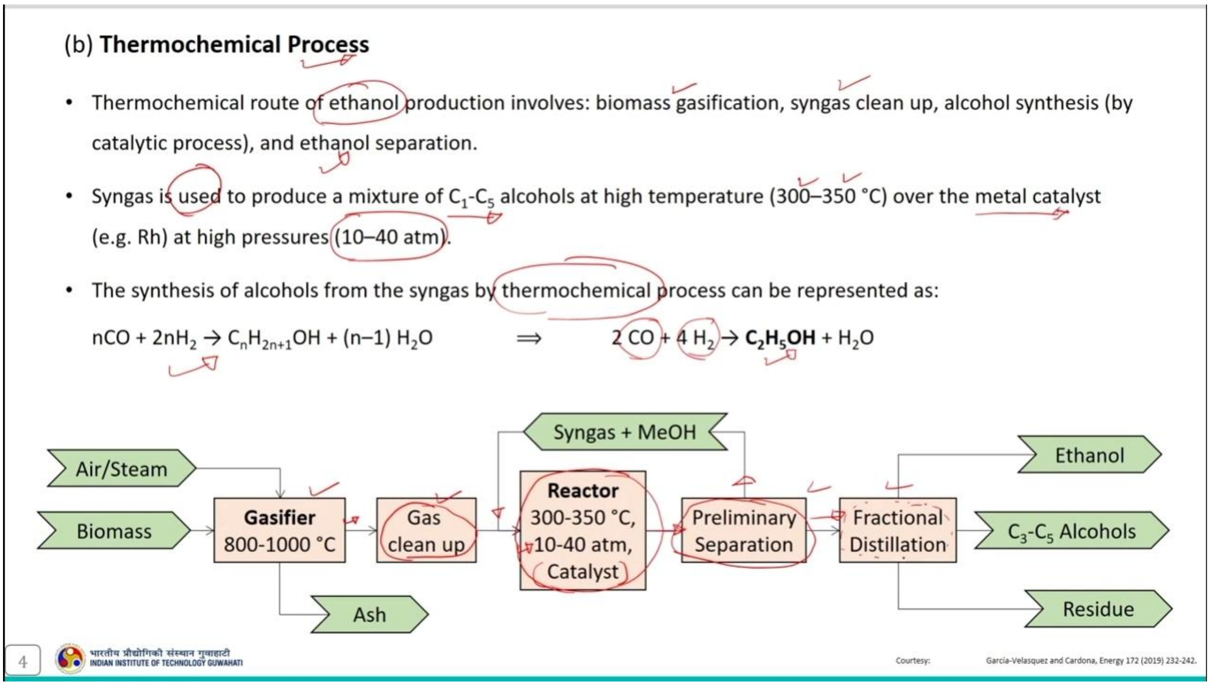


3

Ethanol is an important industrial chemical. It is used as solvent in the synthesis of other organic chemicals and as a viable alternative to petroleum based fuel. Ethanol can be produced by chemical process, thermochemical process and biochemical process that is also known as alcoholic fermentation. So, let us first discuss about the chemical synthesis of ethanol. This schematic here, it represents the process arrangement of ethanol production by hydration of ethylene and the key reactants are ethylene and steam. Acid catalyze hydration of ethylene forms ethanol which is referred to as a chemical process.

And in this process, phosphoric acid is used most commonly as a catalyst in the chemical process. And it takes place at around 300 degree Celsius and 60 to 70 atmospheric pressure. After reaction, first the unconverted ethylene is separated by flashing and the washing unit. And the separated ethylene is recycled back into the system for reaction. Then the resulting water ethanol mixture is separated in a series of distillation units and this system it features two loops - One loop for ethanol recycling and other for water recycling. So, the water produced during this distillation unit is recycled back into the system. And if this water is not recycled back into the system, then it is treated using a suitable wastewater system. And after distillation, the product obtained is hydrous ethanol.

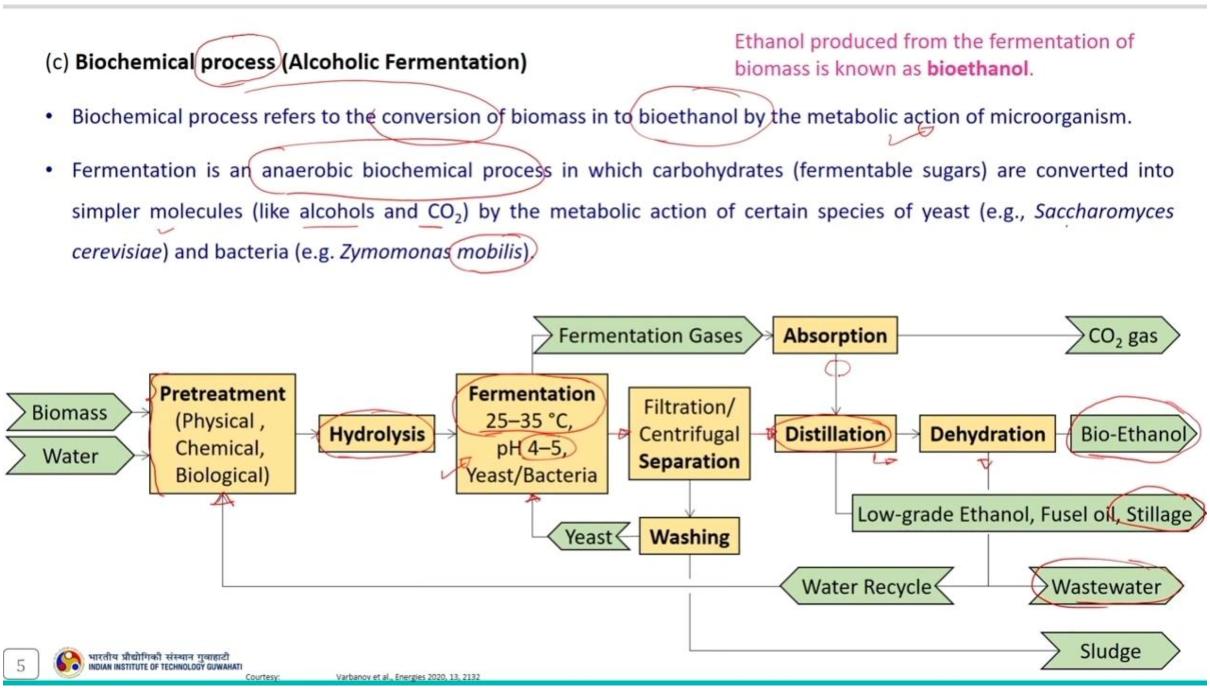
Refer slide time: 03:34



So, another process is a thermochemical process to produce ethanol. Fermentation of syngas from gasification is another possible route for the production of ethanol from woody biomass. The thermochemical route of ethanol production, it involves biomass gasification as shown here in this schematic as well. The syngas cleanup, alcohol synthesis using a suitable reactor and ethanol separation. This syngas produced from the gasifier, it is used to produce mixture of C1 to C5 alcohol at temperature 300 to 350 degrees Celsius over the metal catalyst and pressure is around 10 to 40 atmospheric pressure. The synthesis of this alcohol from the syngas by thermochemical process is represented using this reaction scheme and in the form of carbon monoxide and hydrogen, it is represented here, which gives ethanol as a product.

So, in this process, the syngas produced from the gasifier is cleaned using a gas cleaning unit and the clean gas is reacted at 300 to 350 degrees Celsius over the metal catalyst and 10 to 40 atmospheric pressure. The product mixture is separated using the preliminary separation unit. And here the syngas and the methanol is separate out and recycle back into the system. And the resulting product is separated using fractional distillation unit to separate out ethanol C3 to C5 alcohols and solid residue.

Refer slide time: 05:40



Another possible process for the production of the ethanol is biochemical conversion process. So, in this process, the conversion of biomass into bioethanol is carried out by the metabolic action of microorganisms and this fermentation it is an anaerobic biochemical conversion process in which the carbohydrate are converted into the simpler molecule like alcohol and the CO_2 by the metabolic action of the certain species of yeast that is *saccharomyces cerevisiae* and bacteria example, *zymomonas mobilis*. So, in this case, the lignocellulosic biomass or suitable bio-based feedstock is pre-treated using suitable pre-treatment technique either physical pre-treatment, chemical or biological pre-treatment technique. The produced material is hydrolyzed to convert carbohydrate into fermentable sugars, which can be fermented here at around 25 to 35 degrees Celsius, between pH of 4 to 5 and in presence of certain species of yeast that is *saccharomyces cerevisiae* or even bacteria that is *zymomonas mobilis* here. The product obtained from the fermentation is filtered to separate out the yeast and the separated yeast is recycled back into the next batch of the fermentation. The resulting product is distilled using a distillation unit to separate out the low grade ethanol and stillage.

The product obtained after the distillation which is mostly a hydro ethanol is converted into a high quality ethanol that is 99.5% ethanol using a dehydration unit. And the water removed during the dehydration unit is recycled back for the pre-treatment operation. And if the water is not being used into the system, then it is treated using a suitable wastewater system. And the gas produced during this fermentation process is absorbed to recover the ethanol.

And this absorbed ethanol is also recovered using the distillation process to obtain the high quality ethanol and CO_2 as a byproduct gas can be obtained after this absorption unit.

Refer slide time: 08:30

Comparison of Biochemical and Thermochemical Routes for Biomass Conversion into Ethanol

Process	**Biochemical Route** *(Fermentation)*	**Thermochemical Route** *(Gasifiation + Liquefaction)*
Feedstock	Sugarcane/Starch/Corn	Cellulosic Stock/Wood/MSW
Reactor Type	Batch	Continuous
Reaction Time	Days	Minutes
Water Usage	3.5 – 170 L/L ethanol	< 1 L/L ethanol
By-products	Distiller's dried grain	Syngas/Electricity
Yield	~ 400 L/ton	~ 265 – 492 L/ton
Energy efficiency	~ 53%	~ 47%
Technology Maturity	> 100 plants in the United States	Pilot Plant

6 INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

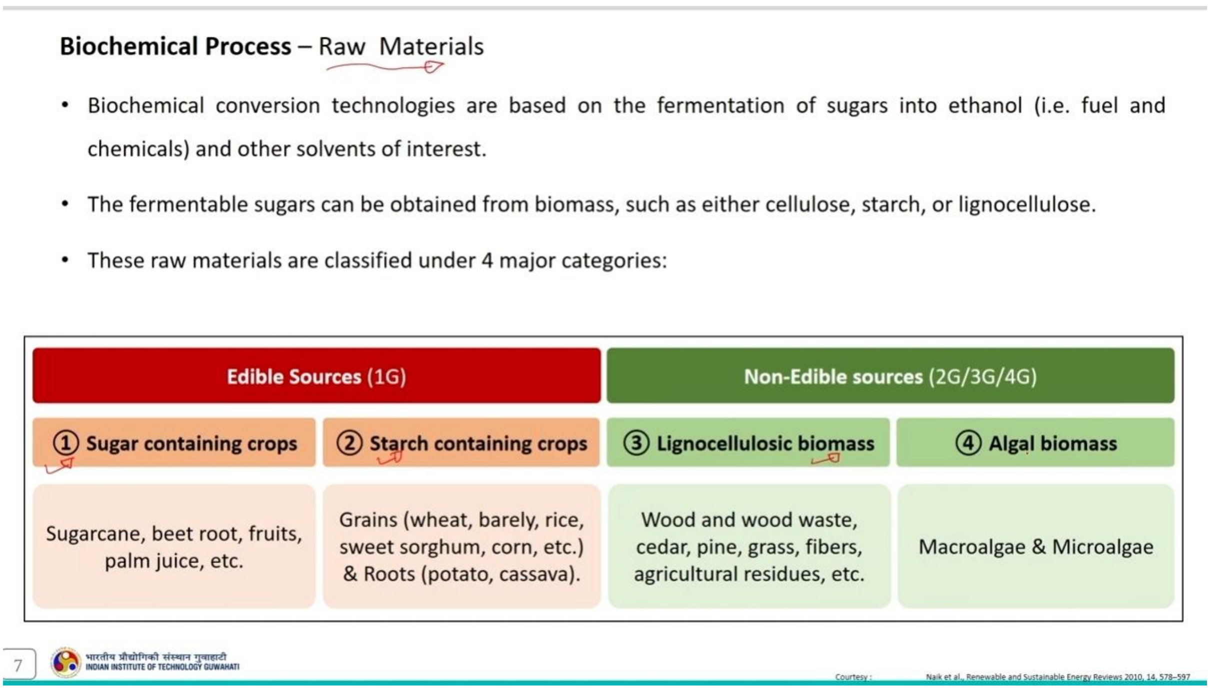
Courtesy: Basu, Biomass Gasification, Pyrolysis and Torrefaction, AP 2013

This table here it compares the biochemical and thermochemical route for biomass conversion into the ethanol. In case of biochemical route, the feedstock includes sugarcane, starch and corn, whereas in case of thermochemical route, the feedstock include lignocellulosic stock, wood or MSW. The reactor type here it is a batch type reactor is used in the biochemical conversion process, whereas in case of thermochemical route it is a continuous reactor.

Reaction time in days here the operation can be completed in minutes. Water usage is sufficiently high in the biochemical conversion route, whereas in case of thermochemical route, the water consumption is very less. Byproducts it produces distillers, dried grain, whereas in this case it produces thin gas which can further be used to produce the electricity. Whereas in this case it produce thin gas which can further be burn to generate the electricity and heat. Yield is around 400 liter per ton, whereas in case of thermochemical route it is around 265 to 492 liter per ton.

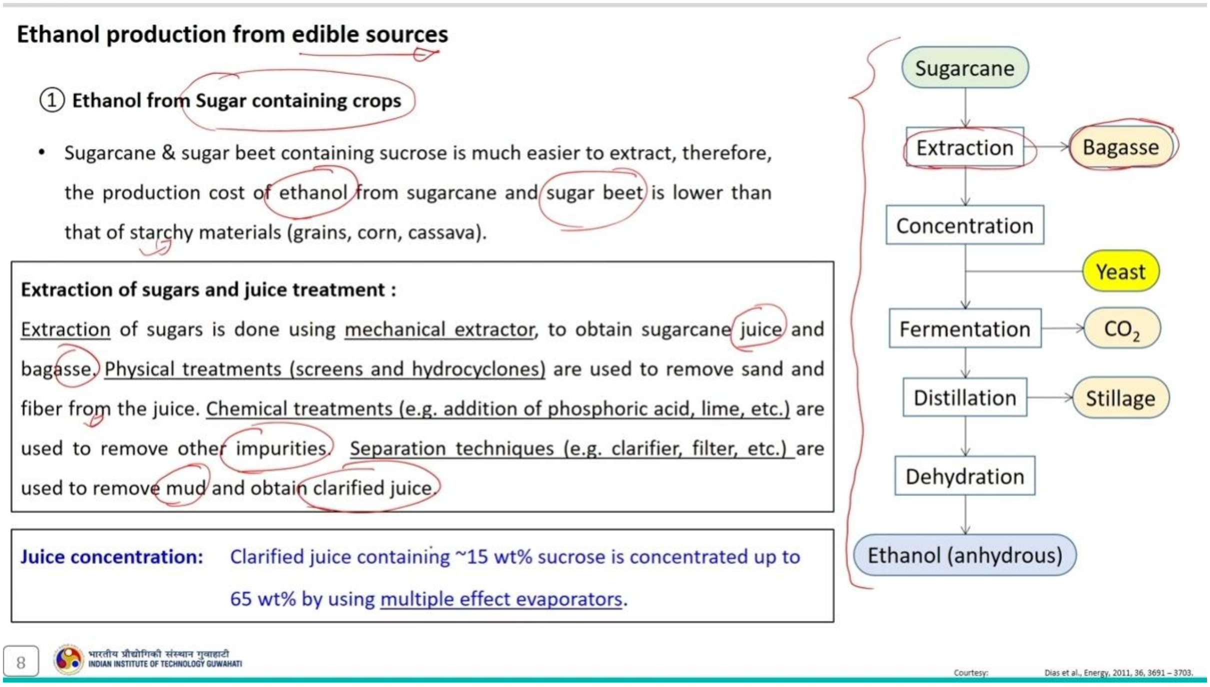
Energy efficiency is around 53% in the biochemical conversion process, whereas in case of thermochemical route it is around 47%. Numbers of such plants are available in United States as well as in India to produce ethanol using the biochemical conversion route. The technology of thermochemical route is still being tested at pilot scale.

Refer slide time: 10:13



So, now let us discuss in detail about the biochemical process and its raw materials. Biochemical conversion technologies are based on the conversion of sugar into the ethanol and other solvents of interest. And fermentable sugars can be obtained from various types of biomass that is either cellulose containing biomass, starch containing biomass and lignocellulosic biomass. And these raw materials are classified under four categories as shown here on the slide that is sugar containing crops, starch containing crops, lignocellulosic biomass and algal biomass. And further these raw materials are grouped as edible source material and non edible source material.

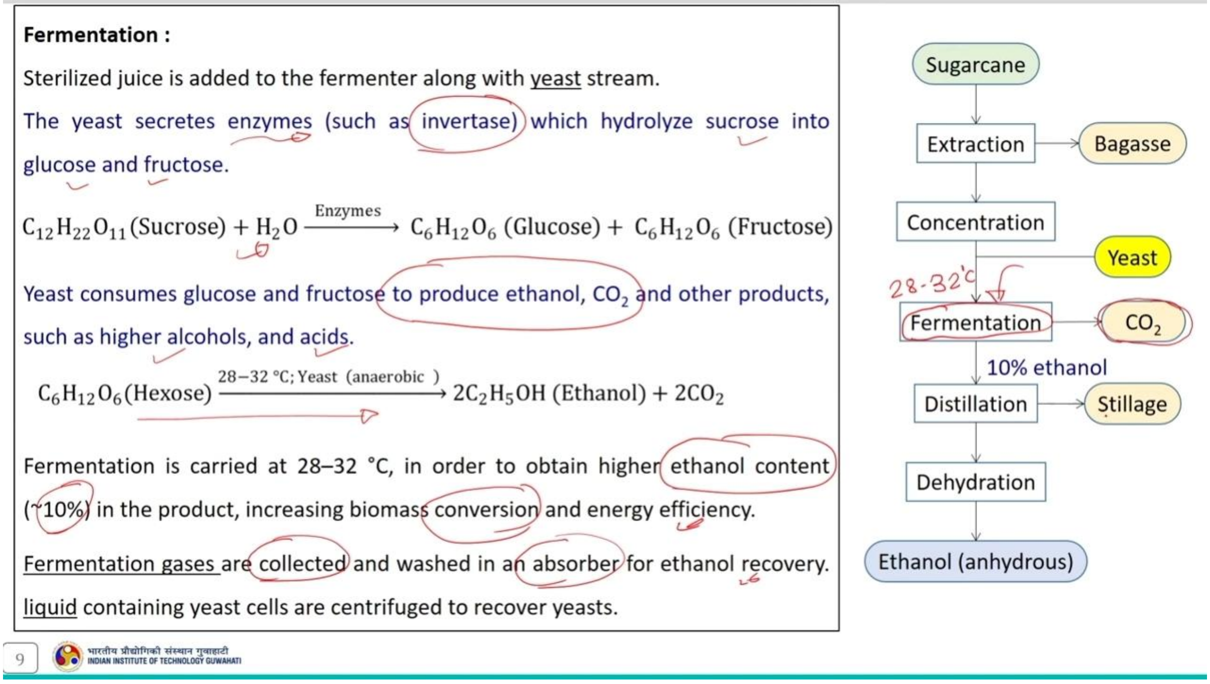
Refer slide time: 11:12



So, now let us discuss about these different raw materials one by one to begin with let us discuss about the ethanol production from edible sources. In that let us first discuss about the ethanol production from the sugar containing crops. The sugar cane and the sugar beet containing sucrose is much easier to extract. Therefore, the production cost of ethanol from the sugar cane and the sugar beet is lower than the starchy material that is grains, corn and cassava. And this schematic here shows the conversion of sugar cane to ethanol. So, in this process the extraction of sugar is done using a mechanical extractor to obtain sugarcane juice and bagasse. And this bagasse is the byproduct of this particular operation.

The physical treatments are used to remove the sand and the fiber from the juice followed by the chemical treatment to remove the other impurities. And then the separation techniques are used to remove the mud and obtain the clarified juice. And this clarified juice containing around 15 weight percent of the sucrose is concentrated up to 65 weight percent by using a multiple effect evaporator. And for that this concentration unit is used in this process to concentrate the sucrose from 15 percent to 65 percent.

Refer slide time: 12:51



Followed by that is the fermentation operation here in which the sterilized juice is added along with the yeast. And the yeast secretes enzyme such as invertase which hydrolyze sucrose into glucose and fructose as per the reaction scheme shown here. And the glucose and fructose produced during this step is used to produce ethanol and CO_2 along with other products such as higher alcohol and acids. And this reaction scheme represents the conversion of glucose to ethanol. The fermentation is carried out here at 28 to 32 degree Celsius in order to obtain the higher ethanol content that is close to around 10%, in the product increasing the biomass conversion and the energy efficiency of this particular process. And during this fermentation the CO_2 is released as a gas. Fermentation gases are collected and washed in an absorber for ethanol recovery. The liquid containing yeast cells are centrifuged to recover the yeast and recycled back into the next batch of the fermentation.

Refer slide time: 14:31

Distillation :

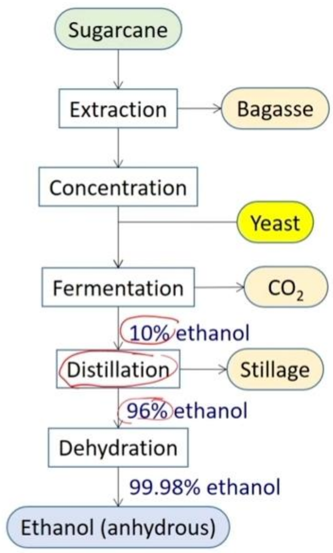
This includes successive fractional distillation system (pressure cascading technique), involving stripper, extractive tower, rectifying tower, and concentrating tower. (Jacques et al., 2003)

The concentration of ethanol is increased from 10% to 96% (by volume). The product is known as "**industrial grade ethanol**" or "**pure commercial ethanol**" or "**96 °GL Ethanol**". This is used as fuel in IC engines or thermal applications.

The commercial 'pressure cascading' or 'multistage pressure' distillation system (consume **3.0–4.2 kg of steam/L of ethanol**) is more energy saving than conventional distillation system (consume 6 kg of steam/L).

Byproducts/residues: low grade ethanol, fusel oil, & stillage.

°GL = Degree Gay-Lussac = % ethanol (by volume)

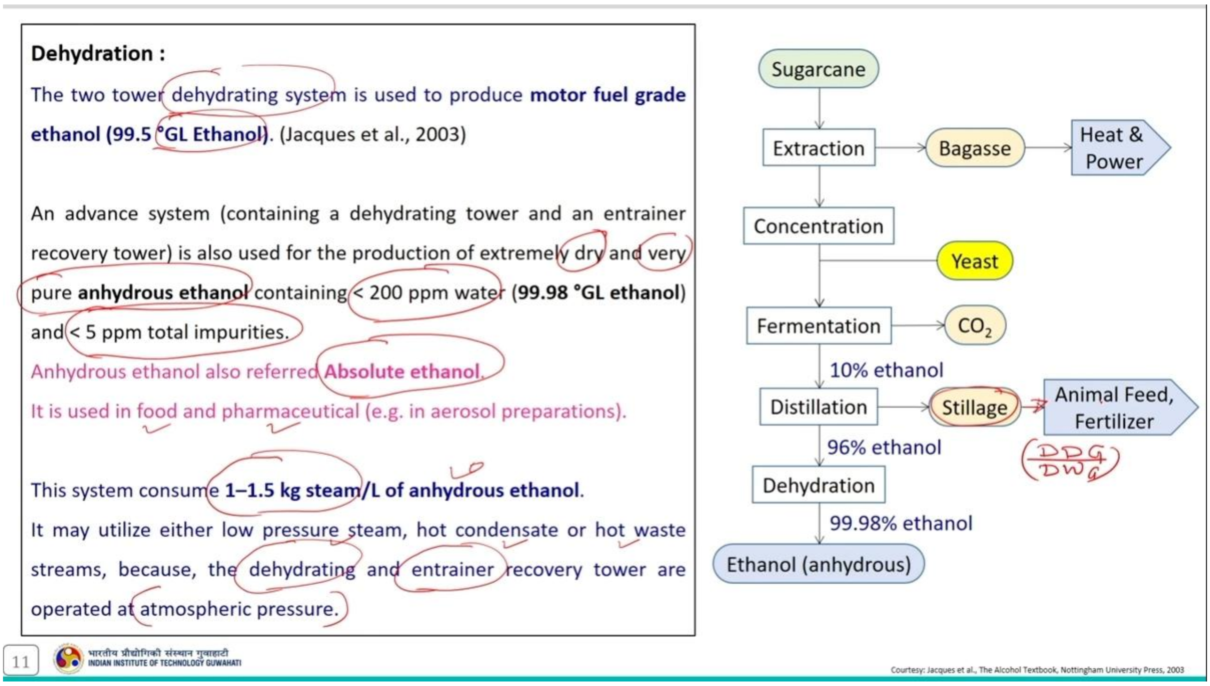


10 भारतीय प्रौद्योगिकी संस्थान गुवाहाटी INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

Courtesy: Jacques et al., The Alcohol Textbook, Nottingham University Press, 2003

Followed by that is the distillation operation in which the successive fractional distillation system is involved to concentrate the ethanol from 10 percent to 96 percent. And the product is known as industrial grade ethanol or pure commercial ethanol or 96 degree GL ethanol. This used as fuel in the IC engines or thermal application. And the commercial pressure cascading or the multistage pressure distillation system is used which consume around 3 to 4.2 kg of steam per liter of the ethanol which is more energy saving than the conventional distillation system, which consume around 6 kg of steam per liter of the ethanol. And byproduct and residue obtained during this distillation process is a low grade ethanol and stillage.

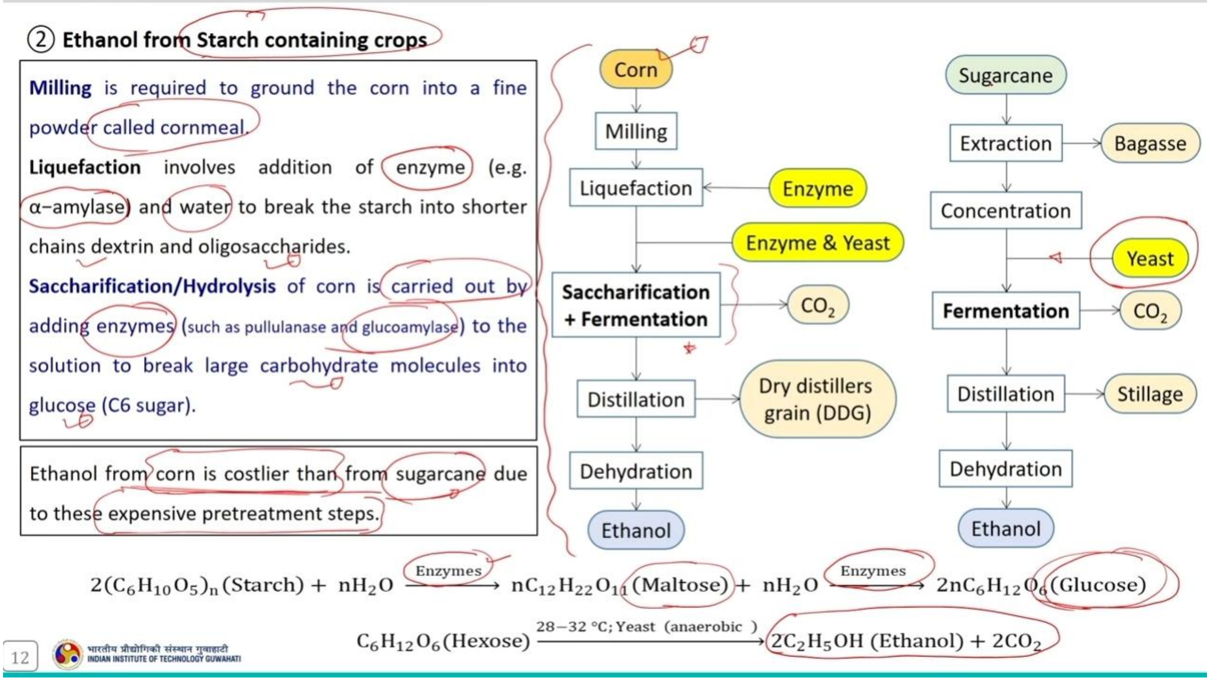
Refer slide time: 15:37



Followed by distillation is the dehydration step where two tower dehydrating system is used to produce motor fuel grade ethanol that is 99.5 degree GL ethanol. Here an advanced system is used for the production of extremely dry and very pure unaddressed ethanol containing less than 200 ppm water and less than 5 ppm total impurities. And this unaddressed ethanol is also referred as a absolute ethanol. And it has wide application in food and pharmaceutical industries. And this system consumes around 1 to 1.5 kg of steam per liter of the unaddressed ethanol.

It may utilize either low pressure steam, hot condensate or hot waste steams because the dehydration and internal recovery tower are operated at atmospheric pressure. The byproducts of the distillation process are mostly low grade ethanol and stillage which is a liquid effluent from the distillation process and is known as a spent wash or stillage. It is a mixture of unfermented dissolved solids, insoluble grains, fine proteins, dead yeast and water. And this stillage further processed to derive evaporator syrup and distillers grain that is commonly known as DDG or DWG. And this produce stillage may be used as a food supplement for cattle but it has an undesirable laxative effect on animals.

Refer slide time: 17:44

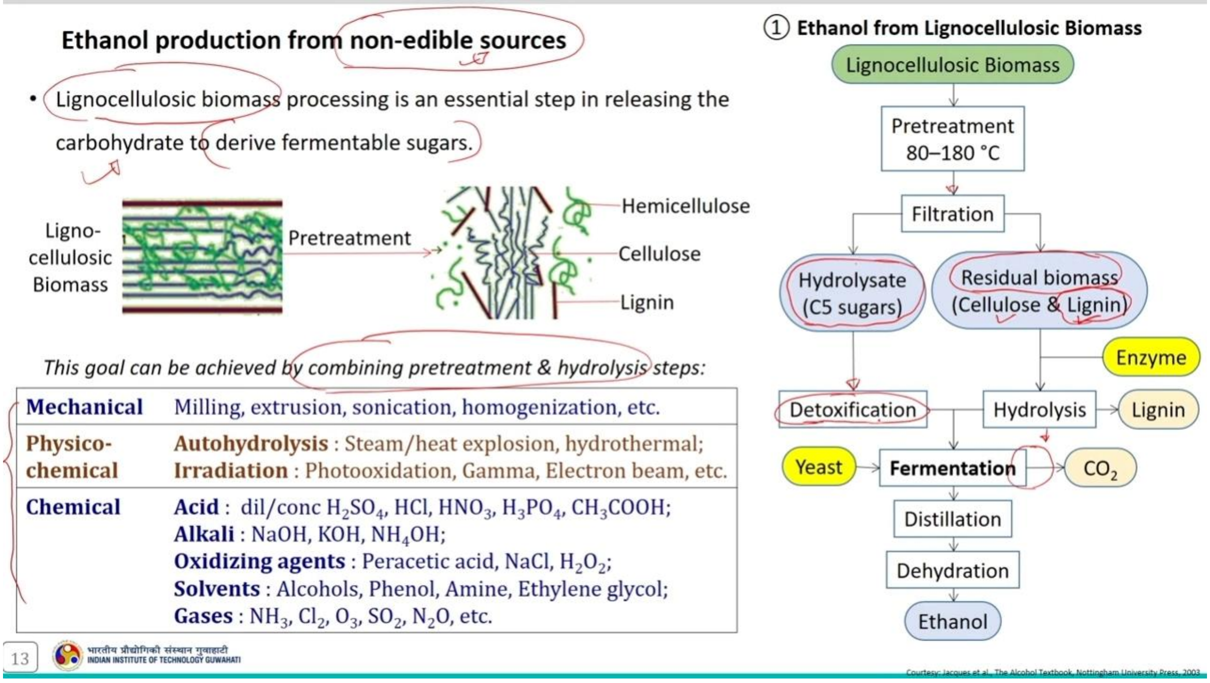


Second most potential raw material for the ethanol production is starch containing crops. And this schematic here represents the ethanol production from starch containing crops. In this process first the material need to be milled into a fine powder. If the corn is being used as a feed material then the corn need to be milled to produce corn meal. Followed by milling is the liquefaction process which involves the addition of enzyme that is alpha amylase and water to break down this starch into shorter chain dextrin and oligosaccharides.

Followed by that is the saccharification and the hydrolysis process where the corn is hydrolyze by adding enzymes that is glucomylase to solution to break large carbohydrate molecules into glucose. Followed by the fermentation to produce ethanol from corn and this process of production of ethanol from corn is costlier than the sugar cane due to this expensive pre-treatment step here. If you take a look at this reaction scheme here the starch is treated here using a specific enzyme to convert into maltose which further hydrolyze to produce reducing sugar that is glucose and the produced glucose is fermented to obtain ethanol. So, in this process two different types of enzymes are used in the pre-treatment stage and because of that the ethanol production from corn is costlier than sugar cane. If you compare this to process flow chart in case of sugar cane only the yeast is used for the fermentation process here.

While in case of corn two different types of enzymes are used during the pre-determined stage to release fermentable sugar as a result the ethanol from the corn it becomes costlier than sugar cane.

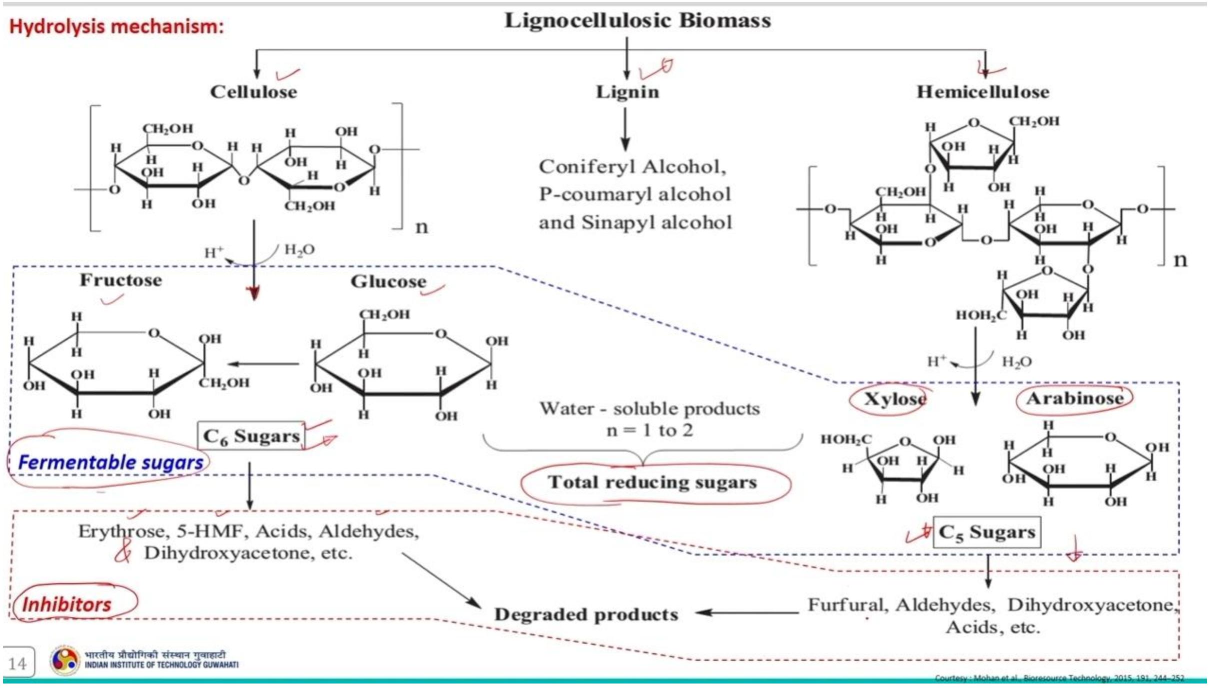
Refer slide time: 20:39



Another class of raw material which can be used for ethanol production is non-edible material, which includes lignocellulosic biomass. Pre-processing of lignocellulosic biomass is essential in releasing the carbohydrate to derive fermentable sugars and this can be achieved by combining pre-determined and hydrolysis step. Number of pre-determined and the hydrolysis techniques are available to convert the carbohydrate to fermentable sugar which are mentioned here. So, after the pre-determined stage the product mixture is filtered to separate out the hydrolysate and residual biomass which mostly contains cellulose and lignin.

The produced residual biomass further hydrolyzes to separate out the lignin fraction to obtain cellulose rich residual biomass which can be hydrolyzed enzymatically to produce fermentable sugar. And the fermentable sugar obtained from the cellulose fraction is mostly a hexose sugar that is glucose and can be fermented using a separate fermentation unit to produce ethanol. And the hydrolyzed fraction obtained here that is mostly a C5 sugar is detoxified to remove the toxic component and other inhibitory component present in the hydrolysate. And the detoxified fraction is fermented in a separate fermenter to produce ethanol.

Refer slide time: 22:44



And this scheme here it represents the mechanism of hydrolysis of the lignocellulosic biomass as we know the lignocellulosic biomass is mostly consisting of cellulose hemicellulose and lignin. So, the cellulose is hydrolyzed to produce fructose and glucose which are termed as fermentable sugars and also termed as a C6 sugar. And the hemicellulose fraction hydrolyzed to produce xylose and arabinose which are termed as C5 sugars. And these fermentable sugars are referred as total reducing sugars. During this hydrolysis stage the degradation of the C6 sugar is possible which may get converted into erythrose 5 HMF acids aldehydes and dihydroxy acetone. Similarly, the degradation of the C5 sugar may result into the formation of furfural, aldehydes, dihydroxy acetone and acids and these are inhibitory product which may inhibit the fermentation process.

Refer slide time: 24:14

- The hemicellulose and cellulose are not hydrolyzed as easy as the starch, but on heating with dilute sulphuric acid under specified pressure they undergo hydrolysis to produce xylose and glucose, respectively.

$$(C_5H_{10}O_5)_n\,(\text{Xylan}) \xrightarrow{90\,°C;\ 1\ atm;\ dil\ H_2SO_4} nC_5H_{10}O_5\,(\text{Xylose})$$

$$(C_6H_{10}O_5)_n\,(\text{Cellulose}) + nH_2O \xrightarrow{120\,°C;\ 2-3\ atm;\ dil\ H_2SO_4} nC_6H_{12}O_6\,(\text{Glucose})$$

- The fermentation of glucose mainly yields ethanol and CO_2, whereas, the xylose fermentation results in range of byproducts, including xylitol, isobutanol, 2,3-butandiol, lactic acid, and formic acid.

$$3C_5H_{10}O_5\ (\text{Pentose}) \xrightarrow{28-32\,°C;\ Yeast\ /Enzymes} 5C_2H_5OH\ (\text{Ethanol}) + 5CO_2$$

$$C_6H_{12}O_6\,(\text{Hexose}) \xrightarrow{28-32\,°C;\ Yeast} 2C_2H_5OH\ (\text{Ethanol}) + 2CO_2$$

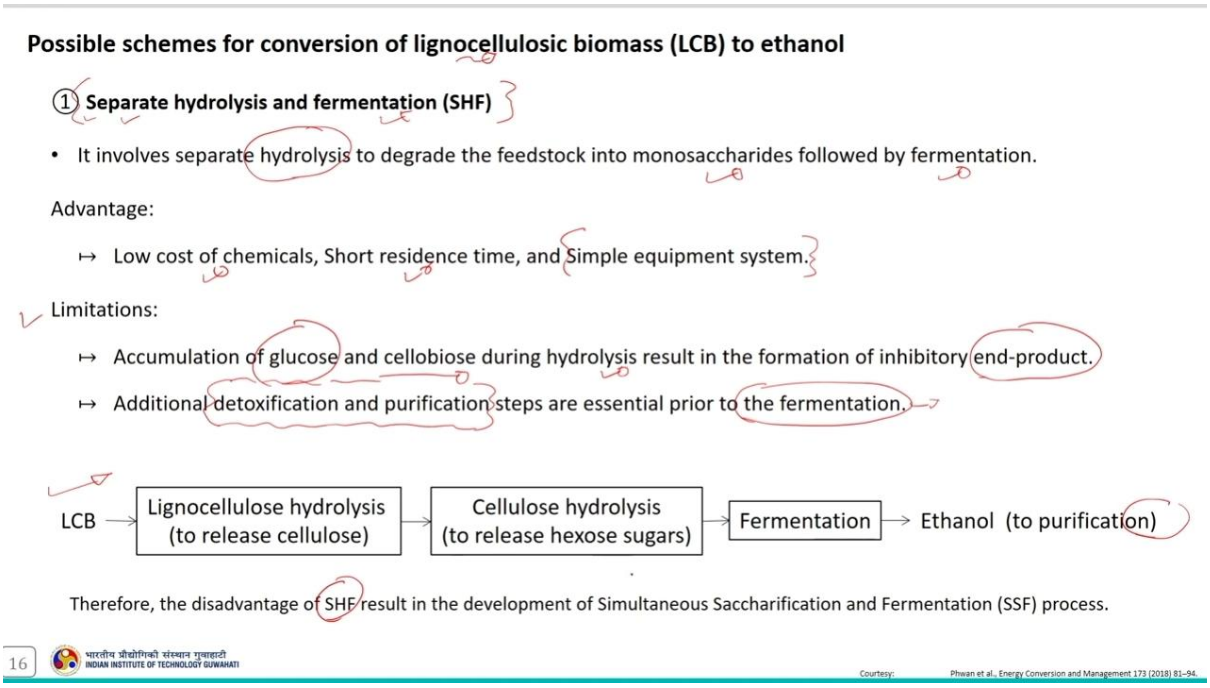
15 भारतीय प्रौद्योगिकी संस्थान गुवाहाटी INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

Courtesy: Khan, Non Conventional Energy Resources, McGraw Hill, 2017.

These hemicellulose and cellulose are not hydrolyzed as easily as starch but on heating with the sulfuric acid that is a dilute sulfuric acid under specified pressure they undergo hydrolysis to produce xylose and glucose as a product respectively. So, this reaction scheme represents the hydrolysis of hemicellulose fraction that is xylene which produces C5 sugar that is xylose as a product. And this reaction scheme represents the hydrolysis of cellulose which produces C6 sugar that is glucose. And the fermentation of glucose mainly yields ethanol and CO_2 whereas the xylose fermentation results in the range of products including xylitol, isobutanol, 2,3-butanediol, lactic acid, and formic acid along with the ethanol and CO_2. Because of this reason the C6 sugar is fermented separately and the C5 sugar is fermented separately to achieve a higher ethanol yield.

However, there are more technological advancements are there in the fermentation technology now where this C5 and C6 can be co-fermented to produce the ethanol that we would be discussing later in this lecture.

Refer slide time: 25:48

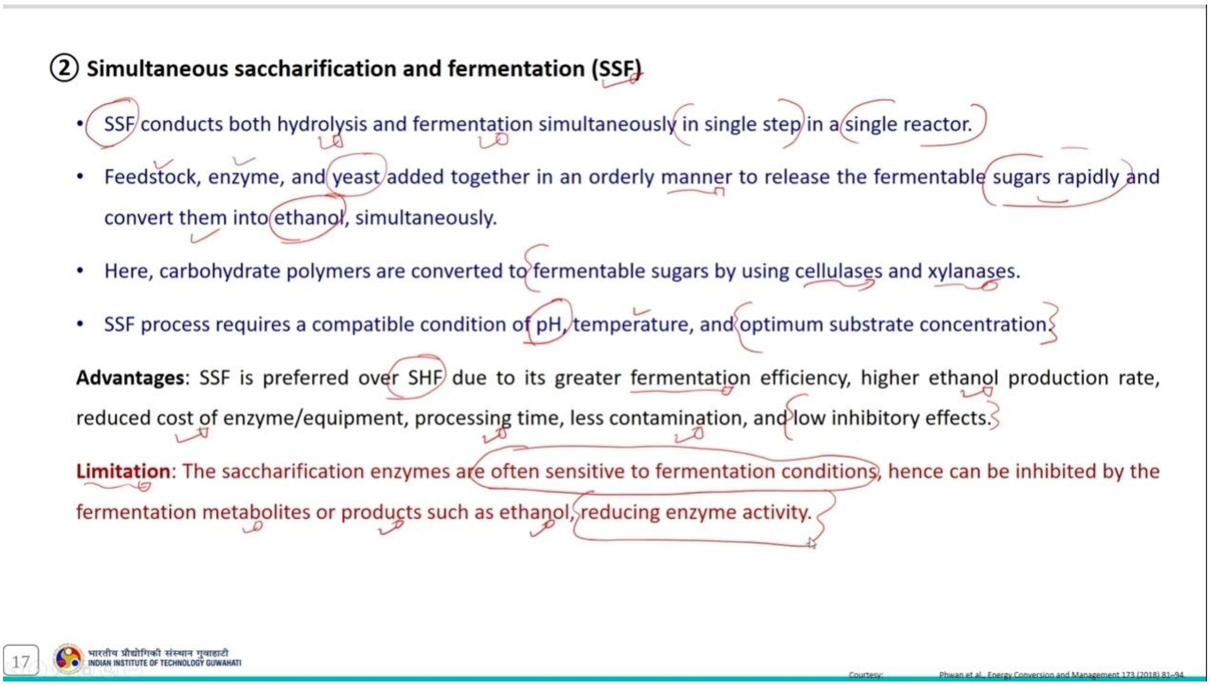


After learning about the biomass conversion processes as well as the raw material required for the biomass conversion processes. Let us discuss the possible scheme for the conversion of lignocellulosic biomass to ethanol. Different schemes are available for the conversion of lignocellulosic biomass to ethanol. So, let us first discuss about the separate hydrolysis and the fermentation.

This scheme it involves separate hydrolysis to degrade the feedstock into monosaccharides followed by its fermentation. Advantage of this scheme is low-cost of the chemicals, short residence time and simple equipment system is used for the separate hydrolysis and the fermentation process. However, its limitation includes accumulation of the glucose and cellobiose during the hydrolysis results in the formation of inhibitory end product. And second is additional detoxification and the purification step required prior to the fermentation. This point we already discussed in one of the slide before where the hydrolyzed of C5 sugar is detoxified prior to the fermentation to achieve higher fermentation efficiency.

And this scheme here represents the conversion of lignocellulosic biomass to ethanol. And the disadvantages of this SSF process results in the development of simultaneous saccharification and the fermentation process which is commonly referred as SSF process. So, now let us discuss about this SSF process.

Refer slide time: 27:43

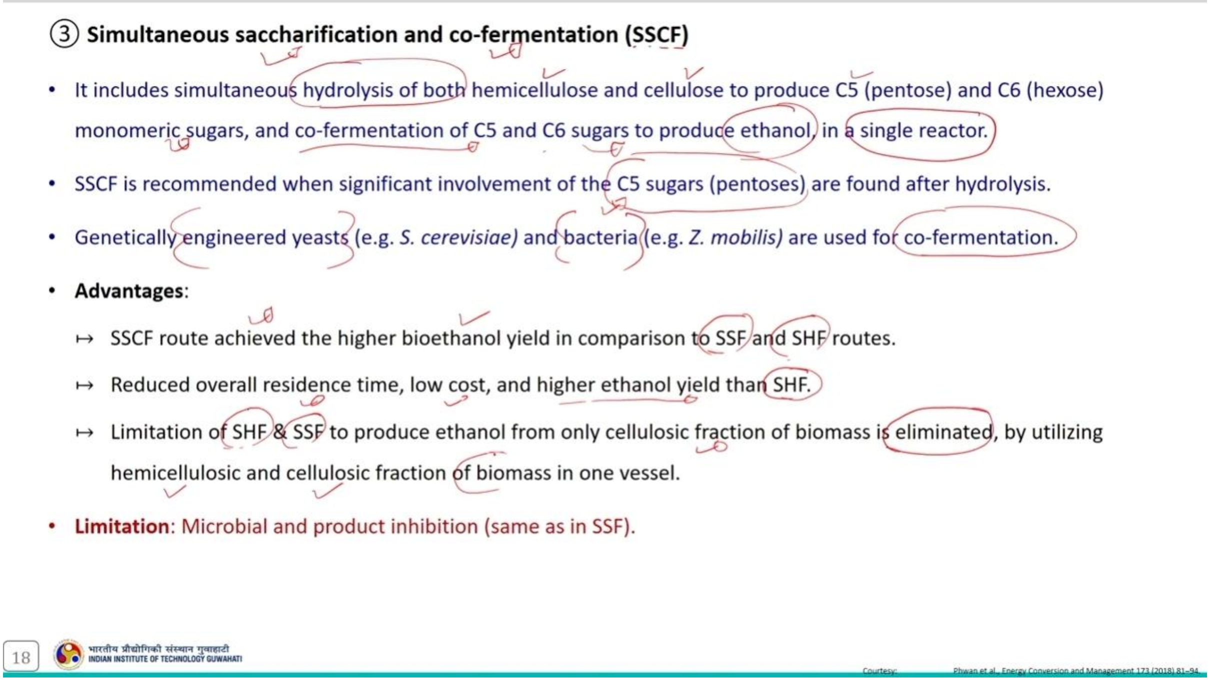


Simultaneous saccharification fermentation commonly referred as SSF process. SSF conducts both hydrolysis and fermentation simultaneously in a single step in a single reactor and that is the advantage of this process.

This process can be carried out in a single step in a single reactor. The feedstock, enzyme and yeast added together in an orderly manner to release the fermentable sugars rapidly and then convert them into the ethanol simultaneously. And that is why it is named as simultaneous saccharification and fermentation process. And here the carbonate polymers are converted into the fermentable sugars by using cellulases and xylenases enzymes. And this process requires compatible condition of pH, temperature and optimum substrate concentration.

And the advantage of this process is it is preferred over the previous process due to its greater fermentation efficiency, higher ethanol production rate, and reduced cost of enzyme processing time, less contamination and low inhibitory effects. However, this particular process also has a limitation. In this process the enzymes are often sensitive to fermentation condition. Hence can be inhibited by the fermentation metabolites or products such as ethanol, which eventually results in reducing the enzyme activity.

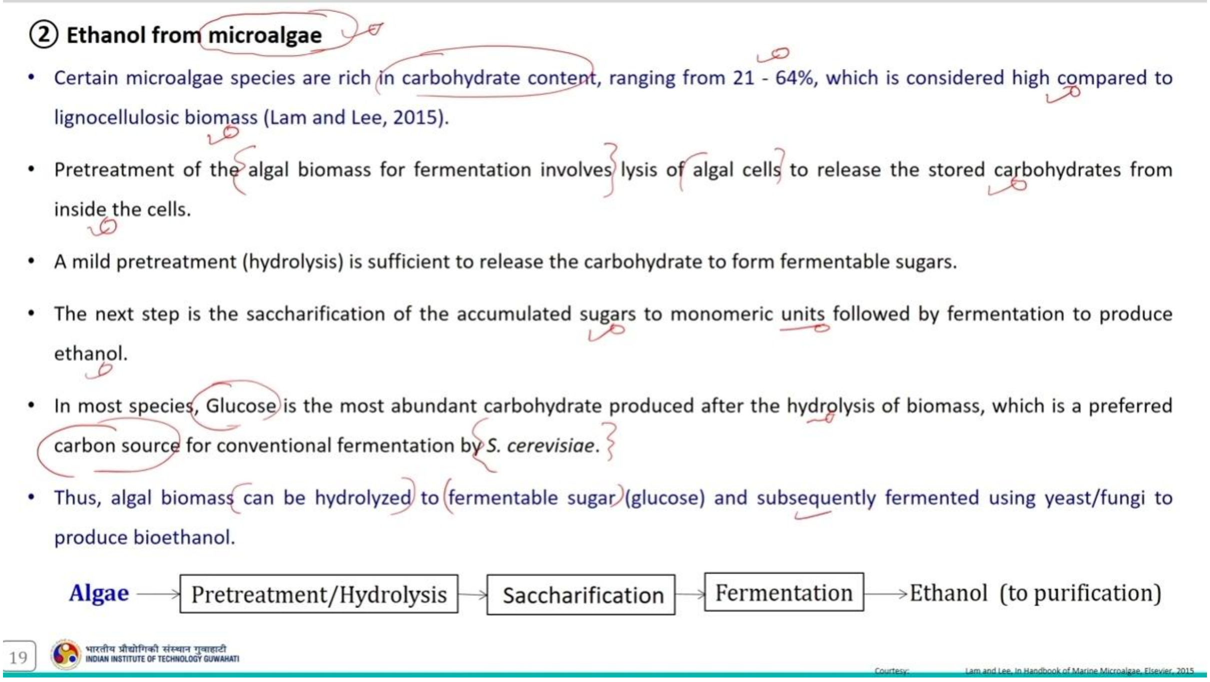
Refer slide time: 29:51



So, another process which is available is simultaneous saccharification and co-fermentation that is referred as SSCF. This process includes the simultaneous hydrolysis of both hemicellulose and cellulose to produce C5 and C6 monomeric sugars. And co-fermentation of C5 and C6 sugar to produce ethanol in a single reactor. And I was talking about this particular process here where now C5 and C6 can be co-fermented in a single reactor. And this process is recommended when significant involvement of the C5 sugar is found after the hydrolysis. That means, if the concentration of C5 sugar is significantly high, then it is better to go for simultaneous saccharification and the co-fermentation process.

In this process genetically engineered yeast and bacteria are used for the co-fermentation purpose. And advantages of this process includes higher biothanol yield in comparison to previous two processes, reduced overall residence time, low cost and higher ethanol yield than SHF. Limitation of this SHF and SSF to produce ethanol only from cellulosic fraction of biomass is eliminated by use of this process. Here it can ethanol only from cellulosic fraction of biomass is eliminated by use of this process. Here it can utilize hemicellulosic and the cellulosic fraction of biomass in one vessel and convert into the ethanol. The limitation of this process, the microbial and product innovation is one of the limitations of this process as well.

Refer slide time: 31:56



Another potential feedstock under the classification of non-edible sources for the production of the ethanol includes microalgae. Certain microalgae are rich in the carbohydrate content ranging from 21 to 64%. Which is considered high compared to the lignocellulosic biomass. And thus the pretreatment of this algal biomass for the fermentation involves lysis of the algal cells to release stored carbohydrate from inside the cells.

In this case, a mild predicament is sufficient to release the carbohydrate to form the fermentable sugars. And the next step is then the saccharification of the accumulated sugar to monomeric units followed by its fermentation to produce the ethanol. In most species, glucose is the most abandoned carbohydrate produced after the hydrolysis of biomass, which is preferred carbon source for the conventional fermentation by *Saccharomyces cerevisiae*. Hence, the algal biomass can be hydrolyzed to fermentable sugars and subsequently fermented using yeast to produce bioethanol. And the process scheme of conversion of algal biomass to ethanol is shown here, which also involves the similar operation as that of the other biomass sources.

Refer slide time: 33:42

Comparing ethanol yield from various types of biomass

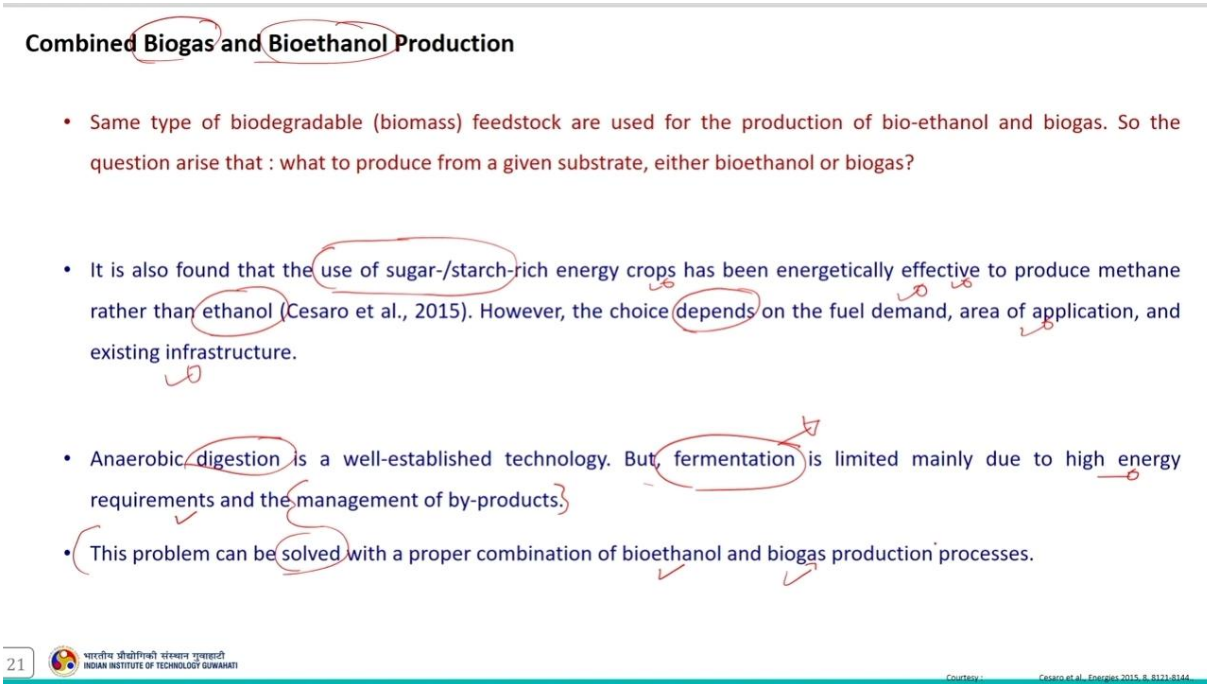
Type of biomass	Raw material	Ethanol yield per ton of biomass (L/ton)	Ethanol yield per hectare per year (L/ha-year)
Sugar containing crop	Sugarcane	60–80	3500–7000
	Sugar beet	90–100	3800–4800
Starch containing crop	Maize	360–400	1500–3000
	Potato	100–120	2200–3300
	Cassava	175–190	2200–2300
Lignocellulosic biomass	Softwood	230–270	2200–3800
	Hardwood	190–220	1800–3000
	Straw	160–180	300–600
Algal biomass	*C. vulgaris*	230–600	2300–9000
	Chlorococcum sp.	260–330	2600–5000

20 भारतीय प्रौद्योगिकी संस्थान गुवाहाटी INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

Courtesy: Basu, Biomass Gasification, Pyrolysis and Torrefaction, AP 2013

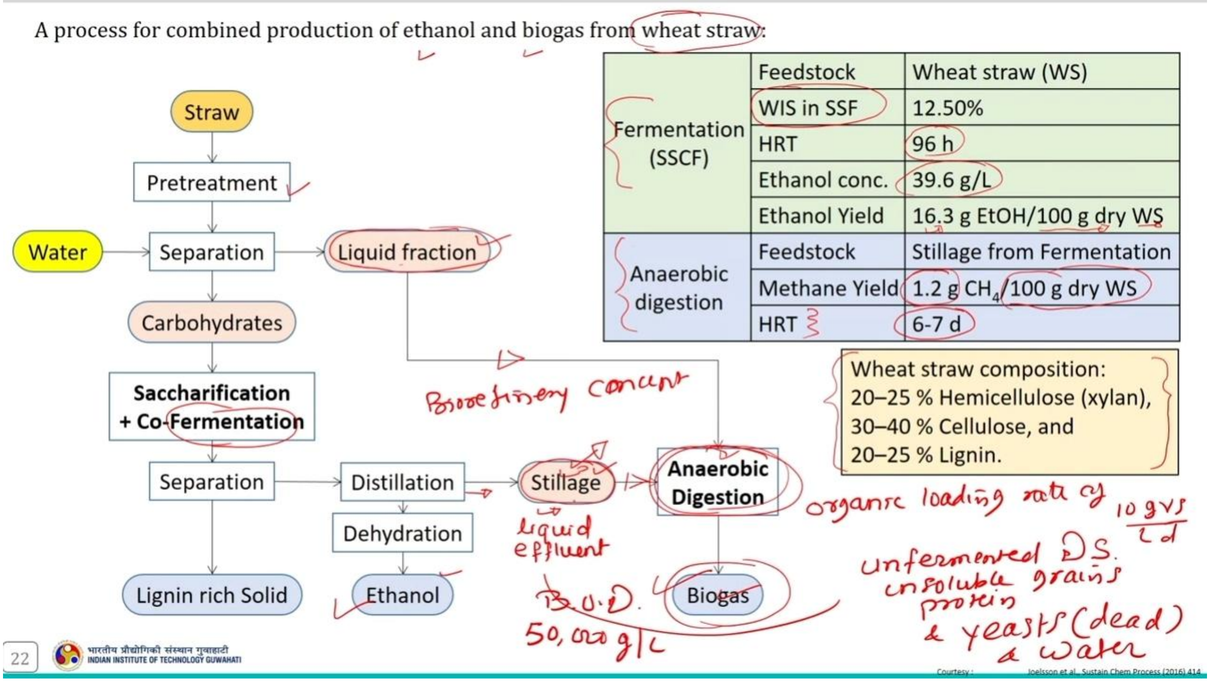
After learning about the ethanol production from various biomass sources that is edible source and non-edible source, let us compare the ethanol production from these different biomass sources. In this case here, if you look at this table, so this table here, it depicts the different types of biomass which can be used to produce ethanol. Which includes the raw materials such as sugar cane, sugar beet that is sugar crop, starchy crop that is maize, potato, cassava, Lignocellulosic biomass includes softwood, hardwood, straw and algal biomass. So, the comparative analysis of these different types of biomass indicates that the starch containing crop that is mostly maize gives relatively higher ethanol yield compared to that of the sugar containing crop. Similarly, the lignocellulosic biomass in that the softwood gives relatively higher ethanol yield and in case of algal biomass, the ethanol yield is relatively high compared to that of the sugar containing crop.

Refer slide time: 35:04



So, now let us discuss about the combined biogas and bioethanol production. Since same type of biodegradable feedstock are used for the production of ethanol and biogas, so the question arises that what to produce from a given substrate that is either ethanol or biogas. Because it is found that the sugar or starch rich energy crops has been energetically effective to produce methane rather than the ethanol. However, the choice of the feedstock it depends on the fuel demand, area of application and existing infrastructure available for the processing of the given feedstock. Anaerobic digestion is well established technology and same as the fermentation, but the fermentation is limited that is here fermentation we are referring it as a alcoholic fermentation which is mainly due to high energy requirements and the management of byproducts. And this problem can be solved with proper combination of bioethanol and biogas production process.

Refer slide time: 36:30



The configuration of combined production of ethanol and biogas from wheat straw is shown in the following schematic here. The hydrolysate that was obtained after the pre-treatment mostly C5 stream and the liquid fraction obtained after the distillation residue is used in the anaerobic digestion to produce biogas. This table here it indicates the fermentation operation and this particular part of the table indicates the anaerobic digestion operation. So, here the feedstock use is wheat straw and water insoluble solid in the SSF is around 12.5 percent. HRT of this process is around 96 hour and ethanol concentration is 39.6 gram per liter. And the respective ethanol is 16.3 gram of ethanol per 100 gram of dry wheat straw. While in anaerobic digestion process the feedstock is stillage from fermentation system as well as the liquid fraction obtained after the pre-treatment process.

The methanol yield is here 1.2 gram per 100 gram of dry wheat straw and HRT of this process is only 6 to 7 days. And this part here represents the composition of the wheat straw which is used for the fermentation process. The stillage is a liquid effluent from the distillation column of the fermentation process is a significant environmental problem. It is a mixture of un-fermented dissolved solids, insoluble grain, protein and yeast that is mostly a dead yeast and water. And its biological oxygen demand is around 50,000 gram per liter that is BOD.

Stillage may be used as a food supplement for cattle but it has an undesirable laxative effect on animals. The stillage can be used as a carbon source rather than a waste to gain economic and the social benefits. And we discuss about the utilization of this stillage in one of the slide in this lecture. The thin stillage from ethanol fermentation process can be utilized as a substrate for the anaerobic digestion. The anaerobic digestion it converts up to around 80% of stillage COD into biogas at the organic loading rate of 10 gram volatile solid per liter per day.

And the hydraulic retention time as we discussed before is 6 to 7 days. And this fermentation here act as a biomass pre-treatment so that the energy required to convert this stillage into biogas via anaerobic digestion process is lower than the one necessary to treat this whole substrate. Therefore the proper combination of both ethanol and biogas production process has been regarded as a suitable strategy to improve the competitiveness of fermentation plant by producing both ethanol and biogas in a biorefinery concept. Such strategy follows the combination of material flows of different bio industries so that the residue from bio industry that is in the form of say liquid fraction. And stillage becomes the input for another one that is for the anaerobic digestion process and this gives a very good example of biorefinery concept. That is the waste generated from one process can be used as a feedstock for the other one to produce a usable product.

Refer slide time: 42:12

Properties of Ethanol

- Azeotropic ethanol (96 °GL) occur in liquid state between –114 °C and +78 °C.
- It has a flashpoint of 9 °C and a self-ignition (auto-ignition) temperature of 423 °C.
- Therefore it has the characteristics for a commercial liquid fuel, being used as a direct substitute or additive for petrol (gasoline).

Characteristic	Gasoline	Diesel	Butanol	**Ethanol**	Methanol
Density (kg/L)	0.737	0.846	0.810	**0.789**	0.791
Boiling point °C	32 – 210	204 – 343	118	78	65
HHV (MJ/kg)	**46.4**	**45.6**	**37.3**	**29.7**	**23.0**
LHV (MJ/kg)	44.5	43.0	33.1	**26.9**	19.6
HHV (MJ/L)	34.2	38.6	30.2	**23.4**	18.2
LHV (MJ/L)	31.9	38.9	26.7	**21.1**	15.4

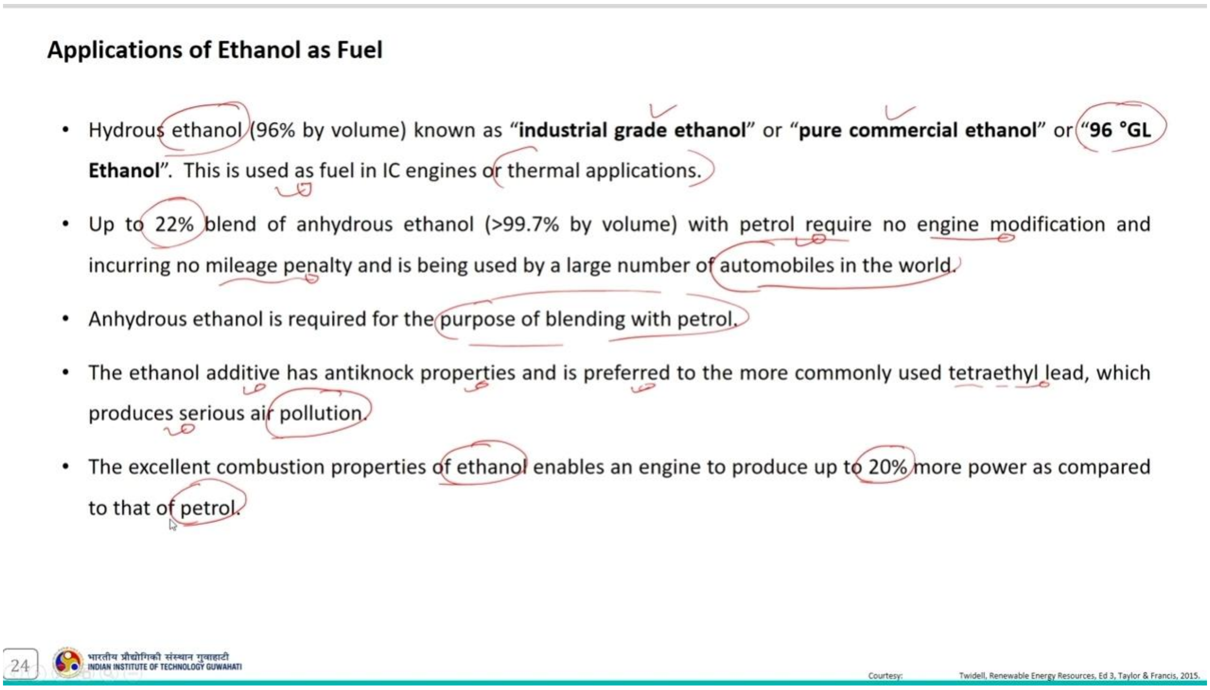
23 भारतीय प्रौद्योगिकी संस्थान गुवाहाटी INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

Courtesy: Twidell, Renewable Energy Resources, Ed 3, Taylor & Francis, 2015.

So until this point we discuss about the different processes which can be used for the ethanol production. So now let us discuss about the properties of this ethanol. Azeotropic ethanol occurs in the liquid state between -114 degree Celsius and plus 78 degree Celsius. It has a flash point of 9 °C and a self-ignition temperature of 423 °C. Therefore it has characteristics for a commercial liquid fuel being used as a direct substitute or additive petrol that is gasoline.

If you just take a look at the properties of the ethanol and compare it with butanol, methanol and conventional fuel that is gasoline and diesel. So the comparative analysis here indicates that the ethanol has slightly higher density compared to that of the gasoline. However, its boiling point is 78 °C which is in the range of gasoline. However, the high reading value of the ethanol is relatively low compared to that of the gasoline.

Refer slide time: 43:49



Lastly is the application of ethanol as fuel. The hydrous ethanol which is also known as industrial grade ethanol or pure commercial ethanol or 96 degree GL ethanol, this is used as fuel in IC engines or thermal applications. Up to 22% blend of anhydrous ethanol with petrol required no engine modification at all and incurring no mileage penalty and is being used by large number of automobiles in the world. Unaddressed ethanol is required for the purpose of blending with petrol. Ethanol additive has anti-knocking properties and is preferred to more commonly used tetraethyl lead which produces serious air pollution. And the excellent combustion properties of the ethanol enables an engine to produce up to 20% more power as compared to that of the conventional petrol.

This covers discussion about the biochemical processes. In the next lecture, we will discuss few more important concepts on biochemical conversion process that is alcoholic fermentation and anaerobic digestion. Followed by that, we will practice few examples on the concept of biochemical conversion process.

Thank you.