LECTURE-14

(BIOETHANOL)

INTRODUCTION

- Bioethanol is the ethyl alcohol or ethanol obtained from bioresources (biomass) by hydrolysis or sugar fermentation processes.
- It is a principle fuel used as a petrol substitute for road transport vehicles.
- Although ethyl alcohol or ethanol can also be produced by the chemical process of reacting ethylene with steam, but cannot be said bioethanol because of the lack of renewable source of raw material and the nature of production route.
- Sugar fermentation is the process widely used.
- The main sources of sugar required to produce ethanol come from fuel or energy crops.
- These crops include corn, maize and wheat crops, waste straw, willow and popular trees, sawdust, reed canary grass, cord grasses, Jerusalem artichoke, myscanthus and sorghum plants.
- There is also ongoing research and development into the use of municipal solid wastes to produce ethanol fuel.
- Ethanol or ethyl alcohol (C_2H_5OH) is a clear colourless liquid, it is biodegradable, low in toxicity and causes little environmental pollution if spilt.
- Ethanol burns to produce carbon dioxide and water.
- Ethanol is a high octane fuel and has replaced lead as an octane enhancer in petrol.
- By blending ethanol with gasoline we can also oxygenate the fuel mixture so it burns more completely and reduces polluting emissions.
- Ethanol fuel blends are widely used in the United States.
- The most common blend is 10% ethanol and 90% petrol (E10).
- Vehicle engines require no modifications to run on E10 and vehicle warranties are unaffected too.
- Only flexible fuel vehicles can run on up to 85% ethanol and 15% petrol blends (E85).

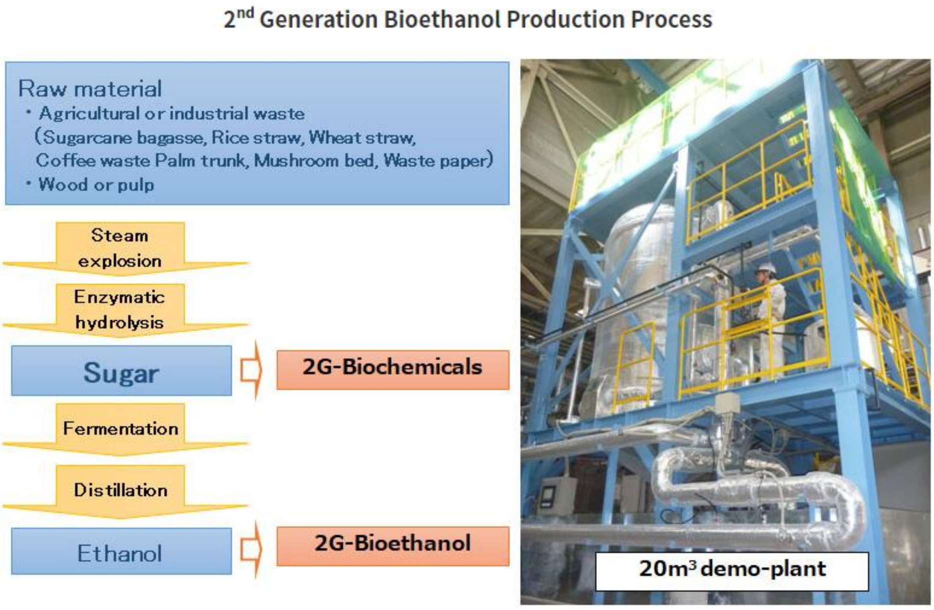
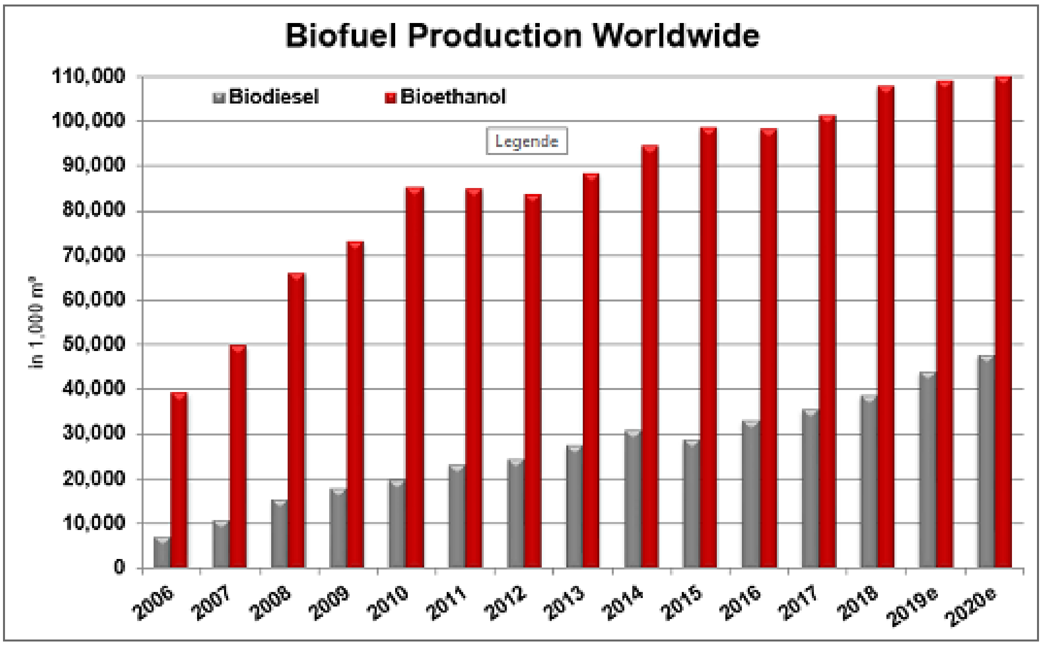


Figure-1: 2G-Bioethanol production process and plant.

➢ GLOBAL BIOETHANOL SCENARIO

Worlwide Biofuel Production



Source: F.O.Licht

Figure-2: Worlwide biofuel production.

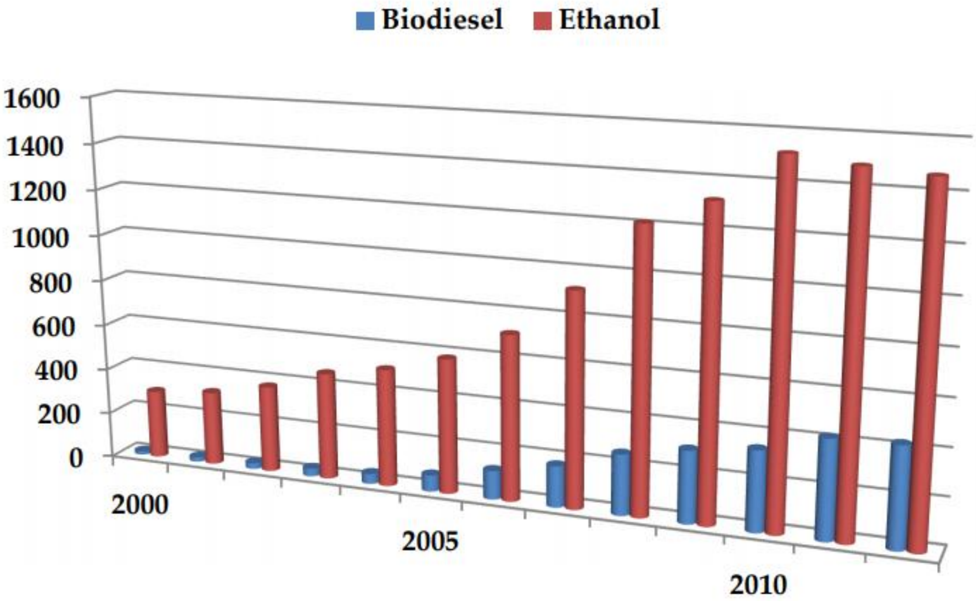


Figure-3: Global biofuel production by fuel type (thousand barrel per day)

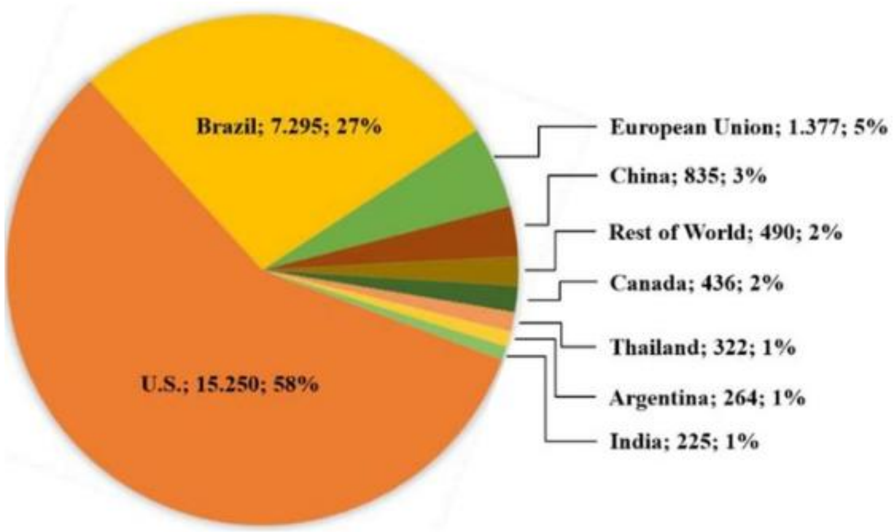


Figure-4: Bioethanol production by country, million gallons, 2017 (RFA, 2017).

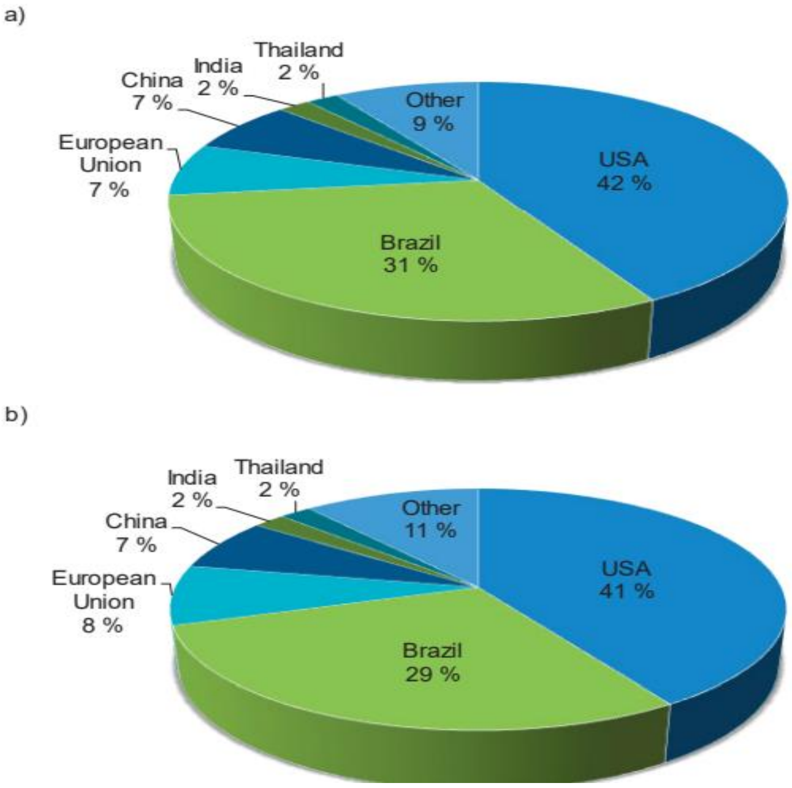


Figure-5: Prediction of world bioethanol production (a) and consumption (b) by 2024.

Note: According to the International Renewable Energy Agency, the advanced biofuels (based on 2nd, 3rd and 4th generation feedstocks) market is expected to grow to reach 124 billion litres per year by 2030.

➢ CLASSIFICATION OF ETHANOL AND BIOETHANOL

- Based on the source of raw materials and production routes (like: chemical, biological /biochemical/microbial/biotechnological, physical), ethyl alcohol/ethanol may be categorized into two groups:
  i. Ethanol which is produced by chemical reaction using the non-biogenic source as raw materials, simply known as ethanol or ethyl alcohol. Like the traditional old method of producing ethyl alcohol by chemical reaction of ethylene and steam, i.e. $C_2H_4 + H_2O \rightarrow C_2H_5OH$, where ethylene has non-renewable source.
  ii. Ethanol which is produced by fermentation (biochemical/ microbial/ enzymatic/ biotechnological route) using the renewable source (like bioresource) as raw materials, known as bioethanol. Like anaerobic fermentation of sugar in the presence of yeast culture results ethyl alcohol (i.e. bioethanol), i.e. $C_6H_{12}O_6 + \text{Yeast} \rightarrow 2C_2H_5OH + 2CO_2$, glucose has the renewable source.

  Based on the feedstock and biological conversion processes, bioethanol can be understood with the help of the following **Figure-6**:

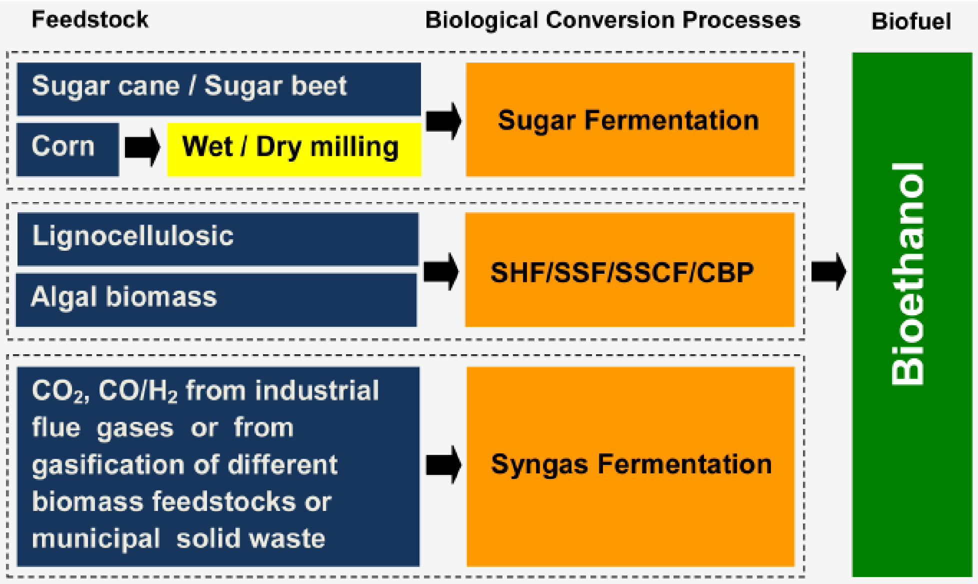


Figure-6: Bioethanol obtained from different feedstocks and production routes.

- Based on the source of raw materials, bioethanol may be classified into two groups: First generation (**1G**) bioethanol, second generation (**2G**) bioethanol and the third generation (**3G**) bioethanol

  i. First Generation (1G) Bioethanols
  - The first generation bioethanols refer to the ethanols that have been derived from the food-based feedstocks, such as starch, sugar, etc
  - These are alcohols produced by the use of enzymes and micro organisms through the process of fermentation of starches and sugar.
  - These are the most common type of alcohols.
  - Sugar crops such as sugar cane, sugar beet and sweet sorghum mostly consist of glucose, fructose, and sucrose as their major components are used.

- These fermentable sugars are extracted by grinding or crushing followed by fermentation to ethanol.
- Further, ethanol is separated from the products stream by distillation followed by dehydration.
- Grains such as corn and wheat contain starch, which is a polysaccharide of glucose units linked by α (1-4) and α (1-6) glycosidic bonds.
- Starch is not directly fermented by yeast.
- After milling the grains and extracting starch, starch is hydrolyzed into glucose using α-amylase and glucoamylase.
- Glucose is then fermented to ethanol.
- The cost efficiency of ethanol production from food based feedstocks and impacts on change in land usage has been criticized.
- Such drawbacks of first generation bioethanol gave rise to the need for ethanol production from non-food based feedstocks such as biomass.
- The Figure-7 briefly shows the production the first generation (1G) bioethanol.

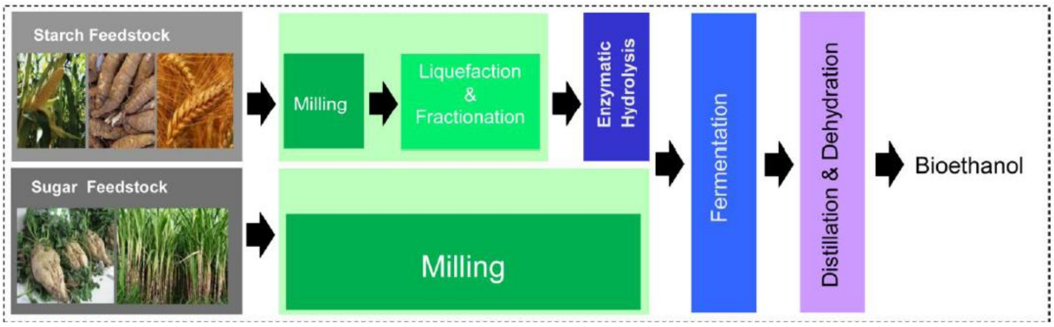


Figure-7: Bioethanol production from first generation biomass.

ii. Second Generation (2G) Bioethanol

- The second generation bioethanols are those produced from non-food feedstocks.
- Since the second generation bioethanols are derived from different feed stock, different technology is often used to produce them.
- The non-food based feedstocks used for production of second generation ethanol comprises of cellulosic biomass such as dedicated energy crops (e.g., switchgrass, miscanthus) and agricultural and wood residues (e.g., woodchips, cornstover, sugarcane bagasse, and sawdust).
- Cellulosic biomass mainly consists of cellulose, hemicellulose, and lignin polymers interlinked in a heterogeneous matrix.
- Cellulose is a linear polysaccharide consisting of several β(1-4) linked D-glucose units.
- Hemicellulose is a heteropolymer of xylose, mannose, galactose, rhamnose and arabinose.
- Lignin is a complex polymer of cross-linked aromatic compounds.
- Lignin acts as a protective barrier and hinders the depolymerization of cellulose and hemicellulose to fermentable sugars.

- Unlike first generation ethanol production, the process for conversion of cellulosic feedstocks to ethanol is complex.
- Cellulosic biomass is first pretreated either chemically or enzymatically to breakdown the polymeric units and increase the accessibility of C5-C6 sugars for microbial fermentation to produce ethanol.
- In 2014, 25 million gallons per year capacity commercial scale hanol plants were commissioned by POET-DSM and Abengoa Bioenergy.
- While commercialization of second generation ethanol plants looks promising, the sustainability of these plants will largely depend on the market availability of the feedstocks at reasonable prices.
- The simple schematic diagram for production of the second (2G) bioethanol has been shown in Figure-8.

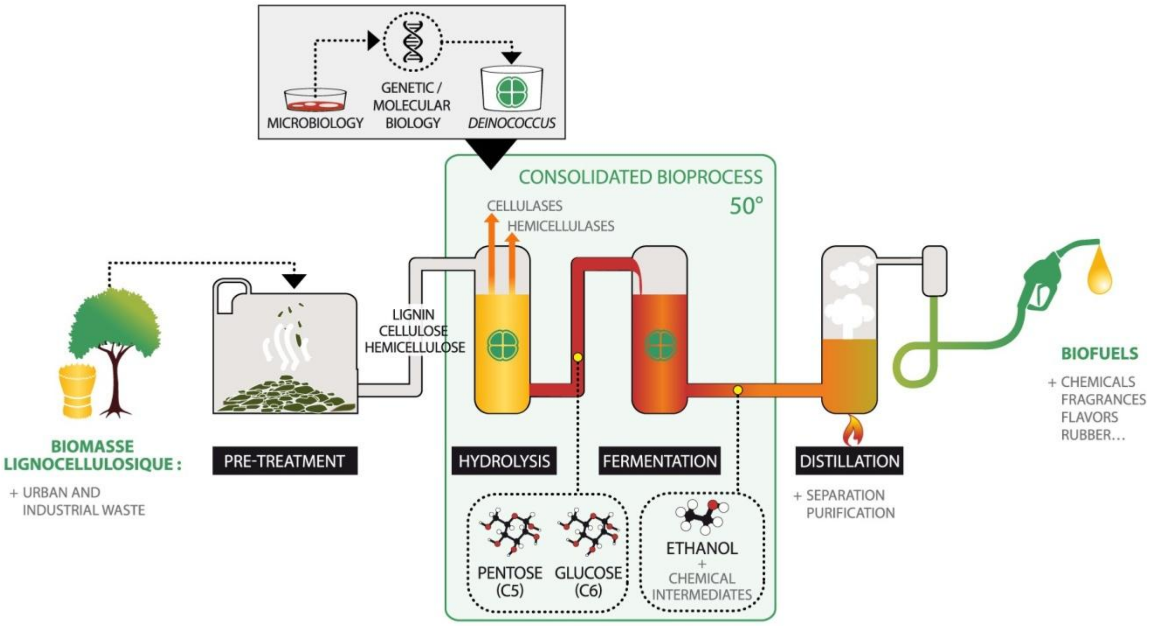


Figure-8: Production of the second generation (2G) bioethanol from non-food feedstocks.

- Conversion of non-food based feedstocks to bioethanol and other products can be broadly classified into chemical and biological processes.
- Further, biological conversion of biomass can be through direct or indirect fermentation.
- Bioethanol can be produced through direct fermentation of the biomass via hydrolysis-fermentation and through indirect fermentation via syngas fermentation.

iii Third Generation Bioethanol (3G)

- The third generation bioethanol is obtained from the algal biomass.
- Algae can be used to produce a variety of biofuels such as hydrogen, diesel, isobutene, and ethanol.
- Microalgae are unicellular organisms that are either autotrophic or heterotrophic and can grow in diverse environment.

- Autotrophic algae harness sunlight and fix atmospheric CO_2 into carbohydrates such as starch and cellulose via photosynthesis.
- On the other hand, heterotrophic algae species can utilize small organic carbon compounds that are turned into lipids, protein, and oils.
- Conversely, macroalgae are large multicellular marine algae obtained from natural and cultivated resources.
- Harvested macroalgae (red, brown and green) are mainly used to produce hydrocolloids that constitute 10-40% of their biomass.
- Macroalgae has a low concentration of lipids and primarily contains 35-74% carbohydrates and 5-35% proteins.
- Conversely, most of the microalgae such as *Botryococcus braunii*, *Chlorella sp.*, *Nannochloris sp.*, *Nitzschia sp.*, *Schizochytrium sp.* have at least 20-50% oil content.
- Several studies have reported the production of bioethanol from both micro and macro-algal biomass.
- Starch and cellulose are extracted from algae biomass using mechanical shear or by enzyme hydrolysis, after which they are utilized for bioethanol production.
- Enzymatic hydrolysis of cellulose from algae is simpler than from plant biomass due to negligible or no presence of lignin in algae.
- Various species of algae were reported to contain different starch and biomass content after oil extraction.
- Ethanol production from algal starch is similar to conversion processes of starch or sugars to ethanol (plant source).
- The conversion technologies of algal and plant based cellulosic biomass to ethanol are similar.
- Algae can grow on non-arable lands and do not change land usage.
- Further, CO_2 produced in industrial flue gases can be used to produce algal biomass.
- Another main advantage of algal biomass is that it does not require fresh water for cultivation.
- Waste water from industrial and domestic sewage can also be used for the cultivation of algal biomass.
- The major obstacle for the commercialization of algal biofuels is process economics.
- Harvesting corresponds to 20-30% of total cultivation costs.
- Cultivation of microalgae through open ponds is economical but has inherent disadvantages such as low productivity, water loss, low CO_2 utilization, and high affinity to be contaminated by other algal strains.
- The disadvantages of open ponds led to development of closed photobioreactors, which facilitate higher productivity, less contamination, and less water loss.
- However, photobioreactors suffered from CO_2, O_2 and pH gradients, wall growth, fouling, hydrodynamic stress, and high scale up costs.

- While macroalgae has recently gained renewed interest as bioethanol feedstock; its process economics are not fully addressed.
- Nevertheless, a recent quantitative sustainability assessment on macroalgae reported it to have a potential as a sustainable bioethanol feedstock.
- Different systems for cultivation of algal biomass (microalgae) and the conversion technologies to biofuels are shown in Figure-9 and 10, respectively.

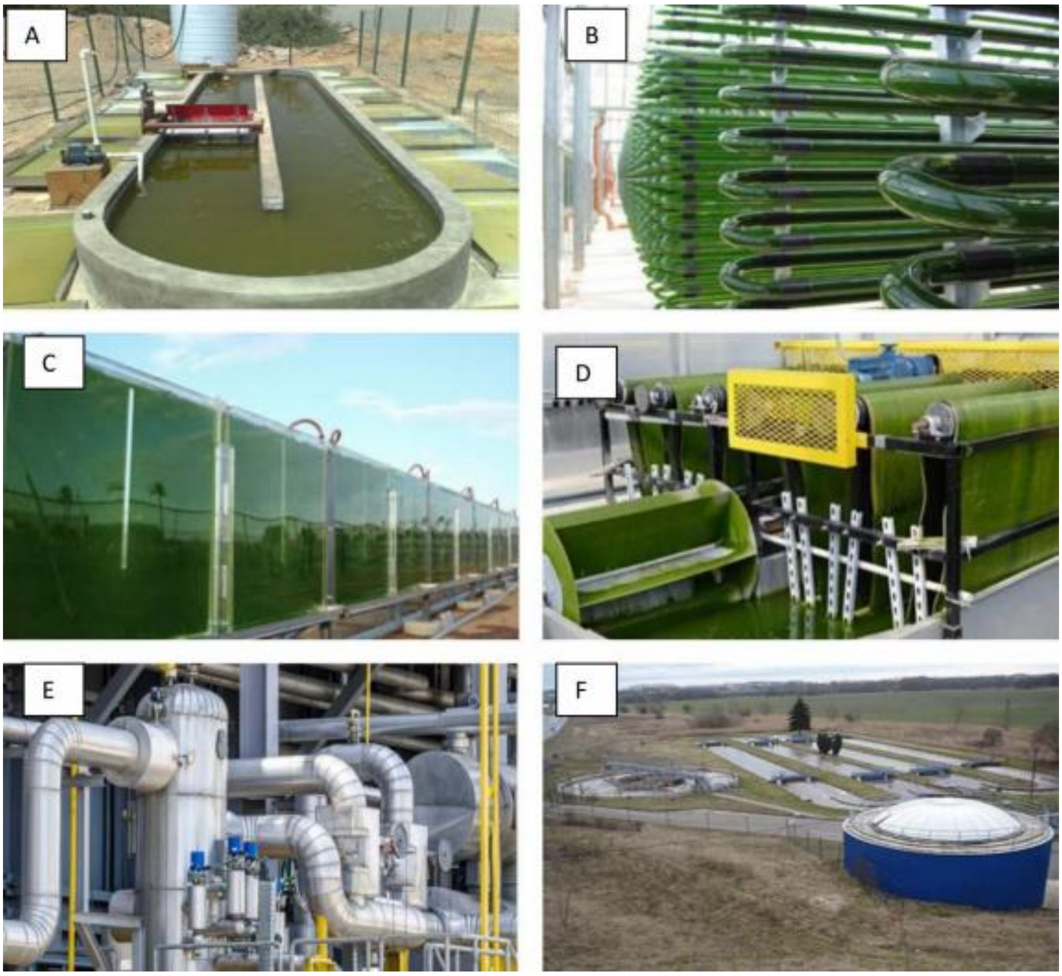


Figure-9: Different systems for algal cultivation A) Open ponds B) Tubular PBRs C) Flat PBRs D) Biofilm based PBRs E) Fermentor cultivation F) algal biomass cultivation using waste water. (PBRs: Photo Bioreactor Systems)

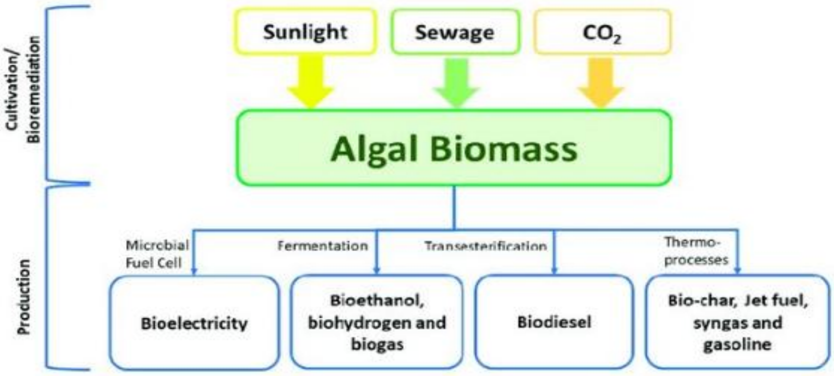


Figure-10: Various conversion processes of algae for biofuel production.

CLASSIFICATION OF BIOETHANOL FEEDSTOCKS (RAW MATERIALS)

The available feedstocks for bioethanol can be categorized into four major types, as illustrated in Figure-11.

(i) First-generation bioethanol feedstock

- ✓ It is mainly edible food crops such as rice, wheat, barley, potato, corn, sugarcane, and vegetable oil, for example, soybean oil, sunflower oil, olive oil, canola oil, mustard oil, etc.
- ✓ Although first-generation bioethanol has gained attention in a number of countries, the feasibility of production is still questionable due to competition with the food supply and land utilization, which increases the food cost.

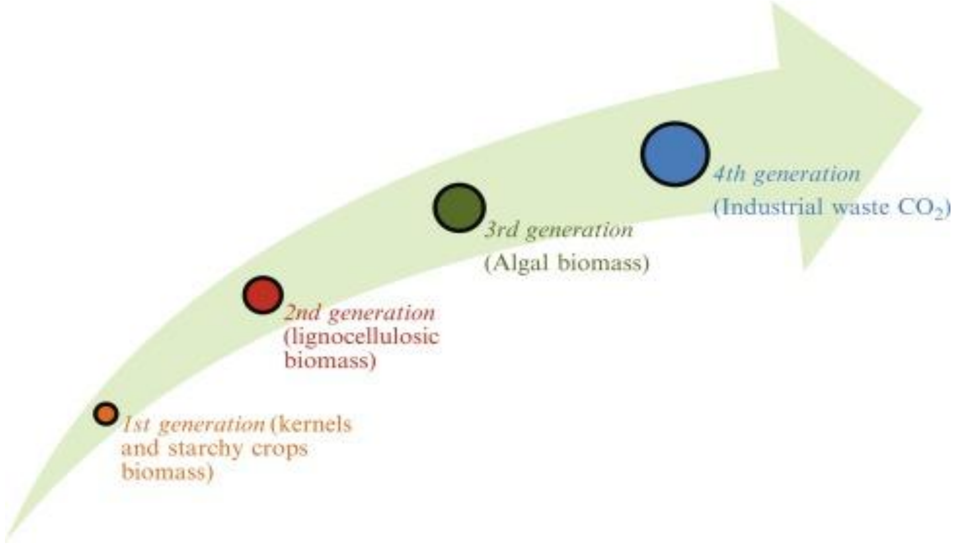


Figure-11: Bioethanol feedstock classification.

(ii) Second Generation Bioethanol Feedstock

- ✓ A strategy has been made for producing bioethanol from nonedible second-generation bioethanol feedstocks, including lignocellulosic biomass such as forest residue, woody biomass, herbaceous biomass, etc.; nonfood crops; municipal solid waste; and animal fat.
- ✓ The second-generation bioethanol production has some definite advantages over the first-generation bioethanol production.
- ✓ For instance, second-generation feedstocks can grow on poor quality marginal land with less water and fertilizer and no direct competition with food crops.
- ✓ Figure-12 shows the bioethanol production potential of major first- and second-generation feedstocks.
- ✓ However, it can be seen from the Figure that the first-generation feedstocks have a higher sugar concentration for producing ethanol compared to second-generation feedstocks.
- ✓ Although second-generation bioethanol feedstocks have addressed some of the issues associated with first-generation feedstocks, they still have some drawbacks.

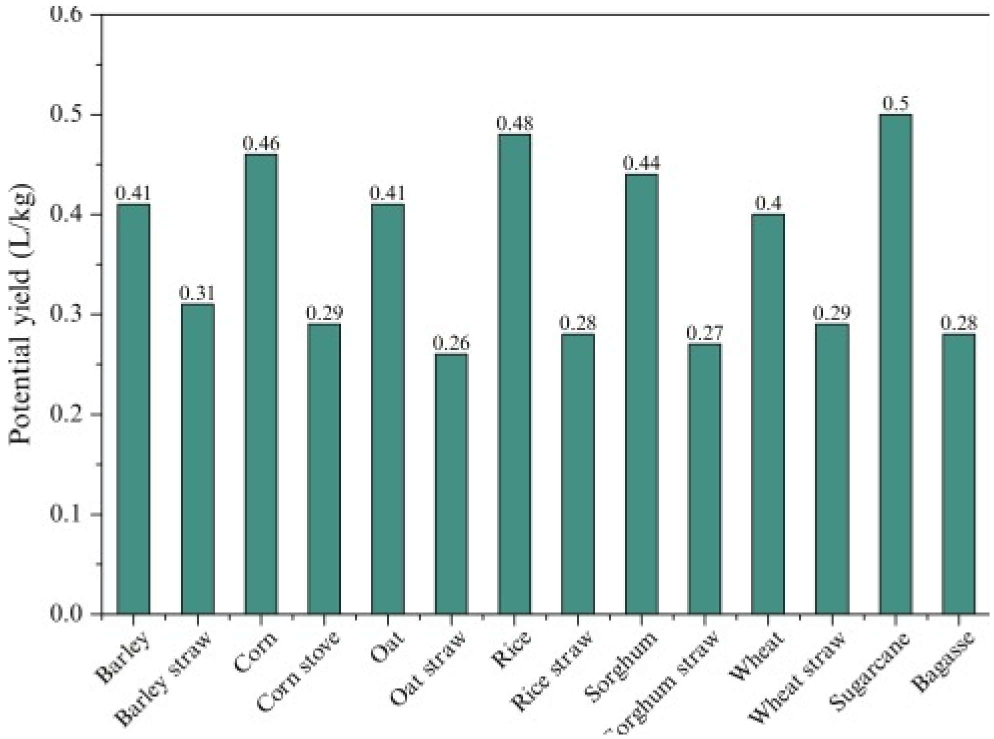


Figure-12: Bioethanol yield of different feedstocks.

- ✓ For example, second-generation bioethanol production requires more capital cost due to the sophisticated processing equipment and lower energy density compared to first-generation bioethanol.
- ✓ However, second-generation bioethanol has lower greenhouse gas (CO_2 2.85 kg/kg) emissions compared to the other feedstocks.

(iii) Third Generation Bioethanol Feedstocks

- ✓ With the aim of addressing the issues associated with first- and second generation bioethanol, researchers have explored an alternative feedstock for bioethanol production.
- ✓ Typically, bioethanol produced from algal biomass (i.e., microalgae, microbes) is considered third-generation bioethanol.
- ✓ Third-generation bioethanol feedstocks represent a promising feedstock due to the number of remarkable advantages over first- and second-generation feedstocks.
- ✓ For instance, microalgae can be cultivated on marginal land with a water environment, a low cost of cultivation, a high conversion efficiency, and a high energy density.
- ✓ However, the bioethanol produced from algae is less stable compared to the bioethanol produced from other sources.

(iv) Fourth Generation Bioethanol Feedstock

- ✓ Bioethanol produced from captured carbon dioxide by using advanced technologies such as electrochemical synthesis, oxide electrolysis, and petroleum hydroprocessing is termed fourth-generation bioethanol.

- ✓ In the environmental context, fourth-generation bioethanol is considered carbon negative as carbon produced from this technology is less compared to the carbon captured.
- ✓ However, this technology is in its embryonic stage.

➢ IMPORTANT RAW MATERIALS SUITABLE FOR BIOETHANOL PRODUCTION

One of the great merits of bioethanol production lies in the enormous variety of raw materials used. The production methods vary depending on whether or not the raw material is rich in fiber. The basic materials for producing biofuels must have certain features, including high carbon and hydrogen concentrations and low concentrations of oxygen, nitrogen and other organic components.

The following is a brief description of some of the most important raw materials suitable for use in bioethanol production.

- **Alfalfa (*Medicago sativa*)**
  - ✓ This is a lucerne of the Fabaceae family that grows in cool subtropical and warm temperate regions.
  - ✓ It demands no nitrogen-based fertilizers and its leaves are a precious source of protein in animal fodder.
  - ✓ In a paper (Dien et al., 2006) it was observed that this plant has a low glucose yield due to a low-efficiency cellulose hydrolysis.
  - ✓ The stems contain high concentrations of crude proteins and organic acids.

Alfalfa Plant Field

Alfalfa Plants in Various Stages

Figure-13: Alfalfa plant field and various stages of individual plants.

- **Switch Grass (panicum virgatum)**
  - ✓ This is a perennial herbaceous plant that grows mainly in the United States.
  - ✓ Its ethanol yield per hectare is the same as for wheat.
  - ✓ It responds to nitrogen fertilizers and can sequester the carbon in the soil.
  - ✓ It is a highly versatile plant, capable of adapting easily to lean soils and marginal farmland. Like maize, it is a type C4 plant, i.e. it makes an alternative use of CO_2 fixation (a process forming part of photosynthesis).
  - ✓ Most of the genotypes of Panicum virgatum have short underground stems, or rhizomes, that enable them with time to form a grassy carpet.
  - ✓ Single hybrids of Panicum virgatum have shown a marked potential for increasing their energy yield, but genetic engineering methods on this plant are still in a

developmental stage and for the time being only their tetraploid and octaploid forms are known; we also now know that similar cell types (isotypes) reproduce easily.

Figure-14: Switch Grass (panicum virgatum).

- **Sweet sorghum (sorghum bicolor L)**
  - ✓ The grains obtained from this plant are rich in starch and the stems have a high saccharose content, while the leaves and bagasse have a high lignocellulose content.
  - ✓ The plant can be grown in both temperate and tropical countries, and it tolerates drought, flooding and alkalinity.
  - ✓ Sorghum is considered an excellent raw material because the methods for growing and transporting it are well established.
  - ✓ Ethanol can be obtained from it by exploiting both its starch and its sugar content.
  - ✓ Research is currently underway on the use of hybrid or genetically modified species, although those obtained so far are weaker and need to be further refined and tested as concerns energy conversion efficiency.

Figure-15: Sweet sorghum plant field.

- **Cassava (manihoc esculenta)**
  - ✓ This tuber is of considerable interest not only for ethanol production but also to produce glucose syrup, and it is available in tropical countries.
  - ✓ The ethanol yield from the whole manioc is equivalent to the ethanol produced from cereals using dry milling methods.
  - ✓ The only known lies in that the manioc has to be processed 3-4 days after it was harvested.
  - ✓ To avoid such lengthy processing times, the manioc is first sliced and then left to dry in the sun.
  - ✓ The waste water produced in the process can be treated by means of anaerobic digestion to produce bio gas.

Figure-16: Cassava plant and root.

- **Spruce (picea abies)**
  - ✓ This tree has attracted a great deal of attention as a raw material for ethanol production because it is a lignocellulose material mainly composed of hexose sugars, which are more readily convertible than pentose sugars.

Figure-17: Spruce (picea abies) tree.

- **Willow (salix)**
  - ✓ This is a member of the Angiosperm family and is consequently characterized by a hard wood.
  - ✓ In this species, a fraction of the xylose units is acetylated.
  - ✓ Some of the OH groups of the xylose carbons C2 and C3 are replaced by O-acetyl groups.
  - ✓ With pretreatment, these groups release acetic acid that, in high enough concentrations, inhibits the yeasts involved in the fermentation process, according to some studies.
  - ✓ It was recently demonstrated that, by pretreating willow with sulfuric acid before the enzymatic hydrolysis process, and then simultaneously performing saccharification and fermentation, they succeeded in obtaining a global ethanol yield of 79%.

Figure-18: Willow (Salix) tree.

- **Reed canary grass (phalaris arundinacea)**
  - ✓ This is a type C3 perennial herbaceous plant that grows in the cool season and has an excellent resistance to flooding.
  - ✓ Its productivity is strongly influenced by high levels of nitrogen fertilizers, a feature that makes it very useful for the distribution of fertilizer from livestock.

Figure-19: Reed canary grass.

- **Sugar cane (saccharum officinarum)**
  - ✓ This plant only grows well in tropical and subtropical regions, which is why it is particularly common in Brazil.
  - ✓ It has a 12-17% sugar content, 10% of which is glucose and the other 90% is saccharose.
  - ✓ Milling can extract 95% of the total sugar content and the juice can subsequently be used to produce sugar or allowed to ferment to produce bioethanol.
  - ✓ The bagasse (i.e. thesolid residue remaining after milling) can be used as a source of energy and heat.

Figure-20: Sugar cane.

- **Sugar beet (beta vulgaris)**
  - ✓ This plant generally grows in the cooler temperate regions, so it is abundant in Europe, North America and Asia.
  - ✓ In the ethanol production process, the sugar beet is sliced and, while the juice is used to produce sugar or ethanol, the pulp is dried and used as animal feed or sold for pharmaceutical purposes.

Figure-21: Sugar beet plant.

- **Cereals**

  These must be ground to obtain starch, from which bioethanol is subsequently obtained. The cereals containing fewer proteins and more carbohydrates are preferable for distilling purposes because they have a higher bioethanol conversion rate. This means that the nitrogen content in the cereals can be adapted to facilitate starch accumulation instead of proteins synthesis, thereby improving both the energy yield and the quality of the fermentation process. The principal cereals are:

  - Wheat
    - ✓ It grows mainly in temperate regions.
    - ✓ The wheat treatment process is much the same as for the other cereals and it is best to use high-gravity fermentation to obtain the best performance in the fermentation process.

Figure-22: Wheat

  - Barley
    - ✓ The most suitable is the so-called Winter variety, which is often underestimated as a foodstuff, despite the fact that it can tolerate drought and is highly adaptable.

Figure-23: Barley.

  - Winter rye (secale cereale L)
    - ✓ This cereal relies heavily on the availability of nitrogen in the soil; it has high contents of both glucan and xylan (40.8% and 22.3% respectively).

When Should I Plant Winter Rye Grass ... Winter Rye Grass Seeds ... Winter Ryegrass Seeds For Bot...

Figure-24: Winter rye grass plants and seeds.

- **Corn stover**
  - ✓ This is what remains on the ground after maize has been harvested.
  - ✓ This raw material is abundantly available and demands no further investment in biomass, although not all of the corn stover can be removed - 30% of it must be left on the ground to prevent erosion (by facilitating water infiltration and reducing evaporation), and as the main source of soil organic carbon (SOC) in order to preserve the soil's productivity.
  - ✓ Corn stover contains polymeric hemicellulose and cellulose, but their biodegradability by glycosidase is strongly inhibited by a small quantity (12-15%) of lignin.

Corn Stover Images, Stock Photos ... Corn Stover Removal: Nutrient Value of ... biofuels from corn stover

Figure-25: Corn stover.

- **Jerusalem artichoke (helianthus tuberosus)**
  - ✓ This plant grows in summer, reaching its maximum height in July and dying in October.
  - ✓ The tubers are rich in inulin (a fructose polymer), which can be used to obtain a syrup for use both in the foodstuffs industry and in the production of ethanol.
  - ✓ It was demonstrated that, towards the end of the season, the potential for bioethanol production of the stems of clones is 38% of that of the tubers.

Illustration of Jerusale... How to grow Jerusalem ar... Jerusalem artichoke Facts, Health ...

Figure-26: Jerusalem artichoke plant and tubers.

- **Various Types of Biomass Wastes (Residues)**
  - ✓ Different types of plant biomass which have been considered by researchers for use in the production of biofuels include dedicated energy crops which grow on low-quality soil (*e.g.* herbaceous crops and perennial grasses such as *Miscanthus sinensis* and *M. giganteus* or switchgrass already discussed.

- ✓ Agricultural wastes, such as cereal straw, wheat straw, corn cob, rice husk and bagasse from processing sugar cane have also been examined as potential sources of lignocellulosic biomass.
- ✓ Other research has focused on forest based woody wastes and forest biomass bark, sawdust, softwood trimmings (pine) and hardwood chips (oak), or on waste from parks and gardens (leaves , grasses, branches.
- ✓ Industrial wastes, such as brewer’s spent grains and spent grains from distilleries, and municipal solid wastes such as food waste, kraft paper and paper sludge containing cellulose have also been considered.
- ✓ Because of its high organic load, the whey obtained as a byproduct of the cheese industry is toxic to the environment and requires treatment before removal as waste.
- ✓ The use of whey as a substrate for the production of biomediated ethanol can reduce the costs associated with the treatment of effluent in dairies.
- ✓ Crude glycerol, which is generated during the transesterification of animal fats and vegetable oils, is a significant byproduct of the biodiesel industry.
- ✓ The fermentation of crude glycerol obtained from waste enables this surplus to be reduced.
- ✓ Fermentation of glycerol is performed by conversion to phosphoenol pyruvate (PEP) or pyruvate, leading to increased content of reducing equivalents and higher bioethanol yield than the fermentation of glucose and xylose from biomass.
- ✓ Lignocellulosic bioethanol generates lower levels of greenhouse gases than first generation bioethanol and causes less air pollution.
- ✓ However, the production of lignocellulosic bioethanol requires feedstock preparation prior to fermentation and the finding/developing of ethanol producers able to ferment sugars from cellulose and hemicellulose breakdown as evident from the **Figure-8**.
- ✓ Various types of biomass which may be used for production of second generation (2G) bioethanol have been summarized by **Figure-19**.

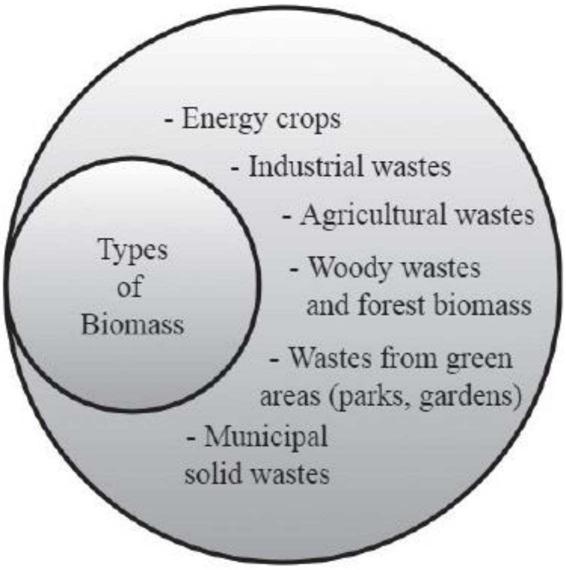


Figure-27: Various types of biomass which may be used for bioethanol.

- **Municipal solid waste (MSW)**
  - ✓ The most suitable waste for converting into bioethanol is the waste from the fruit and vegetable industries, for instance, cotton fiber, milk whey from cheese-making, the waste products of coffee making, and so on.
  - ✓ Generally speaking, such waste contains approximately 45% of cellulose (glucose polymer), which can be simultaneously hydrolyzed and fermented to produce ethanol.
  - ✓ SSL (Spent Sulfite Liquor) is a by product of bisulfite "pulp" manufacturing that can also be fermented to produce ethanol.
  - ✓ Waste varies considerably in content from one area to another, but the majority of the volume generally consists of paper (20-40%), gardening waste (10-20%), plastics, glass, metals and various other materials.
  - ✓ Figure-28 shows the main steps involved in conversion of biogenic municipal solid wastes to bioethanol.

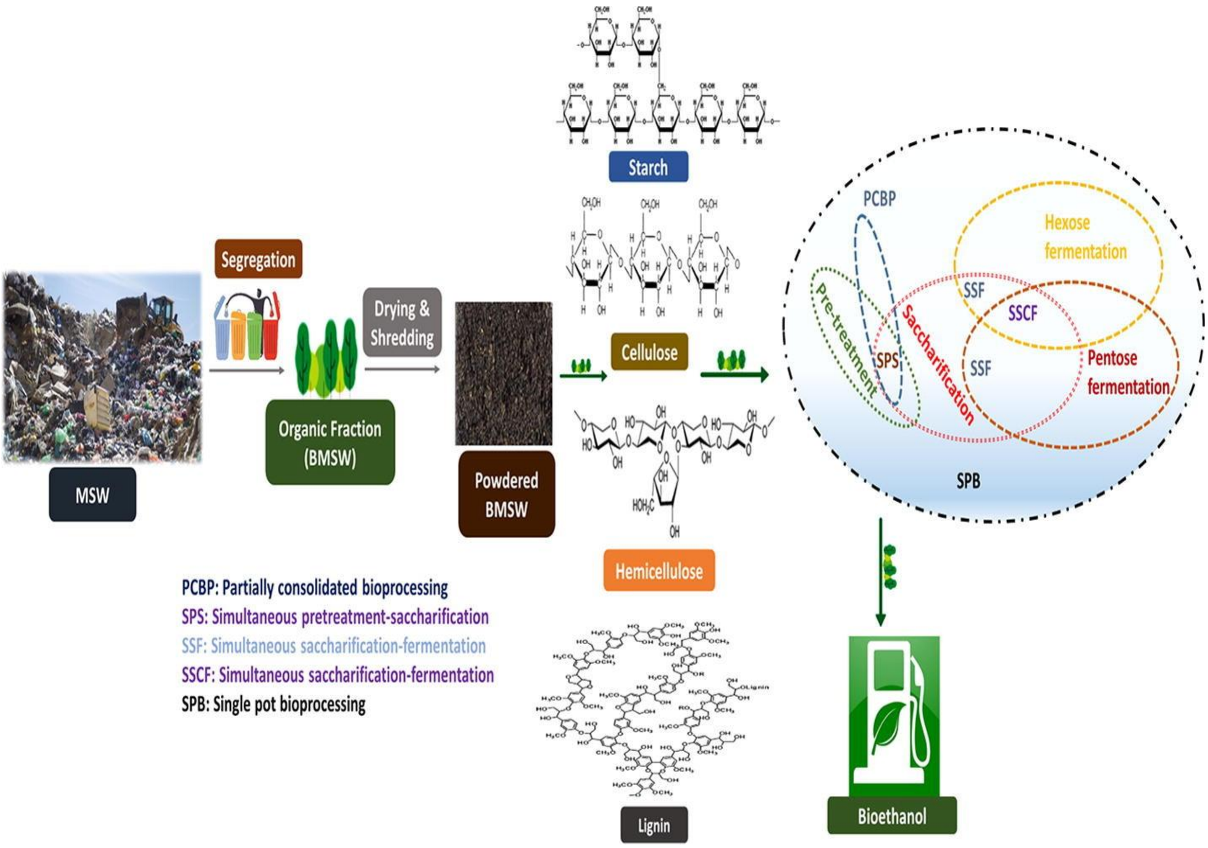


Figure-28: Conversion of biogenic municipal solid wastes to bioethanol.

  - ✓ A picture of Enerkem's state-of-the-art Edmonton biofuels facility (Canada), the world's first commercial scale plant to produce cellulosic ethanol made from non-recyclable, non-compostable mixed municipal solid waste has been shown in Figure-29.
  - ✓ According to the International Renewable Energy Agency, the advanced biofuels market is expected to grow to reach 124 billion litres per year by 2030.

Figure-29: A picture of Enerkem's state-of-the-art Edomonton (Canada) biofuels facility, the world's first commercial scale plant to produce cellulosic ethanol made from non-recyclable, non-compostable mixed municipal solid waste. (CNW Group/Enerkem Inc. 2017)

- Another pilot plant facility of Japan producing 20, 000 lit per annum bioethanol from municipal solid waste has been demonstrated in Figure-30.

20000 lit per annum pilot plant facility (2017)

Figur-30: LanzaTech and Sekisui (Japan) advance conversion of municipal solid waste to ethanol (2017).

➢ COMMERCIAL PRODUCTION OF BIOETHANOL

• Common Flow Diagram for the 1st and the 2nd Generation of Feedstocks

- ✓ Bioethanol production instead of chemical synthesis, the bioprocess, i.e. fermentation of simple sugars by microorganism is nowadays used extensively to produce ethanol from renewable sugar containing biomass.
- ✓ Important ones are sugar crops, starch crops, and lignocellulosic materials derived from agricultural residues.
- ✓ The two former ones are recognized as the first generation feedstock for bioethanol production while the last one is the second generation feedstock.
- ✓ When ethanol is produced by yeast fermentation of sugar feedstock such as sugar cane, molasses, sugar beet and sweet sorghum, yeast can directly consume simple sugars and convert them to ethanol.
- ✓ However, starch and cellulose feedstock are a polymer of glucose and cannot directly be utilized by yeast.
- ✓ They have to be converted or depolymerized to glucose prior to yeast fermentation.
- ✓ Depolymerization or hydrolysis of starch is much simpler and more cost effective than that of cellulosic materials and can be achieved by acid or enzyme or a combination of both.
- ✓ Starch is a polysaccharide comprising solely of glucose monomers which are linked together by glycosidic bonds.
- ✓ It is composed of two types of glucan namely amylose, a linear glucose polymer having only α-1,4 glycosidic linkage and amylopectin, a branched glucose polymer containing mainly α-1,4 glycosidic linkage in a linear part and a few α-1,6 at a branch structure.
- ✓ Most starches contain approximately 20-30% amylose and the rest are amylopectin.
- ✓ Some starches contain no amylose such as waxy corn starch, waxy rice starch, amylose-free potato, amylose-free cassava and some have very high amylose contents upto 50-70% as in high amylose maize starches.
- ✓ These two polymers organize themselves into semi-crystalline structure and form into minute granules, which are water insoluble.
- ✓ Starch granules are less susceptible to enzyme hydrolysis.
- ✓ Upon cooking in excess water, the granular structure of starch is disrupted, making glucose polymers become solubilized and more susceptible to enzyme attacks.
- ✓ At the same time, the starch slurry becomes more viscous.
- ✓ This process is known as gelatinization and the temperature at which starch properties are changed is named as gelatinization temperatures.
- ✓ Different starches have different gelatinization temperatures, implying different ease of cooking.
- ✓ Cassava starch has a lower cooking temperature, relatively to cereal starches; the pasting temperatures for cassava, corn, wheat and rice are 60-65, 75-80, 80-85 and 73-75°C.
- ✓ The starch hydrolysis by enzymes is a two-stage process involving liquefaction and saccharification.

- ✓ Liquefaction is a step that starch is degraded by an endo-acting enzyme namely α-amylase, which hydrolyzes only α-1,4 and causes dramatically drop in viscosity of cooked starch.
- ✓ Typically, liquefying enzymes can have an activity at a high temperature (> 85°C) so that the enzyme can help reduce paste viscosity of starch during cooking.
- ✓ The dextrins, i.e. products obtained after liquefaction, is further hydrolzyed ultimately to glucose by glucoamylase enzyme which can hydrolyze both α-1,4 and α-1,6 glycosidic linkage.
- ✓ Glucose is then subsequentially converted to ethanol by yeast.
- ✓ By the end of fermentation, the obtained beer with approximately 10%v/v ethanol, depending on solid loading during fermentation, is subjected to distillation and dehydration to remove water and other impurities, yielding anhydrous ethanol (Figure-31).

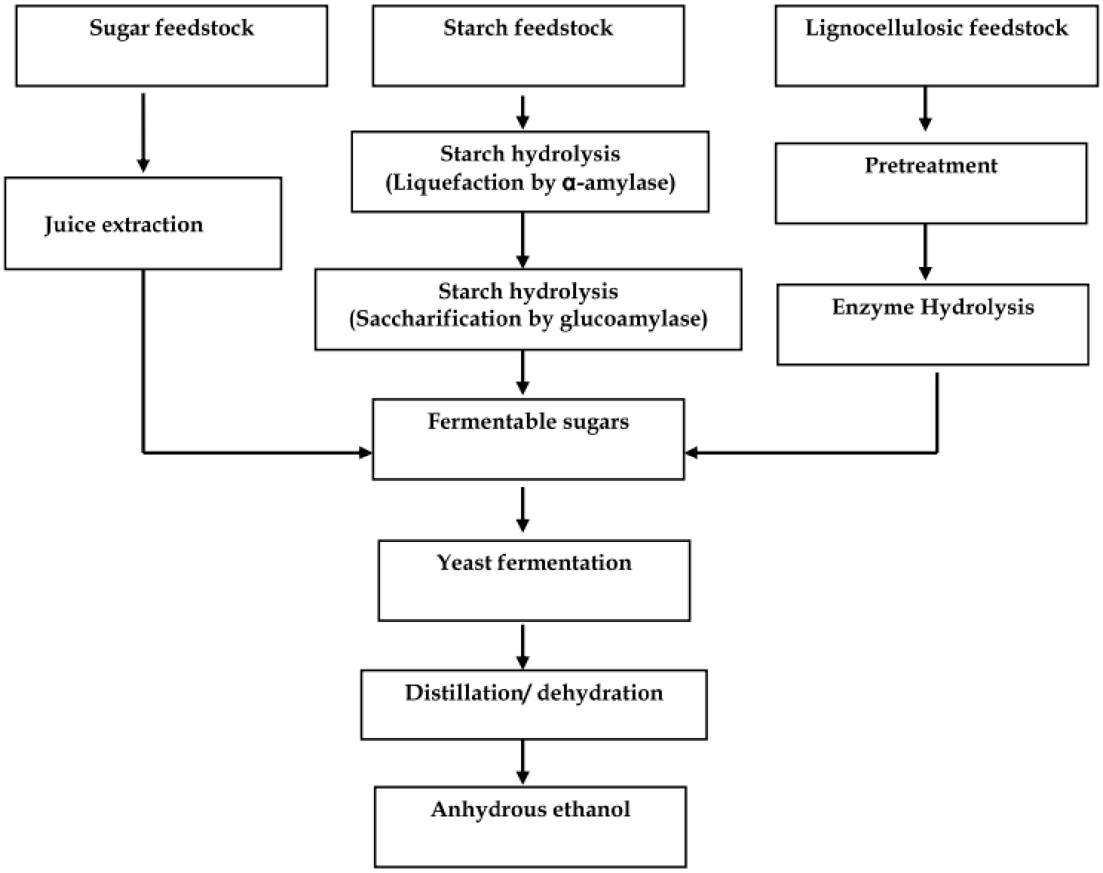


Figure-31: Common flow diagram for bioethanol production for 1st and 2nd generation feedstocks.

• Bioethaol Production from Sugarcane

Introduction:

Increased interest on alternative fuels has been observed in the past few years, as a result of increasing energy demand and forecasted depletion of fossil resources. Global warming and the consequent need to diminish greenhouse gases emissions have encouraged the use of fuels produced from biomass, which is the only renewable carbon source that can be efficiently converted into solid, liquid or gaseous fuels.

Bioethanol is presently the most abundant biofuel for automobile transportation. It is produced from fermentation of sugars obtained from biomass, either in the form of sucrose, starch or lignocellulose.

Sugarcane is so far the most efficient raw material for bioethanol production: the consumption of fossil energy during sugarcane processing is much smaller than that of corn. One of the main by-products generated during sugarcane processing is sugarcane bagasse, which is usually burnt in boilers for production of steam and electrical energy, providing the energy necessary to fulfill the process requirement.

Bioethanol production process

The steps involved have been discused in the succeeding paragraphs. Pictorial view of bioethanol production has been shown in Figure-32. However, a simplified scheme of production and a block-flow diagram have been depicted in Figure-33 and Figure-34, respectively.

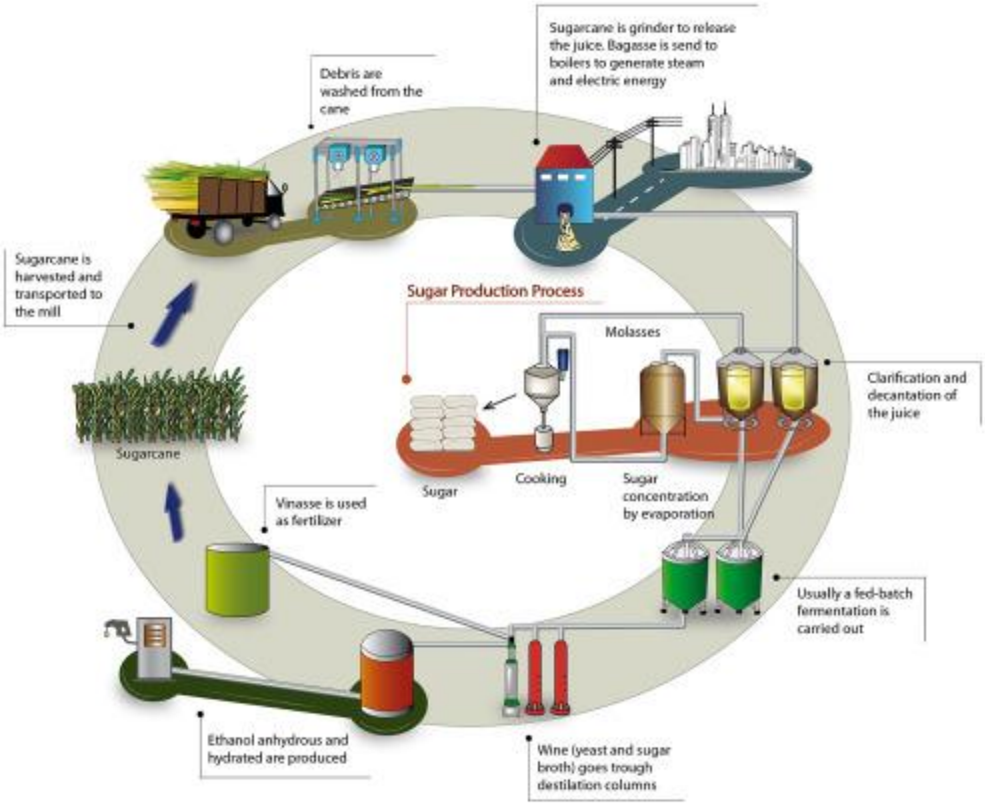


Figure-32: Pictorial representation of biothanol production.

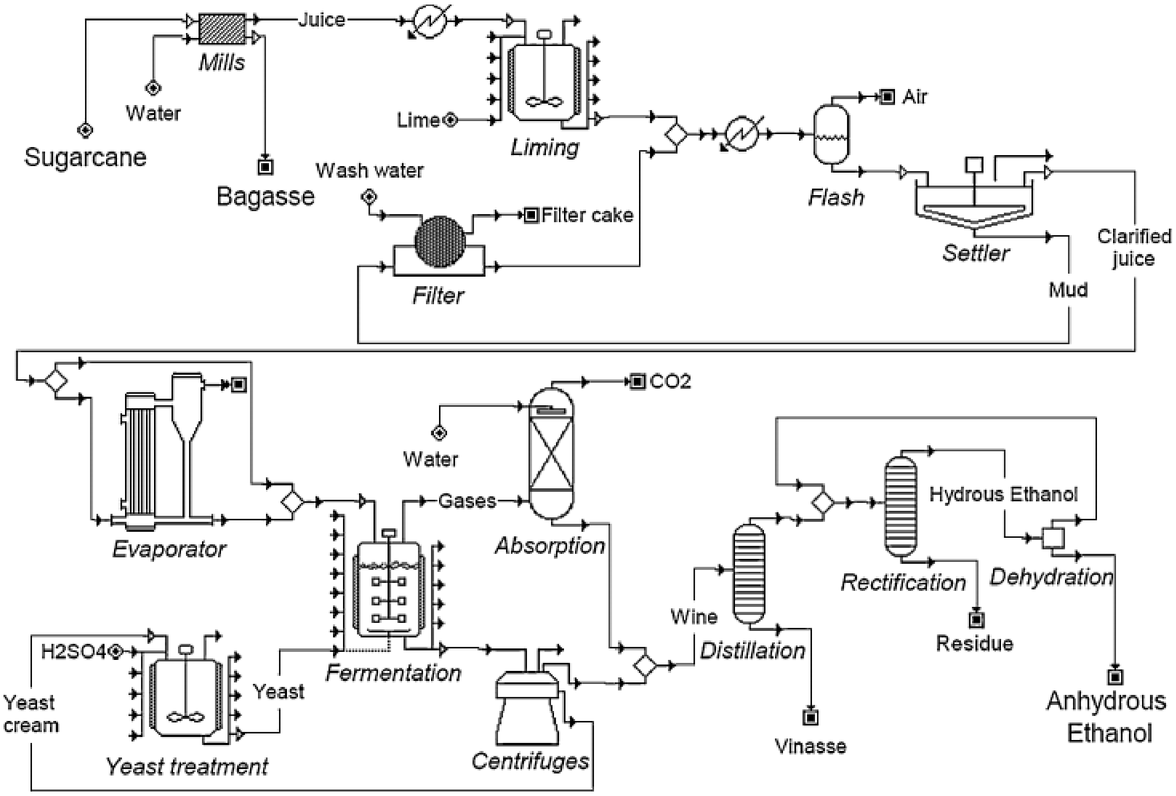


Figure-33: Simplified scheme for bioethanol production from sugarcane.

- ✓ Cleaning, Grinder and Juice Extraction
  - Once sugarcane arrives in the mill, it passes through a cleaning process to wash impurities and other residues.
  - The cleaning can be wet or dry; dry cleaning is more ecologically friendly as it does not waste water, and does not lead to sucrose loss.
  - After that, sugarcane is ground to crush the fiber and to increase the density of the material from 175 to 450 kg/m^3.
  - The juice extraction process is made by a crusher (some mills use a diffusion process) to release sucrose.
  - The milling process extracts the juice using 4–7 mill suits with 3–4 pressure rollers each, while hot water (around 70°C) is passed through the bagasse to improve extraction yield.
  - The remaining bagasse, with a humidity of 50%–52%, is sent to boilers to generate high-pressure steam.
  - The steam turbine converts thermal energy to mechanical or electrical energy.
  - In annexed distilleries, the amount of juice that is going to be directed to produce sugar, usually, depends on the market demand.
  - Due to quality reasons, only the sugarcane juice extracted in the first mill suit is used for sugar production.
  - The juice obtained in following mill suits, which accounts for at least 30% of the total reduction sugar, is directed to ethanol production.

  - After extraction, the juice is sieved and clarified by decanting of impurities to prevent the undesired sugar inversion.
  - Clarification uses chemical compounds such as sulfate (sulfuric gas) and liming, followed by heat and decanting.
  - The clarification process generates a sludge that is used as a fertilizer in the sugarcane crops.
  - During clarification, the juice is heated to 105°C to lower microbial contamination, and to facilitate the coagulation of colloids and emulsification of grease and wax.
  - At sugar processing, high temperatures are used to concentrate the juice through evaporation and to crystallize sucrose.
  - After sugar production, the residual sugar solution is called molasses (or honey), which contains high amounts of glucose (5%–20%) and sucrose (45%–60%).
  - In annexed sugarcane distilleries, molasses can be mixed with sugarcane juice (originating must) to produce bioethanol.
  - This is advantageous, because the juice has some nutritional deficiencies, whereas molasses has inhibitory compounds for yeast fermentation.
  - In some plants, only one or the other is used as a substrate to produce ethanol.
- ✓ Fermentative Processes
  - As discussed above, sugarcane goes through cleaning, extraction, and physical and chemical treatments (Figure-34).
  - After that, sugars are fermented to ethanol by yeasts.
  - Fermentation starts by mixing sugarcane juice or must (molasses and sugarcane juice), which contains 18%–22% (w/w) total reducing sugars, to a yeast cell suspension.
  - During this period, enzymes sucrose and zymase which are present in yeast, convert sugar into ethyl alcohol.

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow{\text{Zymase}} C_6H_{12}O_6 + C_6H_{12}O_6$$

$$C_6H_{12}O_6 \xrightarrow{\text{Yeast}} C_2H_5OH + CO_2$$

  - Different types of fermentation processes were developed over time, such as: batch process, fed-batch process, and continuous process.
  - Fed-batch process is commonly used in 70%–75% of the ethanol distilleries, the feeding time normally lasts for 4–6 hours, and fermentation is finished within 6–10 hours.
  - In the batch process, the fermentation vat is loaded with a carbon source (must or sugarcane juice) prior the addition of yeast (*Saccharomyces cerevisiae*).
  - The yeast suspension (with 30% of yeast cell, on a wet basis) represents 25%–30% of the total volume of fermentation, which is performed in tanks of 300–3000 m^3.
  - This method is not used in industrial ethanol plants, since it can lead to low productivity of ethanol due to the presence of contaminants once the process takes place under aerobic conditions, being used only on a laboratory scale, in small distilleries, or in yeast propagation.

- In the fed-batch process, yeast is added to the fermentation vat and the juice is added continuously during the fermentation process until the maximum volume of the vat is reached.
- This process is performed in serial fermentation vats, where the must is added with constant feed flow rate or intermittently.
- After the vat reaches its maximum volume, the fermentation continues until the total reduction of the sugar is complete, and the product is collected followed by a cleaning and sterilization process of the fermenter for the next batch.
- This fermentation method has some advantages, such as maintenance of the maximum concentration of viable cells, prolongation of cell lifetime, and less inhibition of yeast by the high substrate concentration.
- The fed-batch system is widely used in Brazilian industry, being employed in approximately 75% of the mills, due to a higher ethanol yield at the end of fermentation and being less subject to contamination.

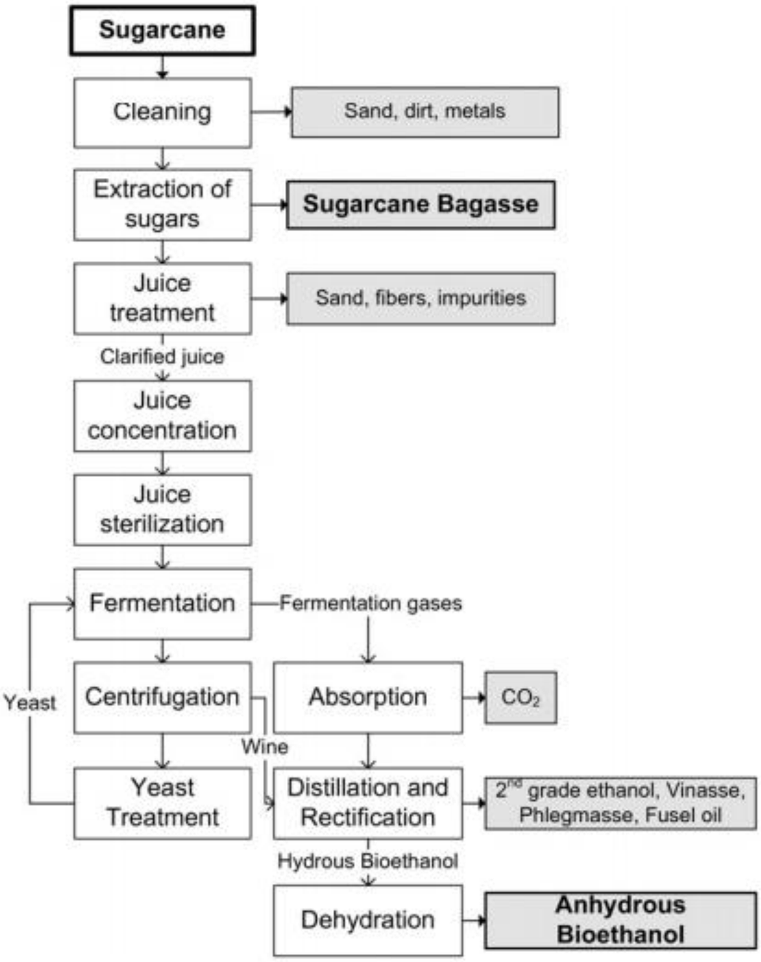


Figure-34: Block-flow diagram of the bioethanol production process from sugarcane.

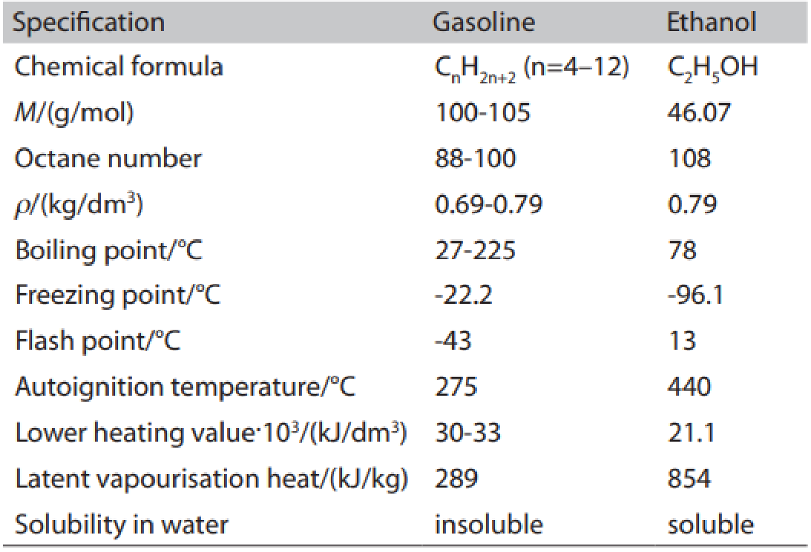
- ✓ The continuous fermentation process is characterized as a system that can operate for long periods at steady state.
- ✓ The fermentation vat works with a constant high volume and flows feed of must, while the juice is withdrawing at the same flow rate of the inlet flow.

- Continuous fermentation is a process that requires greater knowledge of the microorganism's behavior in the environment in which it operates.
- Operating factors such as pH, temperature, substrate concentration, ethanol, and biomass influence the system productivity, requiring greater control of the process.
- The biggest disadvantage is that the continuous fermentations are more susceptible to bacterial contamination for long exposure times.
- When fermentation ceases, the resulting broth (called wine) has about 6%–12% (v/v) of alcohol.
- Yeast cells are separated from wine by centrifugation, resulting in a concentrated yeast cell suspension (the yeast “cream”) with 60%–70% (wet weight basis/volume) of cells.
- As the yeast suspension is recycled, the yeast cream is diluted with water and treated with sulfuric acid for 2 hours to reduce contamination.
- Remaining wine is sent to a distillation vat, and ethanol is recovered in a hydrated form (96° GL), producing stillage or vinasse as a by-product. This by-product is usually sent to cane fields to be used as fertilizer (Figure-34).
- The hydrated ethanol can be stored, or sent to a dehydration vat where cyclohexane is added to produce anhydrous ethanol.
- Another way to produce anhydrous ethanol is through molecular sieves that consume less energy.

SPECIFICATION OF GASOLINE AND BIOETHANOL

- Bioethanol, as an alternative to the fossil fuels, is mainly produced by yeast fermentation from different feedstocks.
- It is a high octane number fuel and its physicochemical features are considerably different compared to the gasoline as shown in Table-2.

Table-2: Specification of Gasoline and Bioethanol

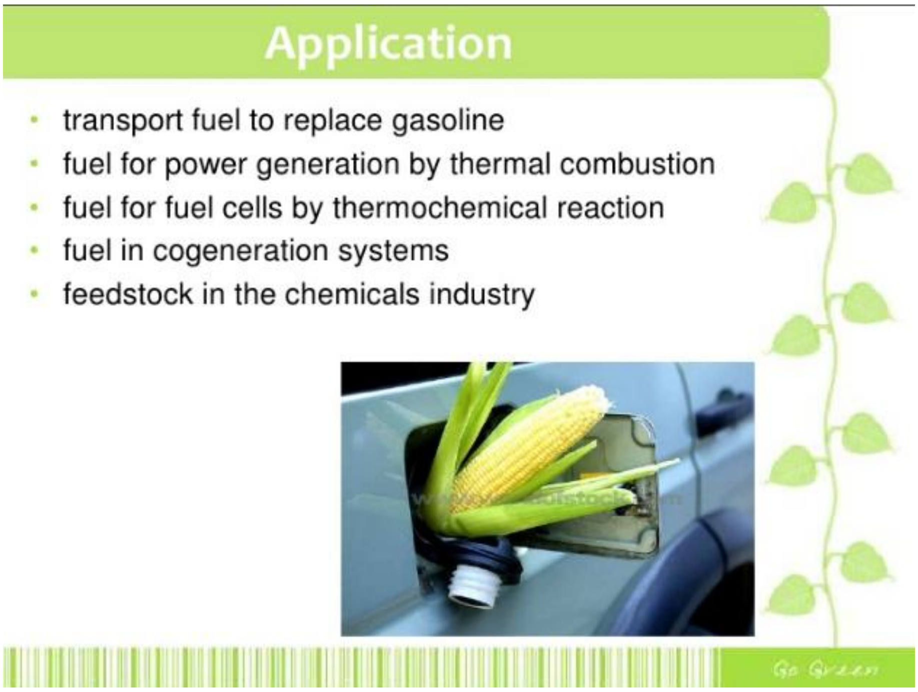


Specification	Gasoline	Ethanol
Chemical formula	C_nH_{2n+2} (n=4–12)	C_2H_5OH
M/(g/mol)	100-105	46.07
Octane number	88-100	108
ρ/(kg/dm^3)	0.69-0.79	0.79
Boiling point/°C	27-225	78
Freezing point/°C	-22.2	-96.1
Flash point/°C	-43	13
Autoignition temperature/°C	275	440
Lower heating value·10^3/(kJ/dm^3)	30-33	21.1
Latent vapourisation heat/(kJ/kg)	289	854
Solubility in water	insoluble	soluble

- Bioethanol has much lower energy content than gasoline (about two-third of the energy content of the latter on a volume base).

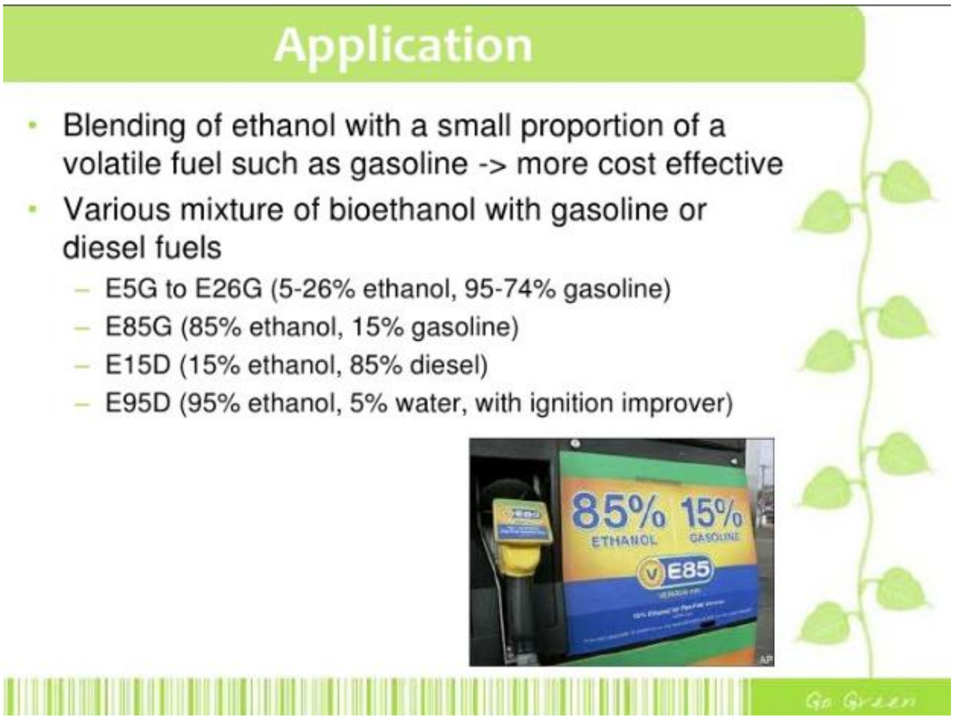
- This means that, for mobility applications, for a given tank volume, the range of the vehicle is reduced in the same proportion.
- The octane number of ethanol is higher than that for petrol; hence ethanol has better antiknock characteristics.
- This better quality of the fuel can be exploited if the compression ratio of the engine is adjusted accordingly.
- This increases the fuel efficiency of the engine.
- The oxygen content of ethanol also leads to a higher efficiency, which results in a cleaner combustion process at relatively low temperatures.
- The Reid vapour pressure, a measure for the volatility of a fuel, is very low for ethanol.
- This indicates a slow evaporation, which has the advantage that the concentration of evaporative emissions in the air remains relatively low.
- This reduces the risk of explosions.
- However, the low vapour pressure of ethanol, together with its single boiling point, is disadvantageous with regard to engine start at low ambient temperatures.
- Without aids, engines using ethanol cannot be started at temperatures below 20ºC.
- Cold start difficulties are the most important problem with regard to the application of alcohols as automotive fuels.
- Bioethanol serves mostly in the transport sector as a constituent of mixture with gasoline or as octane increaser (ethyl tertiary butyl ether (ETBE), consisting of 45 % per volume bioethanol and 55 % per volume of isobutylene).
- Many countries use ETBE instead of methyl tertiary butyl ether (MTBE), which serves for octane number increase, but it is prohibited in the USA and Canada due to cancerous emissions.
- Bioethanol is mixed with gasoline at the volume fractions of 5, 10 and 85 % (fuel names E5-E85).
- A total of 85 % bioethanol by volume can only be used in flexible fuel vehicles (FFV), while mixtures of 5 and 10 % by volume can be used without any engine modifications.
- However, problems related to the use of bioethanol are: corrosive effect on fuel injector and electric fuel pump (bioethanol is hygroscopic in nature), engine start up problem in cold weather conditions (pure ethanol is hard to vaporize) and the tribological effect on lubricant properties and engine performance.
- Bioethanol inside lubricant significantly reduces the properties and performance of engine oil.
- It is miscible with water, but immiscible with oil.
- Therefore, bioethanol has high potential for emulsion formation (bioethanol-water-oil mixture), which causes serious engine failures.
- There are different methods to improve the performance of engines (*e.g.*laser texturing, coatings, mass reduction of engine parts and lubricant composition) and extend their lifetime through thefriction and wear reduction.
- The use of synthetic oil is one possibility to solve the above-mentioned issues.

➢ UTILIZATION OF BIOETHANOL



Application

- transport fuel to replace gasoline
- fuel for power generation by thermal combustion
- fuel for fuel cells by thermochemical reaction
- fuel in cogeneration systems
- feedstock in the chemicals industry



Application

- Blending of ethanol with a small proportion of a volatile fuel such as gasoline -> more cost effective
- Various mixture of bioethanol with gasoline or diesel fuels
  - E5G to E26G (5-26% ethanol, 95-74% gasoline)
  - E85G (85% ethanol, 15% gasoline)
  - E15D (15% ethanol, 85% diesel)
  - E95D (95% ethanol, 5% water, with ignition improver)

INDIA'S STATUS IN BIOETHANOL PRODUCTION, CONSUMPTION AND RQUIREMENT

India has around 330 distilleries, which can produce over 4.8 billion liters of rectified spirits (alcohol) per year. Of this total, about 166 distilleries have the capacity to distill 2.6 billion liters of ethanol (denatured and undenatured) to be used in fuel, industrial chemicals, and beverages. Final C & B Heavy molasses, sugarcane juice, food grains unfit for human consumption, and any other potential domestic raw material sources available in the country may be used for making fuel-grade ethanol.

- **Consumption**
  - ✓ India’s total ethanol consumption in 2019 was forecasted to rise 22 percent to a record 3.8 billion liters.
  - ✓ In 2018, a record of 3.1 billion liters was consumed.
  - ✓ The consumption will outgrow ethanol production for the fifth consecutive year, more so due to the burgeoning demand of fuel ethanol for blending with gasoline.
  - ✓ As a result, supply to industrial and potable sectors will be limited by drop in demand on price sensitivities (illustrated in **Figure-35**).
  - ✓ The ethanol consumption growth (14 % annual, 5-year average, 2015-2019) is rather strong compared to production growth (8% annual, 5-year average).
  - ✓ Both have risen, but in response to different drivers: the rise in fuel prices coupled with very attractive purchase price of ethanol is driving ethanol consumption; consecutive year bumper harvests is supporting production growth.
  - ✓ A 6.6% blend rate seemed achievable where all the ethanol produced (from molasses) in 2019 was blended with gasoline.
  - ✓ Potential blending would be higher yet if imports are permitted and duties lowered.
  - ✓ However, given the demand from the potable and industrial sectors and limitations on imports, a national blend average of 5.8% in 2019 was expected.
  - ✓ The Indian Sugar Mill Association indicate that the Oil Marketing Companies (OMCs) could procure upwards of 2.4 billion liters in 2019.
  - ✓ Of the total requirement of 3.3 billion liters established by OMCs for marketing year 2019, total ethanol offered by the suppliers (from 21 states) to the oil marketing companies for blending with gasoline was 3.13 billion liters.
  - ✓ Of this, some 2.7 billion liters was finalized against which 1.08 billion liters was supplied as of May 20, 2019.
  - ✓ Since the quantity of ethanol demanded at higher prices may be less, the industrial uses and the potable sector will need to augment some of its supply from grain-based distilleries, partly from raw material imports or by directly importing the finished products.
- **Production**
  - ✓ Production was forecasted at 3 billion liters in 2019, which was 11% rise in the production as compared to 2018, a record volume.
  - ✓ Molasses supply for fuel use will increase in response to price incentive to divert B-heavy molasses, in addition to final C-heavy for producing fuel grade ethanol, but at the cost of diverting excess sugar.

- ✓ The Indian Sugar Mill Association supply estimate of 2.4 billion liters in 2019 was based on 1.8 billion liters produced from C-Heavy molasses, some 425-430 million liters from B-Heavy molasses, 165-170 million liters from damaged food grains, and 20 million liters from sugarcane juice.
- ✓ In 2018, an estimated 2.7 billion liter of ethanol was produced (from molasses).
- ✓ The total quantity offered for EBP (**Ethanol** Blended Petrol (**EBP**) programme was launched in January, 2003. The programme sought to promote the use of alternative and environment friendly fuels and to reduce import dependency for energy requirements) was 1.8 billion liters of which 1.6 billion liters was blended with gasoline to mark a 4.1% blend rate for 2018.
- ✓ The differential and remunerative price to ethanol suppliers will substantially increase availability of ethanol for the EBP Program, reduce dependence on crude oil, and in turn help proliferate a more environmentally friendly fuel.
- ✓ For background information on the ethanol program, please see Biofuel Annual 2017 GAIN report IN8085.

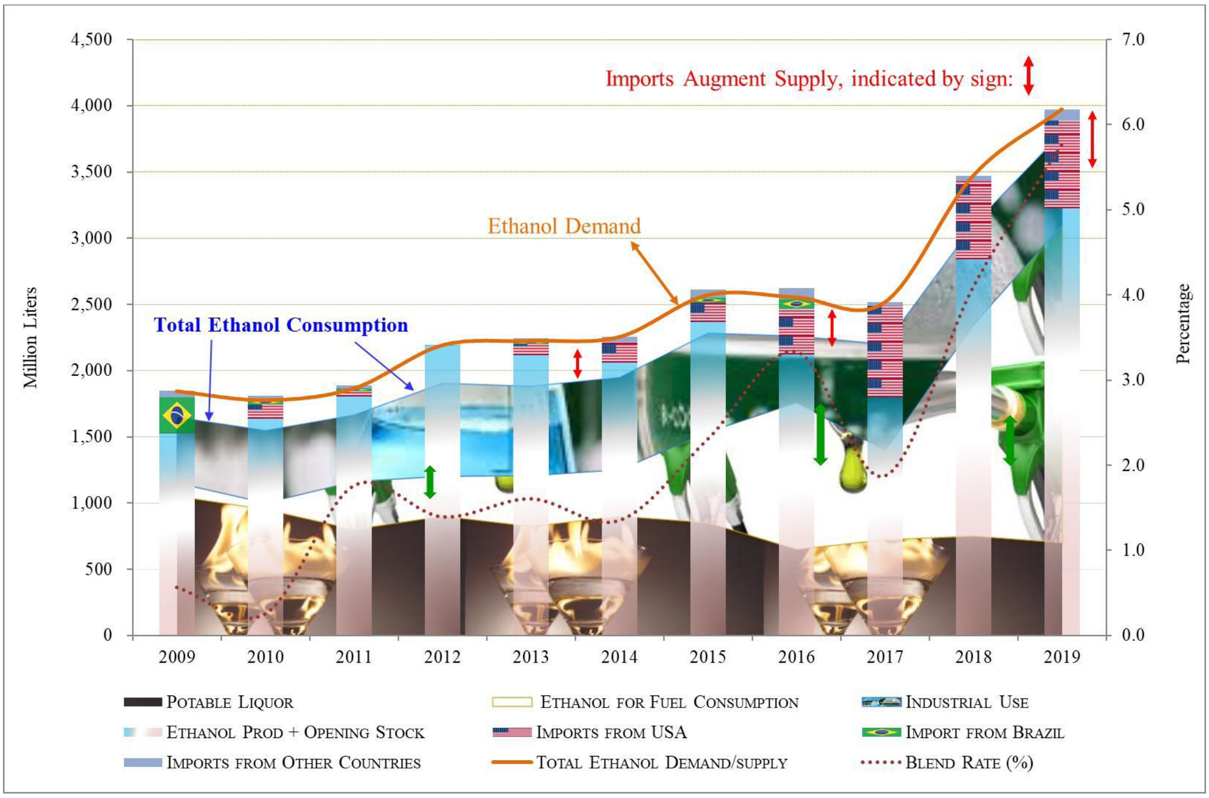


Figure-35: Ethanol/demad/supply, consumption, blend rate and import.

- **Imports**
  - ✓ Although domestic production has risen, India remains a net importer of ethanol (for all end uses).
  - ✓ For the sixth consecutive year the United States is still the single largest ethanol supplier to India.
  - ✓ In calendar year (CY) 2018, Indian ethanol imports (mostly denatured) were down 14 percent to 633 million liters, valued at $269 million.
  - ✓ Despite costlier imports, (INR depreciated 11 percent against the USD), strong local demand for industrial consumption drove Indian imports of U.S. ethanol.

  - ✓ The U.S. ethanol share in the total import basket was down by 4%, but still held a dominant share (94 percent).
  - ✓ Generally, industrial and chemical users in India import ethanol to augment their cumulative demand, particularly when local supply is short.
  - ✓ A recently introduced requirement to obtain an import license to import ethanol (for non-fuel use) may reduce imports temporarily.
  - ✓ While importers scramble to comply with the new import requirements, a few major importers will use existing stocks to cover the shortfallin coming months.
  - ✓ Overall import demand remains high: 2019 imports will grow to upwards of 750 million liters (mostly denatured), the highest in a decade, and the United States will continue to be the largest ethanol supplier to India.
  - ✓ For the record, India imported 718 million liters of ethanol in 2017 worth $280 million, which was the highest volume sourced in the last ten years.
  - ✓ Other small but steady suppliers to India include Pakistan, South Africa, UAE, and UK. (Figure).
  - ✓ China, South Korea, and Netherland are intermittent suppliers. Last year (2018), imports slumped 10 percent to 631 million liters after rising steadily for five years.
  - ✓ Switzerland entered as a new player and supplied almost 4.6% of imports.
- **Exports**
  - ✓ Ethanol exports in 2019 are expected to fall more than 20 percent to 100 million liters (mostly undenatured).
  - ✓ Strong domestic consumption demand (for EBP and industrial use) will limit exportable supply.
  - ✓ Biofuel or fuel grade exports are restricted when domestic supply is less than domestic demand.
  - ✓ Some industry sources indicate that a steady demand from African nations and neighboring countries will keep export sales rolling, albeit in smaller volumes.
  - ✓ In 2018, Nigeria, Ghana, Angola, Cameroon and Nepal were the top five export destinations.
  - ✓ Ethanol suppliers from the United States, Netherland, France, Hungary, Belgium and Spain compete directly with Indian exporters'.

- **Recent Developments w.r.t. Bioethanol in India**

In January 2020, during Brazilian President Jair Bolsonaro's proposed official visit to India, ethanol was on the agenda for discussion. The Brazilian government is expected to offer ways to assist India in boosting its ethanol program, such as increasing production and blending ethanol with petrol, which could help reduce the country' sugar stocks, reduce crude oil imports, reduce pollution in large cities and boost global prices for the sweetener.

Recently, the Union Cabinet, chaired by the Prime Minister Narendra Modi has given the approval for signing of Memorandum of Understanding (MoU) between India and Brazil on Bioenergy Cooperation. This MoU provides a framework to cooperate and promote investment in biofuel, bioelectricity and biogas supply-chains, including feedstock, industrial conversion, distribution and end-use sectors. Few other salient features of the MoU included are reducing greenhouse gas emissions by using Biofuel's Engine and fuel modification that may be necessary for requiring Biofuel blend with fossil fuels.

India has a strong focus in the area of biofuels and stipulated an ethanol blending target of 10 per cent by 2022 and 20 per cent by 2030, while biodiesel blending target has been set at 5 per cent by 2030 when it had announced a new policy on Biofuels in 2018.

Today's global trend towards increased use of environmentally friendly fuels (Ethanol) is likely to gather pace. Brazil which is the second-largest ethanol producer after the United States in the world is home to the world's largest fleet of cars that use ethanol. Ethanol is derived from sugarcane as an alternative to fossil fuel-based petroleum.

India is the second-largest producer of sugar after Brazil in the world and sugar production during the last few years has remained 24-26 million tons. A surplus sugar stock with a stronger financial incentive to convert excess sugar to ethanol should help the oil marketing companies procure upwards of 2.4 billion litres in 2019. This will help to achieve its highest fuel Ethanol blending in petrol penetration at 5.8 per cent, compared to last year's record of 4.1 per cent.

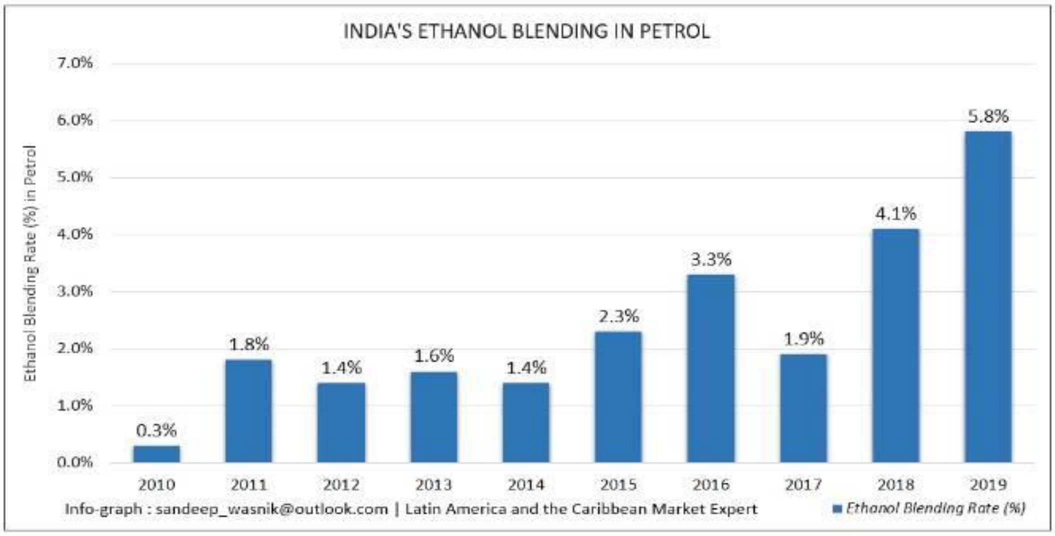
To strengthen the financial condition of sugar mills and cut oil imports, the Government is emphasising on ethanol production. According to the reports, the Centre is planning to reduce the expenditure on oil imports by increasing the ethanol production and blending of ethanol with petrol.

According to a report published in Economic Times, an official from consumer affairs, food and public distribution ministry said, "Government plans to enhance ethanol production capacity to 9 billion litres from 3.55 billion litres in two years. The government has in-principle approved 362 new plants in sugar mills to add capacity of 5.5 billion litres which requires an investment of Rs 18,000 crore."

This will help in meeting the government's target of blending 10% ethanol by 2022. This will reduce the country's import by 2 million tonnes annually reducing bill by Rs 7,000 crore.

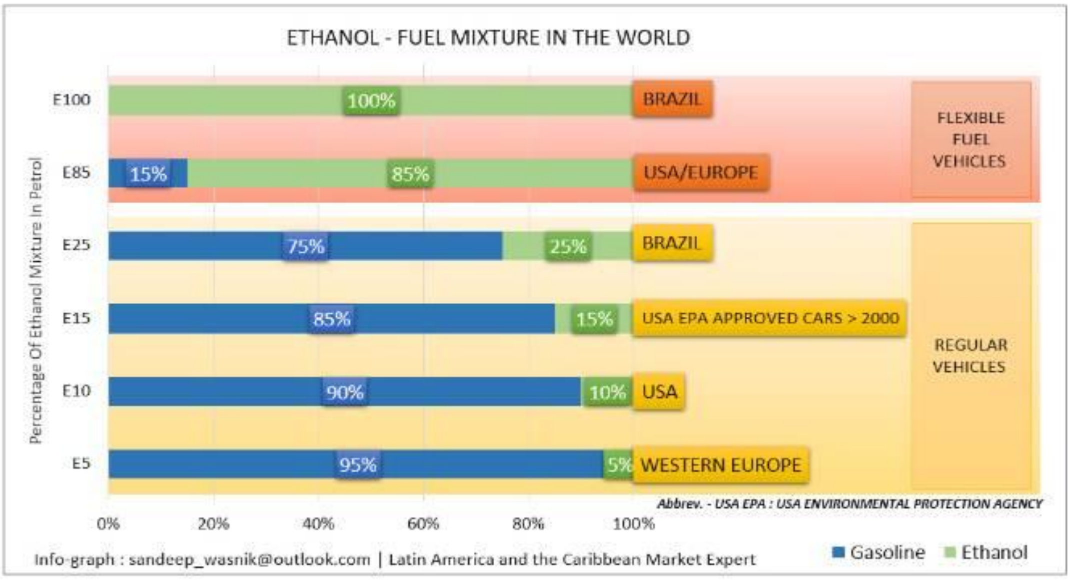
In 2018 in order to assist sugar mills, the Indian government increased the ethanol price from C heavy molasses from Rs.43.46 per litre to Rs.43.75 per litre, and the cost of ethanol from B heavy molasses hiked from Rs.52.43 per litre to Rs.54.27 per litre. Price of ethanol from sugarcane juice/sugar/sugar syrup route was fixed at 59.48 per litre.

As sugar mills in India have been facing issues with depressing sugar prices, surplus stocks and piling cane arrears, experts believe the production of Ethanol will aid sugar mills to improve the financial condition and to clear cane arrears.



INDIA'S ETHANOL BLENDING IN PETROL

Info-graph : sandeep_wasnik@outlook.com | Latin America and the Caribbean Market Expert



ETHANOL - FUEL MIXTURE IN THE WORLD

Abbrev. - USA EPA : USA ENVIRONMENTAL PROTECTION AGENCY

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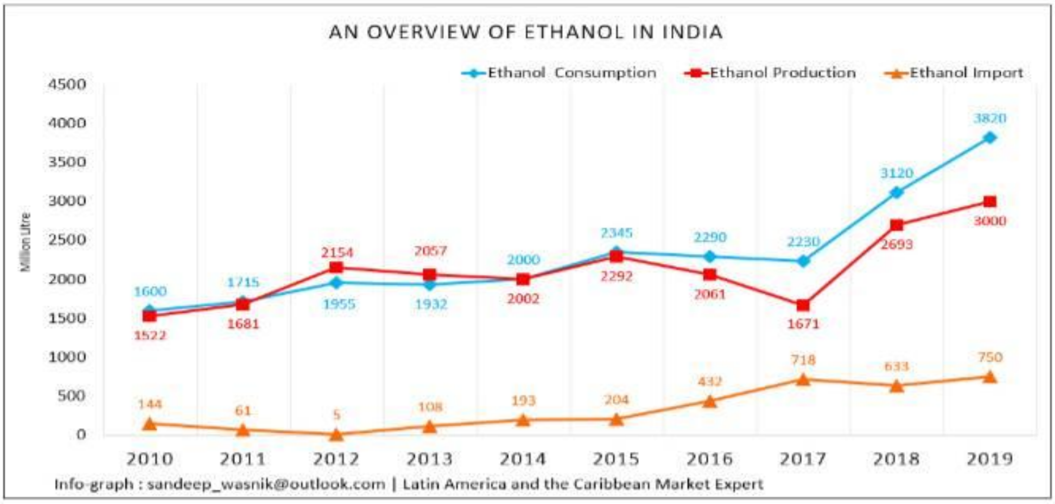

AN OVERVIEW OF ETHANOL IN INDIA

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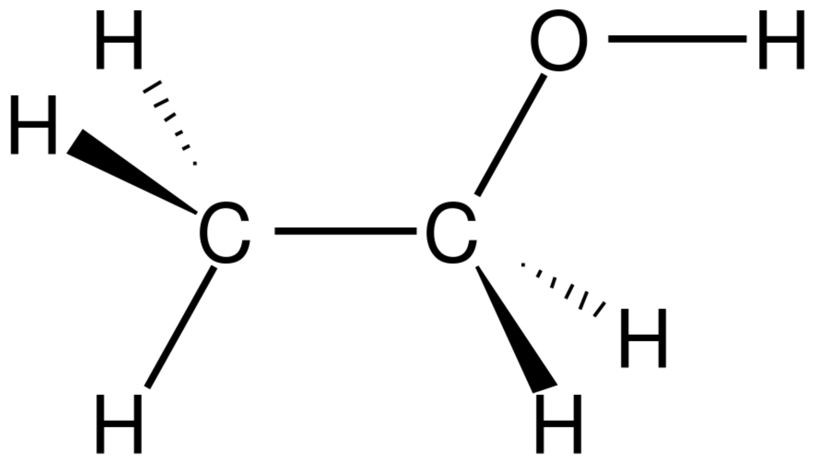
In 2019, the Cabinet Committee on Economic Affairs (CCEA) approved Pradhan Mantri JI-VAN (Jaiv Indian- Vatavaran Anukool fasal awashesh Nivaran) Yojana which aims to provide financial support by Viability Gap Funding (VGF) to Second Generation (2G) Integrated Bioethanol Projects. This is done by using lignocellulosic biomass and other renewable feedstock.

Now, the Indian Automobile sector not only needs to focus on Electric Vehicles (EVs) but also on Flexi-fuel engine. Today, nearly 44.8 million cars are running on Brazilian road, where 75 per cent of the total can run on a mixture of ethanol and gasoline due to its flexible fuel engine. Brazilian flexible-fuel vehicles are optimized to run on any mix of E20-E25 gasoline (E20 contains 20 per cent ethanol and 80 per cent gasoline, while E25 contains 25per cent ethanol) and up to 100 per cent hydrous ethanol fuel (E100).

On the other hand, Indian Automobile sector needs to work on the flexible-fuel engine or flexible-fuel-vehicles technology and safety, which is also helping to reduce greenhouse gas emissions and reduce the hiking in fuel price trend.

BIOETHANOL THE FUTURE PETROL



Ethanol Plant in Turner Country, South Dakota

Ethanol Plant in West Burlimgton, Iowa, USA

Ethanol Plant in Sertaozinho, Brazil

Sugarcane Ethanol Plant in Brazil

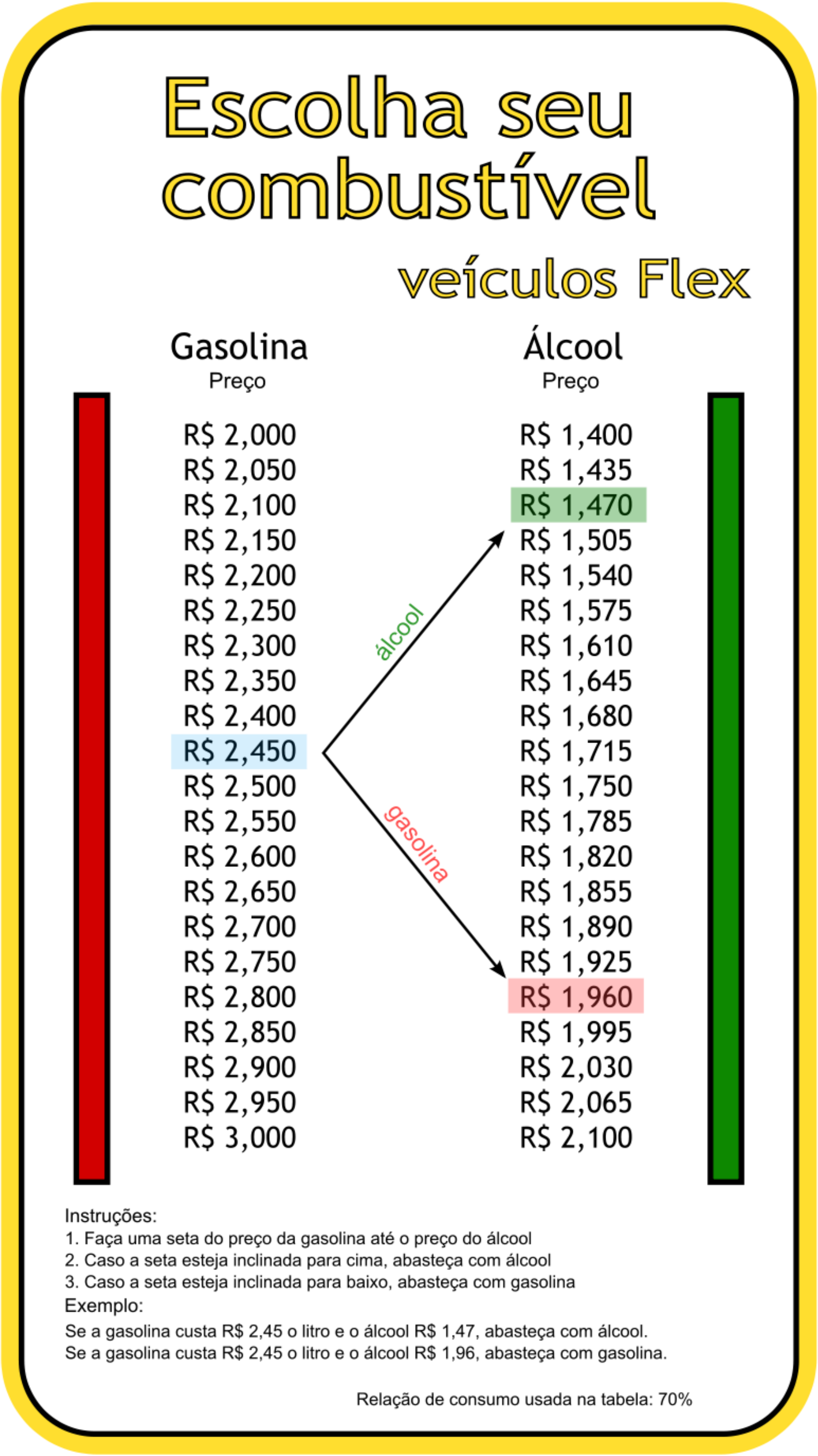
Brazil has ethanol fuel available throughout the country. A typical Petrobras filling station at São Paulo with dual fuel service, marked A for alcohol (ethanol) and G for gasoline.

E85 FlexFuel Chevrolet Impala LT 2009, Miami, Florida.

Typical Brazilian "flex" models from several carmakers, that run on any blend of ethanol and gasoline, from E20-E25 gasohol to E100 ethanol fuel..

The Honda CG 150 Titan Mix was launched in the Brazilian market in 2009 and became the First mass production flex-fuel motorcycle sold in the world.

An example of an ethanol powered bus. This is a Scania OmniCity which has been touring the United Kingdom, which does not use the fuel widely. A larger fleet of similar buses entered service in Stockholm in 2008.



Escolha seu combustível

veículos Flex

Gasolina Preço	Álcool Preço
R$ 2,000	R$ 1,400
R$ 2,050	R$ 1,435
R$ 2,100	R$ 1,470
R$ 2,150	R$ 1,505
R$ 2,200	R$ 1,540
R$ 2,250	R$ 1,575
R$ 2,300	R$ 1,610
R$ 2,350	R$ 1,645
R$ 2,400	R$ 1,680
R$ 2,450	R$ 1,715
R$ 2,500	R$ 1,750
R$ 2,550	R$ 1,785
R$ 2,600	R$ 1,820
R$ 2,650	R$ 1,855
R$ 2,700	R$ 1,890
R$ 2,750	R$ 1,925
R$ 2,800	R$ 1,960
R$ 2,850	R$ 1,995
R$ 2,900	R$ 2,030
R$ 2,950	R$ 2,065
R$ 3,000	R$ 2,100

Instruções:

1. Faça uma seta do preço da gasolina até o preço do álcool
2. Caso a seta esteja inclinada para cima, abasteça com álcool
3. Caso a seta esteja inclinada para baixo, abasteça com gasolina

Exemplo:

Se a gasolina custa R$ 2,45 o litro e o álcool R$ 1,47, abasteça com álcool.
Se a gasolina custa R$ 2,45 o litro e o álcool R$ 1,96, abasteça com gasolina.

Relação de consumo usada na tabela: 70%

Hydrated ethanol × gasoline type C price table for use in Brazil.

ATTENTION

E15

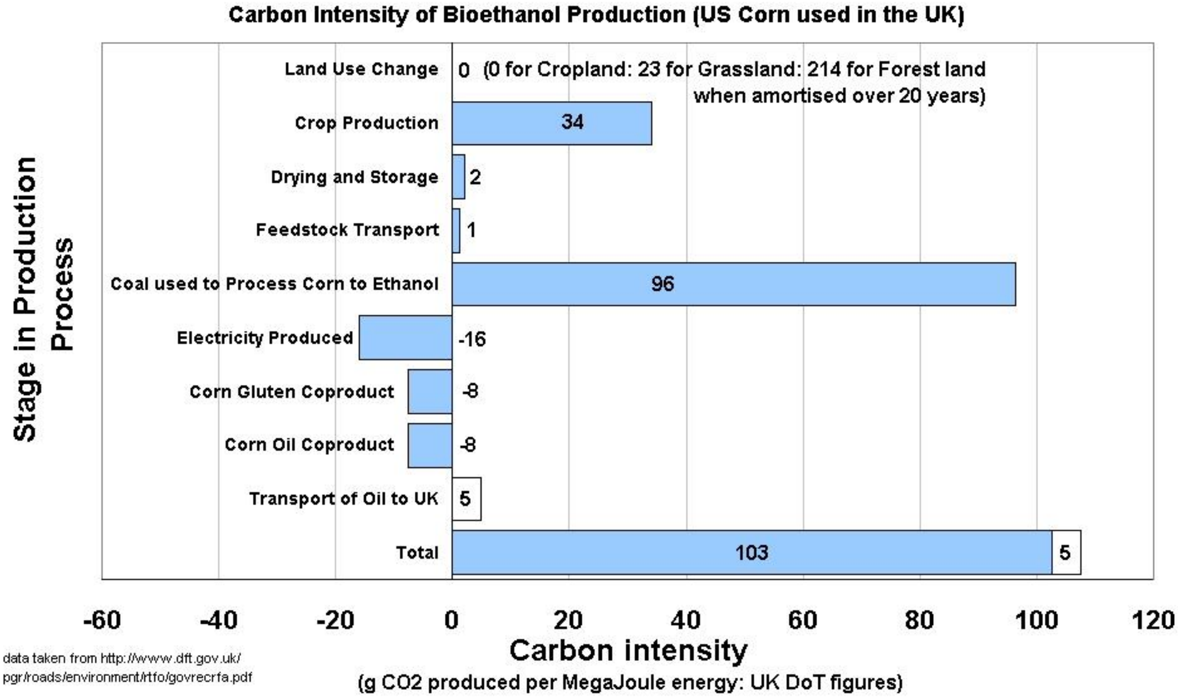
Up to 15% ethanol

Use only in

- 2001 and newer passenger vehicles
- Flex-fuel vehicles

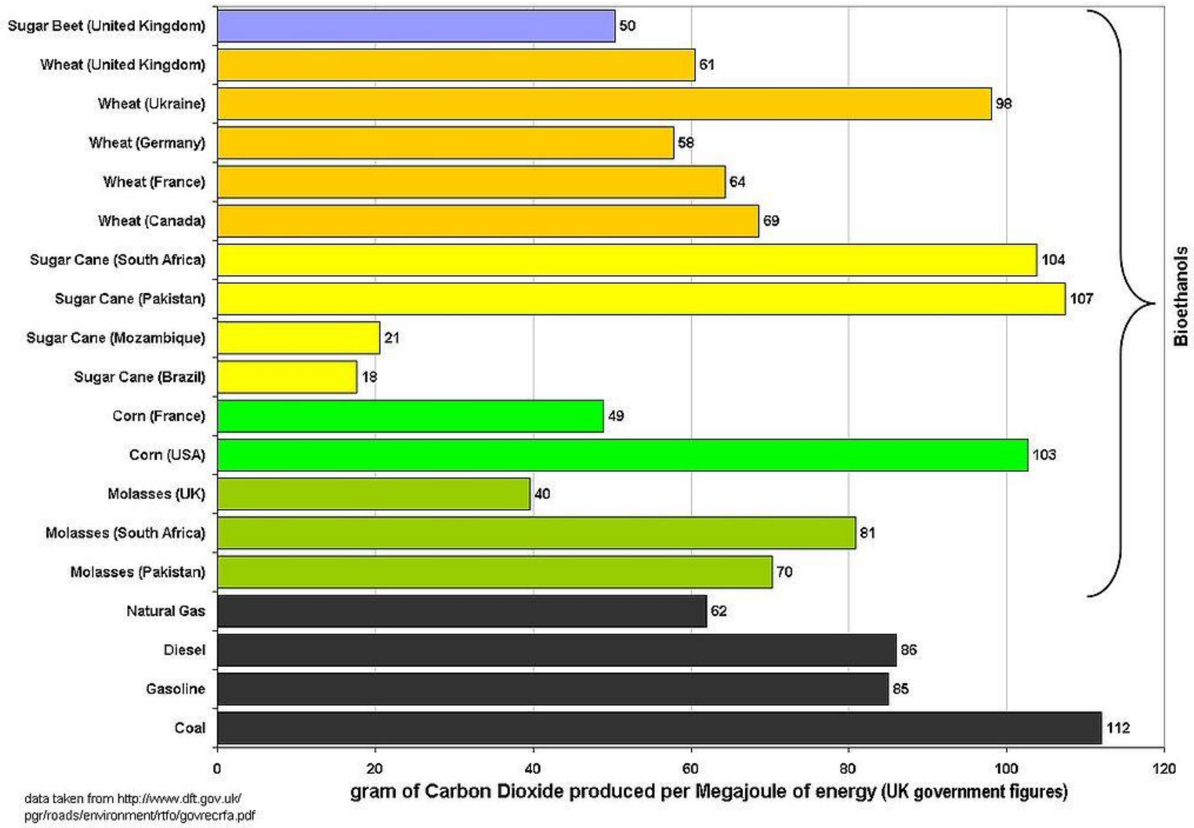
Don't use in other vehicles, boats, or gasoline-powered equipment. It may cause damage and is ***prohibited*** by federal law.

EPA's E15 label required to be displayed in all E15 fuel dispensers in the U.S.



data taken from http://www.dft.gov.uk/pgr/roads/environment/rtfo/govrecrfa.pdf

UK government calculation of carbon intensity of corn bioethanol grown in the US and burnt in the UK.



data taken from http://www.dft.gov.uk/pgr/roads/environment/rtfo/govrecrfa.pdf

Graph of UK figures for the carbon intensity of bioethanol and fossil fuels. This graph assumes that all bioethanols are burnt in their country of origin and that previously existing cropland is used to grow the feedstock.