



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

ENERGY PRODUCTION FROM ORGANIC WASTES THROUGH FERMENTATION-1

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CHEMICAL ENGINEERING



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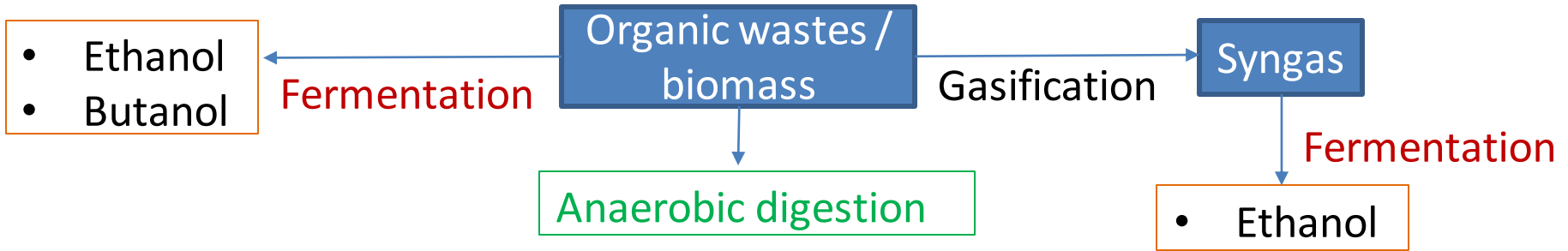
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Fermentation and energy production

Different energy sources from biomass / wastes through fermentation

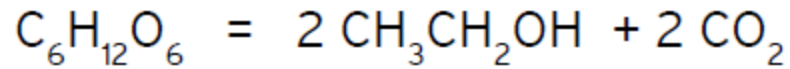
- **Fermentation** is a metabolic process that converts sugar to acids, gases, or alcohol



- Ethanol can be used as blend with gasoline (10 % by volume) (26.8 MJ/kg)
- Butanol can be used in pure form or blended with gasoline at higher concentrations (16 % by volume), (32.5 MJ/kg)

Heating value of gasoline 42.9 MJ/kg

- It is a series of chemical reactions for converting sugars to ethanol in the presence of suitable microbial strain, which feed on the sugars.
- Ethanol and carbon dioxide are produced as the sugar is consumed.
The simplified fermentation reaction for a 6-carbon sugar, glucose, is as follows:



Yeast is normally used for hexose

Source of sugar

Sugar crops

Starchy crops

Lignocellulosic biomass

Sugars may contain

6 carbons (i.e., Hexose)

5 carbons (i.e., Pentose)

Production of ethanol from three different feedstocks

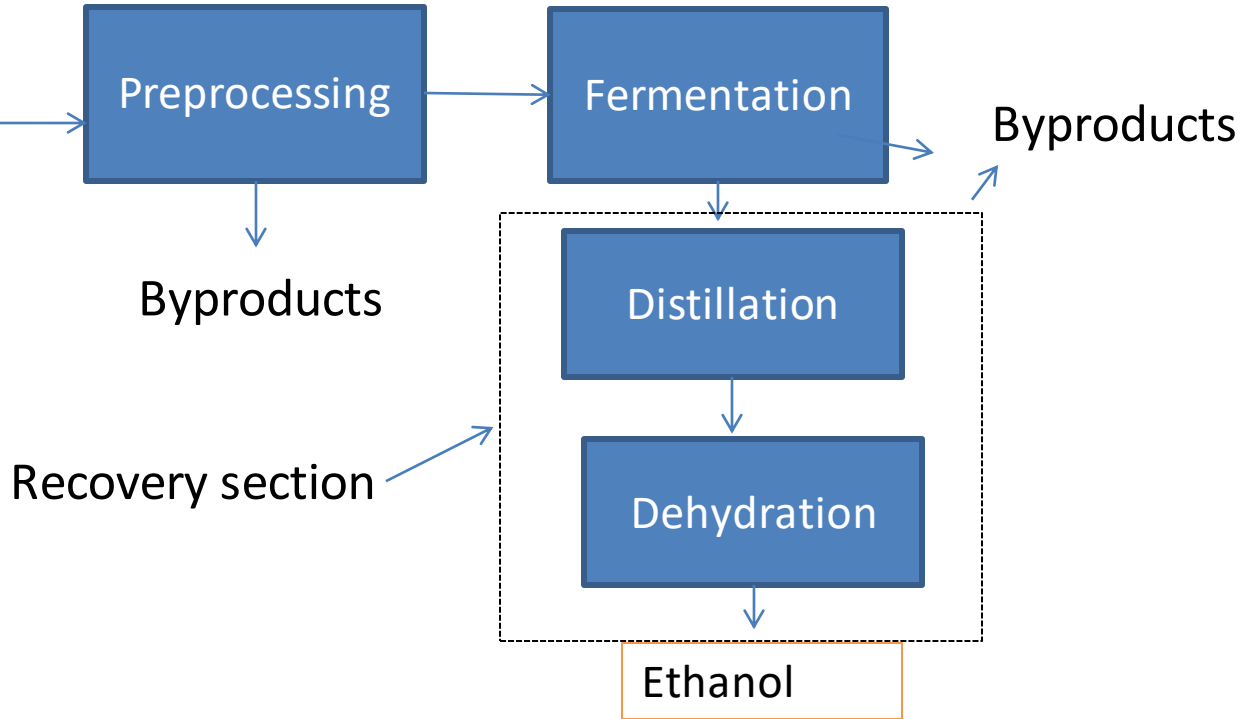
Sugar crops/starchy
crops/lignocellulosic
biomass

Ethanol concentration in:

Fermented mash ~ 4-10%

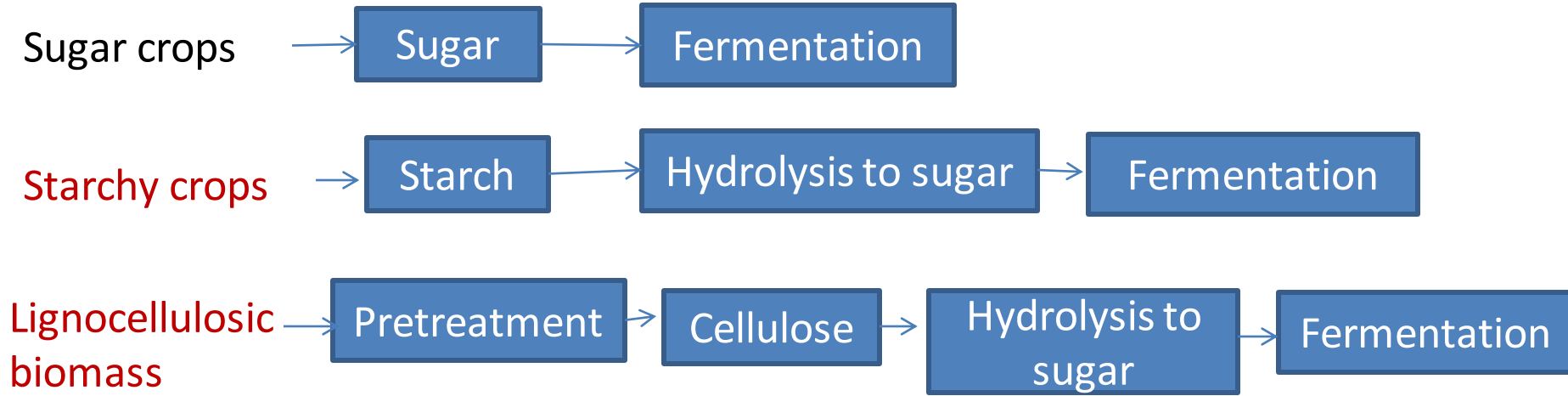
After distillation ~ 95-96%

After dehydration ~ 99.5%



- The ethanol concentration in the fermented mash can attain a level of only 4% to 10% depending on the operating conditions and the strain of yeast being used.
- Ethanol is therefore recovered through distillation but only hydrous ethanol of about 95-96% can be produced through steam distillation of the fermented mash due to the formation of water-ethanol azeotrope.
- To make ethanol fully miscible with gasoline, it is necessary to further remove the residual water to produce anhydrous ethanol with a concentration of at least 99.5%. To attain this concentration, the hydrous ethanol has to undergo a suitable dehydration process or operation.

Preprocessing steps for different sugar sources

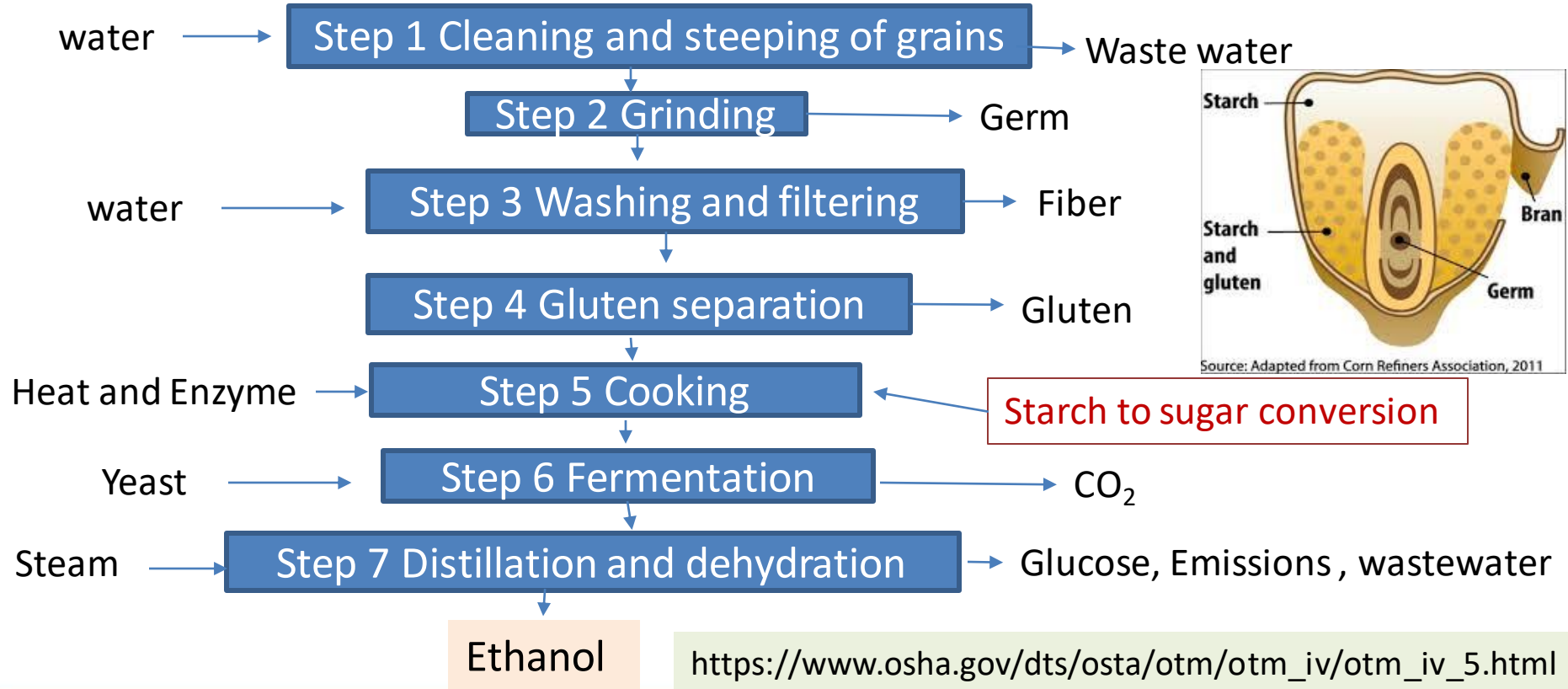


Steps of pre-processing increases as :

Sugar crops < Starchy crops < Lignocellulosic biomass

Production of ethanol from starchy crops (corn)

wet process



Steeping in dilute sulphuric acid and water helps disintegrating different parts of the corn kernel

Grinding is used to liberate the intact germ from the kernel. Germ separation is done by a series of hydrocyclones, High oil content of the germ imparts low density, which makes it tend to float in water, enhanced additionally by starch, suspended in water. After a washing of the germ, oil can be extracted (usually with hexane).

Fibre separation consists of four steps:

an **initial screening** of coarse fibre; a **milling or grinding step** to liberate and disperse all the starch and gluten from the remaining fibre; another **washing step** and a **dewatering and drying step** with the addition of corn steep liquor for the production and sale of gluten feed.

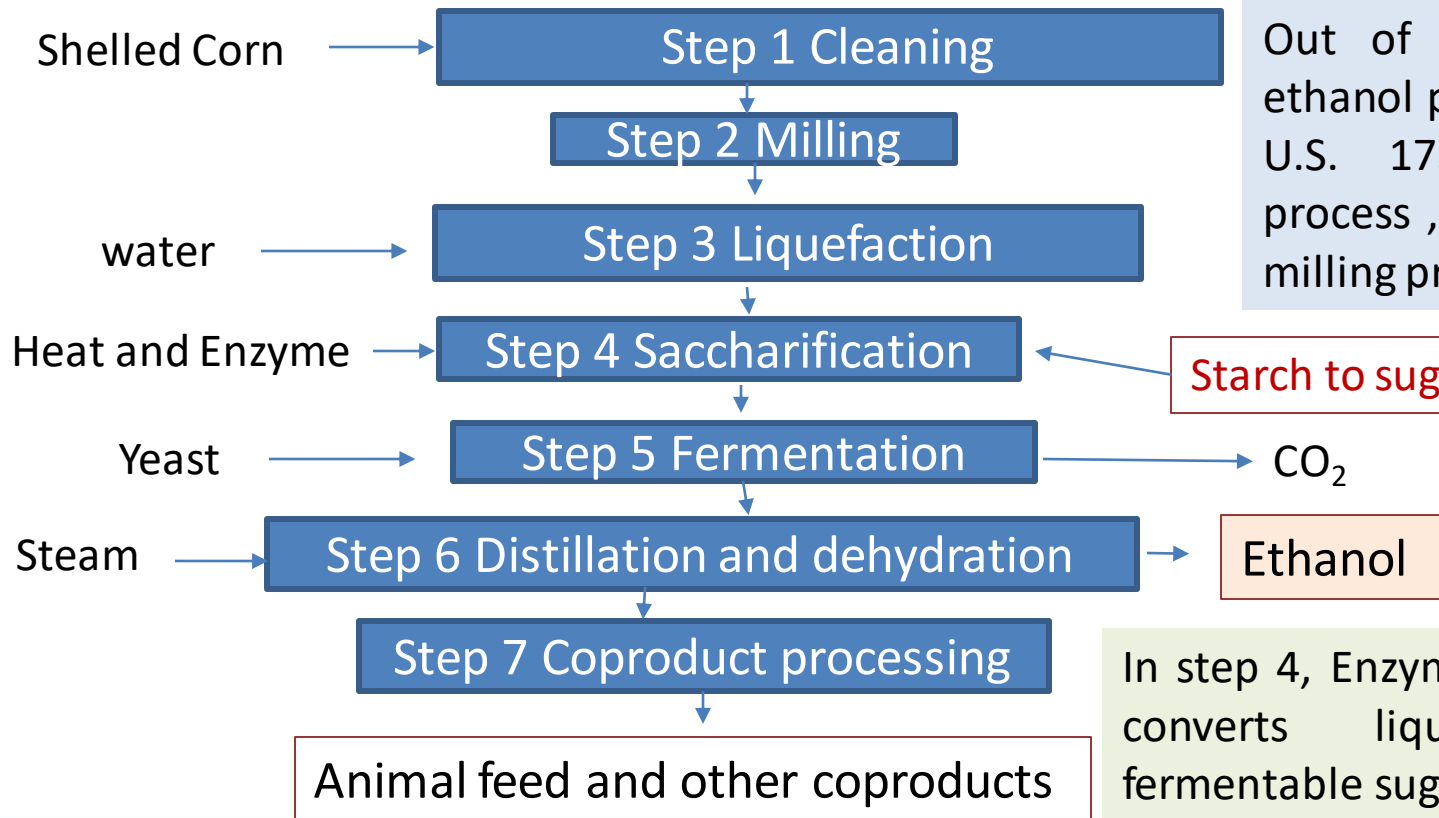
After the fibre removal, starch, protein and miscellaneous soluble components (e.g. salts, minerals, and vitamins) are left.

alpha-amylase may be used for cooking

Starch is separated from the gluten (protein) in several steps and used for cooking

Production of ethanol from starchy crops (corn)

Dry process



Out of 180 corn or starch ethanol plants operating in the U.S. 173 are dry milling process, and only 11 are wet milling process ([EPA, 2010](#)).

In step 4, Enzymes like gluco-amylase converts liquefied starch to fermentable sugars (dextrose)

Production of ethanol from lingo cellulosic biomass and wastes

Step 1 Lignocellulosic biomass / wastes

Step 2 Drying and grinding

Step 3 Slurry formation (10-15 % dry solid)

Step 4 Pre treatment of slurry

Step 5 Detoxification and hydrolysis

Step 6 Fermentation

CO₂

Step 7 Product recovery

- Water is used for slurry formation
- Pre treatment processes may be physical, chemical or biological
- Hydrolysis may be carried out by acid or enzymes
- Fermenting microorganisms are added

Ethanol

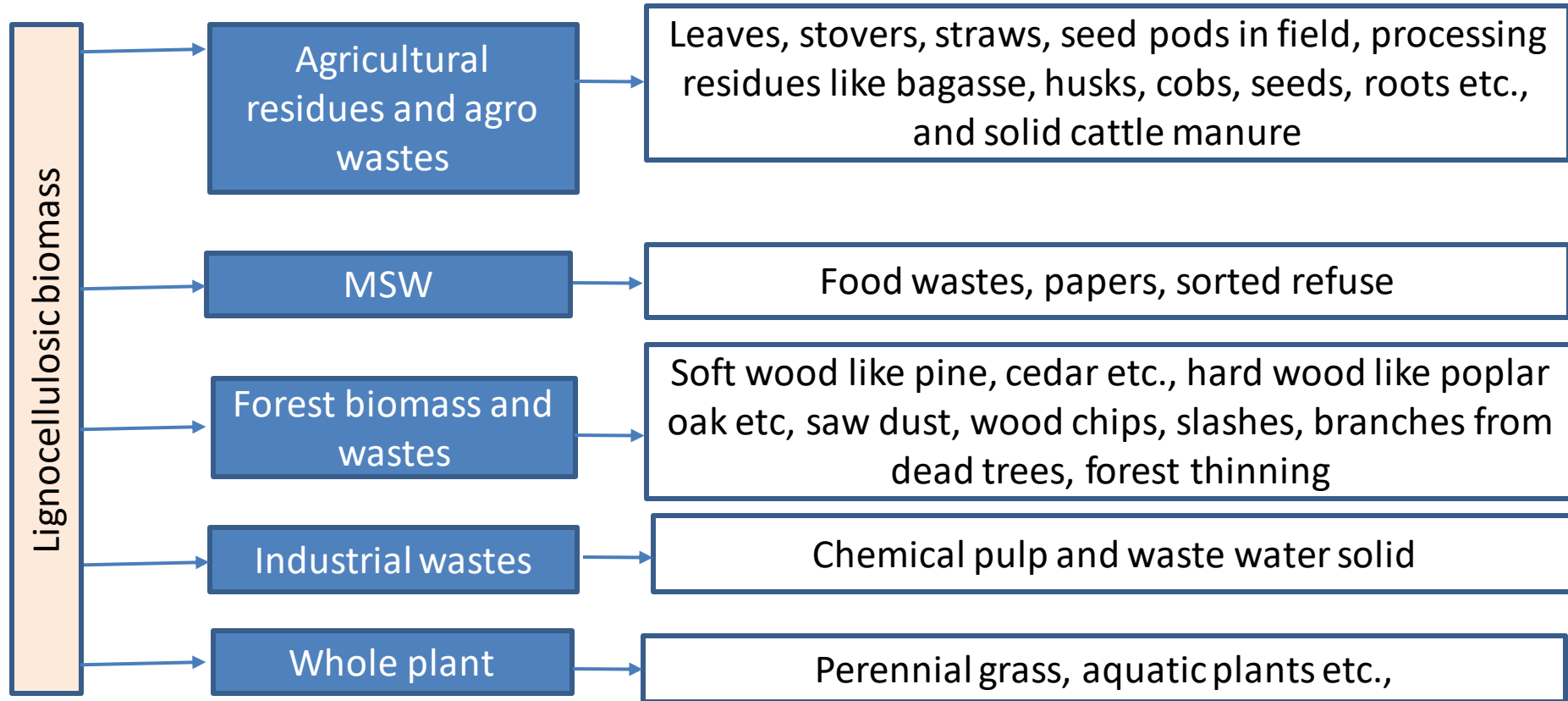
Solid residue

Waste water

Adapted from
Margeot et al. 2009,
Chandel et al. 2007,
Hamelinck et al. 2005



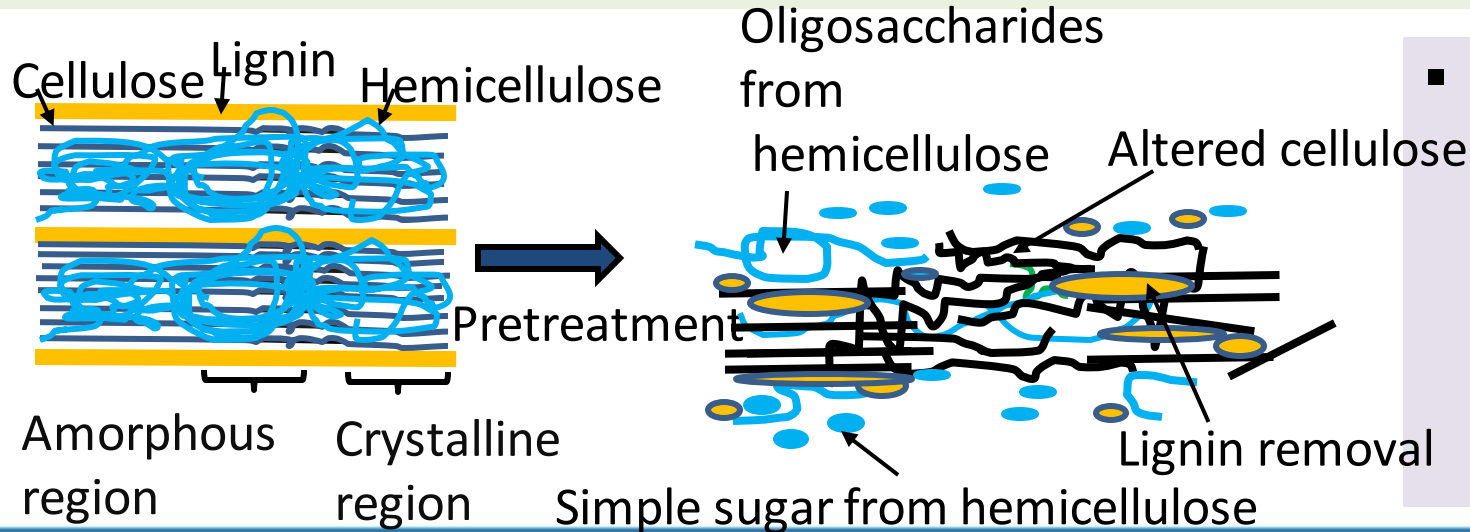
Common lignocellulosic biomass



Pre-treatment

(Adapted from (Mosier et al. 2005, Hsu et al. 1980).

- It is applied to remove the protecting shield of lignin–hemicellulose and make the cellulose more readily available for enzymatic hydrolysis.
- It alters the macroscopic, sub–microscopic and microscopic structure of the biomass to make enzyme easily accessible for hydrolyzing and converting the carbohydrate polymers into fermentable sugars during subsequent hydrolysis step



- Altered cellulose and simple sugar from hemicellulose both are produced during pretreatment

Pre-treatment

Energy efficiency of any pretreatment process can be determined from total sugar yield and energy consumption during the process as shown in the following equation (Zhu and Pan 2010):

$$\eta = TSY / TEC$$

where, η = Pretreatment energy efficiency (kg/MJ);

TSY = Total soluble (monomeric) sugar yield (kg);

TEC = Total energy consumption during pretreatment (MJ)

Favourable characteristics of pretreatment processes

- Obtainment of cellulose with high digestibility
- Avoiding destruction of hemicelluloses and cellulose
- No or little degradation of sugars and sugar derived products
- No loss of sugar
- Production of minimum amount of toxic compounds.
- No requirement of biomass size reduction before pretreatment

Favourable characteristics of pretreatment processes

- Capable of operating in reasonable size and moderate cost reactors.
- No production of solid–waste residues
- Effectiveness at low moisture content.
- Recovery of high amounts of carbohydrates.
- Fermentation compatibility.
- High lignin recovery for conversion into valuable coproducts
- Minimum heat and power requirements

Different types of pre-treatment techniques

Pre-treatment method	Characteristics	Remarks
Physical	Increases accessible surface area and pore volume decreases the degrees of polymerization of cellulose and its crystallinity	Cutting, grinding
Chemical	Increases delignification, decreases the degree of polymerization and crystallinity of cellulose associated with its swelling, and porosity growth Acid pretreatments solubilizes the hemicellulosic fraction of the biomass and makes the cellulose more accessible to enzymes.	Commonly used acid and base are H_2SO_4 and $NaOH$, respectively. Organic acids such as fumaric or maleic acids are also used as alternatives to enhance cellulose hydrolysis



Pre-treatment method	Characteristics	Remarks
Physicochemical	Exploits the use of conditions and compounds that affect the physical and chemical properties of biomass Increases accessible surface area of the biomass for enzyme accessibility, decreases cellulose crystallinity, removes hemicelluloses and lignin	Steam explosion, ammonia fiber explosion (AFEX), ammonia recycling percolation (ARP), soaking aqueous ammonia (SAA), wet oxidation, CO ₂ explosion
Biological	Alters the structure of lignin and cellulose and separate from the lignocellulosic matrix. Slow rate	White rot, brown rot and soft rot fungi are used Brown rot attacks cellulose while white and soft rots attack both cellulose and lignin

Detoxification

- Several unwanted by-products such as pentose and hexose sugars, sugar acids, acetic acid, formic acid, levulinic acid, hydroxymethyl furfural (HMF) and furfural may form due to partial breakdown of lignin and hemicellulose during pretreatment.
- Some of these products act as inhibitors for both fermenting microorganisms and cellulose degrading enzymes when their accumulation is sufficiently high.
- The inhibitors are categorized into three major groups based on the origin such as aliphatic acids, furan derivatives and phenolic compounds.
- Biological, physical, and chemical methods are used to remove the inhibitors.
- Chemical detoxification may be carried out by using sodium dithionite, sodium sulfite, and sodium borohydride



Hydrolysis

The major portions of cellulose and hemicellulose are glucan and xylan, respectively. Digestibility of both glucan and xylan can be determined from the yield of their respective monomers and disaccharides using the equations (Wyman et al. 2005).

$$\text{Digestibility of glucan (\%)} = \frac{\text{Amount of glucose (g)} + 1.053 \times \text{Amount of cellobiose (g)}}{1.111 \times \text{Amount of glucan (g)}} \times 100$$

$$\text{Digestibility of xylan (\%)} = \frac{\text{Amount of xylose (g)} + 1.064 \times \text{Amount of xylobiose (g)}}{1.136 \times \text{Amount of xylan (g)}} \times 100$$

Where, 1.053, 1.111, 1.064, and 1.136 are the hydration factors of cellubiose, glucan, xylobiose and xylan, respectively.

Zhu et al., 2008, Bioresource Technology 99(9): 3817-3828.



$$\begin{aligned}
 \text{Total Sugar Conversion (\%)} &= \frac{\text{Glucose yield} + \text{Xylose yield}}{\text{Theoretical glucose yield} + \text{Theoretical xylose yield}} \\
 &= \frac{([G] - [G_0]) \times V + ([X] - [X_0]) \times V}{\frac{W \times \text{Glucan content}}{0.9} + \frac{W \times \text{Xylan content}}{0.88}}
 \end{aligned}$$

Where,

[G], is glucose concentration in hydrolysis liquid (mg/mL);

[G]₀, is the initial glucose concentration, can be assumed as 0 (mg/mL);

[X], is xylose concentration in hydrolysis liquid (mg/mL);

[X]₀, is initial xylose concentration, can be assumed as 0 (mg/mL);

V, is initial volume of biomass slurry (mL);

W, is the initial dry weight of biomass (mg);

0.9, is conversion factor of glucose to equivalent glucan;

0.88, is the conversion factor of xylose to equivalent xylan.

Thanks...

