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First generation biofuel

The first-generation biofuels are the most conventional form of biofuels. They are primarily produced using edible food crops such as grains, sugar crops, and oil seed crops. The annual yield of these crops varies from region to region and thus the global energy supply depends upon their availability (Table in the next slide). The major examples of first-generation biofuels include bioethanol and biodiesel, which are the only biofuels that have been successfully commercialized so far. Bioethanol is usually produced by the yeast Saccharomyces cerevisiae using an anaerobic fermentation process. Apart from the yeast, certain Gram negative bacteria species such as Escherichia coli and Zymomonas mobilis also have been reported as potent microorganisms for bioethanol production. At present, the major bioethanol producers in the world are the United States and Brazil using corn and sugarcane as feedstocks, respectively. The United Kingdom and Australia on the other hand use wheat as their primary feedstock for the starch-based ethanol industry. Government of India, has identified sweet sorghum as an alternative feedstock for ethanol production in India. Besides India, sweet sorghum-based ethanol production is successfully established in China, the Philippines, and Brazil. Another starch-based feedstock for ethanol production is cassava. It is a tropical root crop which contains 22% starch that can be easily hydrolyzed for the ethanol fermentation process. Due to its drought resistant properties, it has been used extensively in Africa, specifically in parts of Nigeria, and Thailand for bioethanol production.

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Yields of Major Crops and Their Theoretical Energy Potential in the World

Crop	Yield (tons/ha)					World	
	Africa	America	Asia	Europe	Oceania	Yield (tons/ha)	Energy Potential (EJ)
Maize	2.10	7.72	5.0	6.89	5.62	5.62	5.05
Rice	2.31	4.15	4.65	7.33	3.82	3.89	2.05
Wheat	1.75	2.92	3.13	4.25	3.31	3.31	2.46
Barley	1.37	3.28	1.78	3.69	2.91	2.92	0.42
Millet	0.63	1.75	1.36	1.40	0.90	0.90	0.16
Sorghum	0.99	3.79	1.30	3.53	1.53	1.53	0.33
Rapeseed	1.42	1.92	1.57	3.16	2.04	2.04	0.91
Soybean	1.26	2.95	1.31	1.75	2.61	2.62	1.61
Oil palm	4.19	14.9	18.3	0.00	14.7	14.7	0.13
Cassava	11.2	8.42	13.3	21.9	10.2	10.2	0.12
Sugarcane	64.4	67.8	67.8	81.0	69.5	69.5	0.29
Sugar beet	53.8	53.1	53.1	62.0	60.3	60.3	0.21

Source: World Bioenergy Association, WBA Global Bioenergy Statistics 2014, In *World Bioenergy Association*, http://worldbioenergy.org/uploads/WBA GBS 2017_hq.pdf, Accessed May 3, 2018.

The potential of these starch- and sugar-based crops for biobutanol production also has been investigated. Butanol has more **advantage** over ethanol as it has a higher octane number, higher energy density, and it is a direct substitute for gasoline. Butanol is produced by fermentative bacteria such as Clostridium sp. using the acetone-butanol-ethanol (ABE) pathway.

In contrast to the bioalcohols, biodiesel is produced by the transesterification of animal fats or plant oil in the presence of a homogeneous or a heterogeneous catalyst. Biodiesel can serve as a direct substitute for petroleum diesel and can be used in diesel engines either directly or with minute modifications. **Germany** and **France** are the two largest producers of biodiesel using rapeseed oil as feedstock, whereas the **United States** and **Canada** use soybeans for biodiesel production.

However, it is observed that production of both crops might not be enough to meet the energy demands of the future.

Palm oil is another potential feedstock for biodiesel used by **Malaysia** and **Indonesia** that has brought economic benefits to both countries. Selection of feedstock for biodiesel production is much more difficult compared to bioalcohols production because several criteria must be met. For example, the water content must be less that 1% to avoid soap production during transesterification process. The free fatty acids must be less than 0.5%. The phosphorus and sulfur content must be less than 10 and 15 ppm, respectively. High contents of saturated and monounsaturated fatty acids must be present with low contents of polyunsaturated fattyacids (PFA). Most biodiesel that is available commercially today meet these criteria.

- **Advantages and dis advantages of first generation biofuel**

Despite the successful application of first-generation biofuels, they are associated with a number of constraints and concerns that restrict their use in the commercial market. For example, the growing population and the demand for energy bring out the continuing food versus fuel debate, which concerns negligent use of food crops for fuel production. Furthermore, this use of food crops for fuel production contributes to higher world prices for food and animal feeds. Another major issue is the judicial use of land and water resources for biofuel production. The current production processes use fossil-based power to grow, collect, and process the feedstock, thereby reducing the impact of GHG reduction. The production of first-generation biofuels also has a potential negative impact on the biodiversity and accelerates deforestation. Current production costs make biofuels a more expensive option compared to gasoline even when used in the blended form and thus biofuels are not economically favorable. Since the productions costs and food demands are expected to increase over the coming years, there is limited scope for improvement in the production of first-generation biofuels.

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The second-generation biofuels

To overcome the limitations of first-generation biofuels, second-generation biofuels were developed using forest residues and non-food crop based feedstock. These feedstocks either do not require additional land for producing them or they can be grown using marginal or degraded lands. Thus, they do not compete for arable lands with food or fiber production, thus limiting their impact on edible crops. Furthermore, their impact on CO_2 concentrations is expected to be carbon neutral or carbon negative. Apart from the above characteristic features, the second-generation energy crop must meet several other criteria such as:

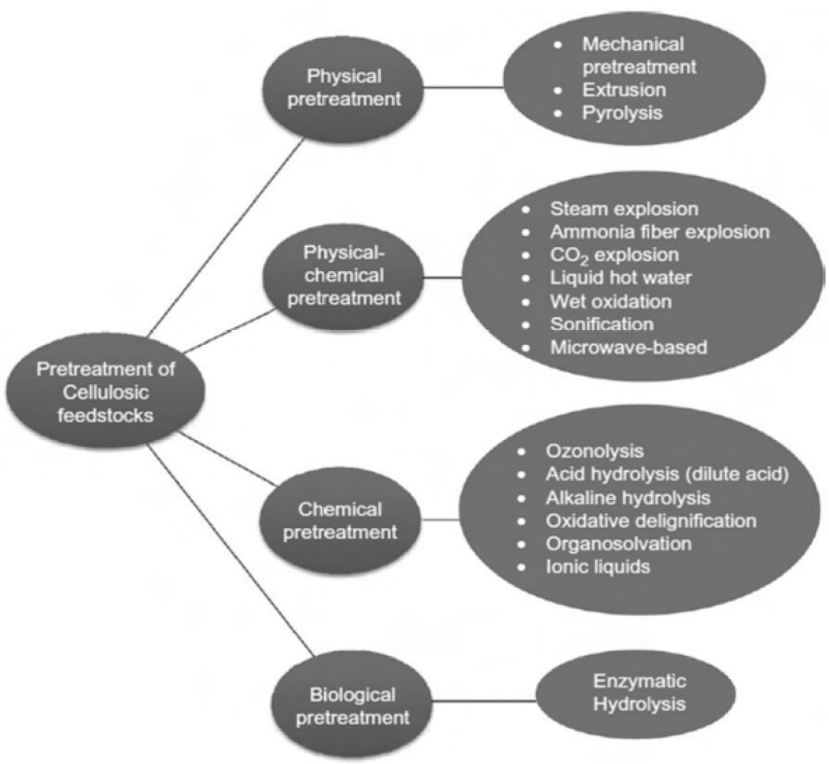
1) being substantially produced,
2) not affecting the biodiversity ecosystem,
3) using water resources efficiently,
4) cultivation being free of exploitation of land owners,
5) ensuring benefit to the national economy of a country.

Satisfying all of the above criteria is a challenge for the selection of the second-generation energy crop. Broadly, the feedstocks used for second-generation biofuel production can be categorized as lignocellulosic feedstocks, dedicated energy crops or short rotation crops, and other waste/residues.

- **Resources of the second-generation biofuel**

1. **Lignocellulosic Feedstock**

Lignocellulosic feedstock is the most abundant renewable feedstock available worldwide with an annual worldwide production of 10–20 billon dry tons. They include biomass-obtained agricultural wastes, wood and forest residues, perennial grasses or trees, and landfill wastes (such as municipal, commercial, and industrial solid wastes). Biochemical conversion of these feedstocks requires pretreatment prior to fermentation so that the complex carbohydrates are accessible to the hydrolytic enzymes or microorganisms. Different pretreatment techniques have been used so far as shown in Figure beside. However, most of these technologies drastically increase the cost of biofuel production.



Lignocellulosic feedstocks are mainly composed of cellulose and hemicellulose polymers interlinked with lignin in a heterogeneous matrix. The combined mass of cellulose and hemicellulose varies from species to species and typically accounts to about 50%–70% of the total dry mass with a significant amount of lignin. The chemical composition of certain agricultural and forest-based lignocellulosic biomass is provided in Table below. Both cellulose and hemicellulose are polymers of sugar moieties which can be hydrolyzed by hydrolytic enzymes. However, lignin is composed of phenolic compounds that inhibit the hydrolysis process. Thus, a biomass with high lignin content is not suitable for biochemical conversion.

Agricultural feedstocks offer significant quantities of low-lignin containing residues with a high potential for biofuel production. These agricultural feedstocks include cereal straw, wheat chaff, rice husk, corn cobs, corn stover, sugarcane bagasse, nut shells, and so on. Biofuels from these residues can be obtained at relatively reasonable costs with limited infrastructure compared to the dedicated cultivation of energy crops with their associated costs such as labor and land. Some of these residues can be concentrated at processing plants (e.g., bagasse, sawmill residues, etc.), while others must be collected and transported (e.g., cereal straw, rice husk, etc.). To further ensure the economic viability of the process, whole crop biorefineries for harvesting value-added products is suggested. For example, the whole crop harvesting of oil seed rape can provide oil for cooking, high protein meal for poultry, and straw for second-generation biofuel production.

Chemical Composition of Selected Lignocellulosic Feedstock

Biomass	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Corn stover	36.9	21.3	12.5
Corn cob	45	35	15
Barley straw	37	44	11
Wheat straw	34	27.6	18
Rice husk	50	–	25–30
Rice straw	37	22.7	13.6
Bagasse	39.7	24.6	25.2
Oat straw	37.1	24.9	15.4
Sorghum straw	35.87	26.04	7.52
Switch grass	31	20.4	17.6
Bamboo dust	41–49	–	25–28
Sawdust	31–64	71–89	14–34
Paddy straw	28–48	–	12–16
Maize stalk straw	38	26	11
Nut shells	25–30	25–30	30–40
Coconut fiber	36–43	1.5–2.5	41–45
Hardwood stems	40–45	18–40	18–28
Softwood stems	34–50	21–35	28–35
Municipal solid waste	21–64	5–22	3–28
Poplar	49	17	18
Eucalyptus	43.3	31.8	24.7
Miscanthus straw	44.7	29.6	21

Another strategy is use of these wastes during the anaerobic digestion process for biogas production. Many biogas plants already have been commercialized and the global market for biogas plants is estimated to reach US$10 billion by 2022 (Global Industry Analysts Inc.). Besides biogas production, these feedstock have shown tremendous potential for biohydrogen production via the fermentation processes such as photo and dark fermentation. These conversion technologies provide the advantage of simultaneous waste treatment along with energy generation.

In recent years, the two-stage anaerobic digestion (i.e., biohythane) process for biohydrogen and biomethane production using organic wastes has gained interest as an alternate renewable source of energy. Although the waste to energy concept is highly attractive, a major hurdle is the separation and the collection of useful residues from the landfill, which makes the process tedious.

2. **Dedicated Energy Crops or Short Rotation Crops**

Energy crops or short rotation crops (SRC) are a subcategory of lignocellulosic feedstocks that are exclusively for accumulating biomass for biofuel production. Most of these crops are densely cultivated to produce ethanol and/or biogas or are combusted to generate heat and electricity. They include the SRCs or short rotation forestry (SRFs) crops such as eucalyptus, poplar, willow, and robinia. They are typically grown in marginal or degraded lands using high yielding varieties. The SRCs are grown in 2- and 4-year rotations with an annual yield of 10 ton hac^{-1} y^{-1}. These yields can be improved further using proper crop management practices. SRCs have several advantages over conventional crops for biofuel production; for example, they can be quickly regenerated after harvesting, they can be steadily supplied to the processing plants avoiding the need for storage, they can provide natural filters to the soil for managing floods or bioremediation of water, and, since the wood processing and harvesting is well established, they can be harvested and transported using the existing technologies. In India, extensive research is being conducted on Jatropha curcas plant seeds (non-edible oil seed) for biodiesel production using SRF-based agroforestry.

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These plant seeds have several advantages such high oil content (40%), carbon neutral nature, and ability to grow in dry marginal, non-agricultural lands unlike soybean, rapeseed, or palm oil. Thus, Jatropha curcas has the potential to provide economic benefits to the country.

However, even with these advantages, none of the crops mentioned in this chapter have been used fully for biofuel production so far because the yields required to reach the desired production scales require substantial time and production costs. A major limitation is the available water content at the cultivation site, which lowers the yielding capacity of these plants. Furthermore, continuous planting and harvesting leads to depletion of soil nutrients.

Like the SRCs, perennial grasses such as miscanthus, switch grass, and prairie grass have been considered as dedicated energy crops. Like SRCs, they can be grown on marginal grazing lands and in arid climatic zones. Additionally, they have beneficial soil effects on degraded lands. They require limited inputs for growing and thus their cultivation is affordable. However, like SRCs, the establishment of dedicated grasslands will require significant time and set up costs. Another major hurdle is the control of pests and diseases, which lower the biomass yields. Also, the selection of a specific species is subjected to biodiversity issues.

3. **Other Waste/Residues/By-products**

Besides the feedstock sources already mentioned, certain wastes and residues such as animal wastes, domestic and industrial wastewater, and by-products of industrial processing plants such as glycerol and molasses are used as feedstocks for second generation biofuel production. Animal wastes are composed of undigested grains and straw which are normally used as fertilizers in farms. The residual animal wastes can be subjected to an anaerobic digestion process for methane production. This form of energy can be readily used on site to satisfy the onsite farm energy requirements thereby reducing the transportation costs. Similarly, the wastewater from sewage or domestic or industrial plants can be used for biogas or biohydrogen production. Molasses, a low-value co-product of raw sugar obtained from sugarcane and sugar beets is extensively used for ethanol production in India, Indonesia, the Caribbean, and other countries. Likewise, vinasse, a by-product of the ethanol distillation process, has been considered a potential feedstock for biogas or biohydrogen production. Glycerol, a by-product of the transesterification process for biodiesel production, is another important feedstock for hydrogen production or for the production of other commercial products. Using these industrial wastes and by-products as feedstocks can provide significant cost reductions to the biofuel production process. However, the main challenge is the composition of these wastes which would vary depending upon the initial source. Thus, reproducibility of the yields obtained is a major concern when these feedstocks are used for biofuel production.

From the previous discussion, it can be speculated that considerable attention has been given over the past few decades to develop second-generation biofuels due to their intrinsic advantages over the first-generation feedstocks. However, although several investments have been made on pilot and demonstration plants, the commercialization of second-generation biofuels is still questionable. It is observed that the feedstock production costs for the harvesting, treating, transporting, storing, and so on and the necessary conversion technologies are the main hurdles that must be overcome for successful implementation of this technology. In addition, the quality and the properties of the biofuel obtained from the second-generation feedstock does not meet the requirement of the consumer and the industry. Since the development and breeding of high yielding second-generation energy crops is currently under extensive research, there is still scope to minimize the production costs and improve the process efficiencies with forthcoming scientific advances.

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