BIOENERGY

3 Bioenergy

3.1 Technology Description

"Biomass" refers to "any material derived from a biological source, the term biofuel refers to the numerous energy products that can be manufactured or processed from biomass feedstock. Biofuels can be solid, liquid, or gaseous.

Feedstock sources

Bioenergy can be produced from different feedstocks. The sun is the source of energy contained in biomass, stored as chemical energy.

- ***Municipal***

A tremendous amount of household waste is collected each year, with the vast majority disposed of in landfills and open fields. The organic content disposed of with waste can be a good source for bioenergy production. Sewage sludge is similar to other animal wastes and can be a source of biomass energy.

- ***Energy Crops***

Plants are specifically planted to be used for energy production. They are treated into biofuels or are directly combusted to generate electricity or heat

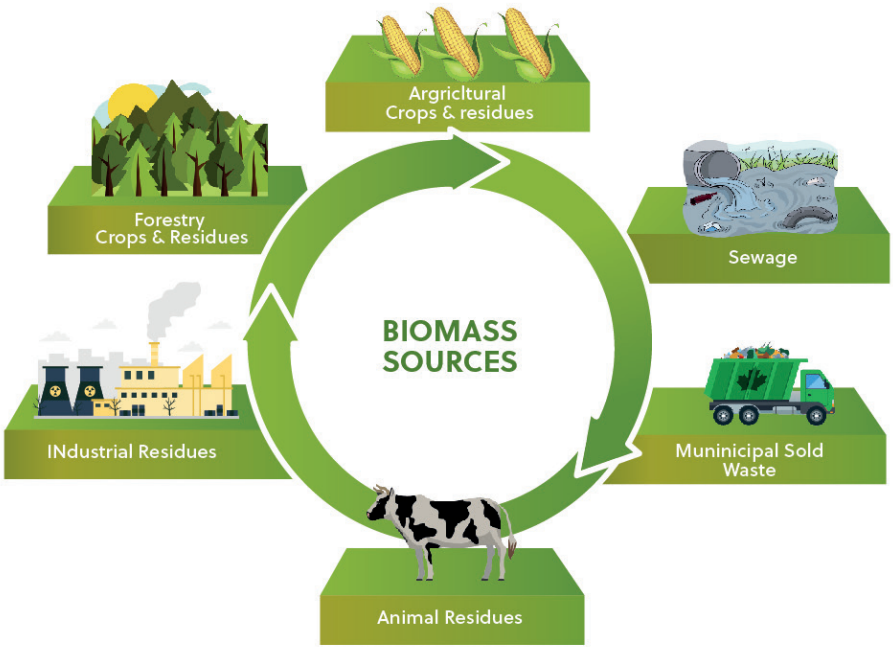

Figure 42: The primary expected biomass sources for biofuel production [47]

- ***Foresty***

Woody biomass comes from trees, bushes, or shrubs. They can be produced by thinning of plantations, clearing for logging roads, and similar regular operations.

- ***Agriculture***

Biomass is unsuitable for direct human food use, such as straw, stalks, leaves, husks, etc., and leftover in the field after the crop portions are used for food production.

- ***Industrial***

A large number of residues and by-products generated from the food industry can be used as biomass energy sources. Liquid wastes can be a good source for biogas production.

- ***Animal manure***

Different animal wastes can be used as feedstock sources. Livestock and poultry manure are the most common sources.

Biomass properties

The properties of biomass feedstock and fuels influence their acceptance, worth, and usability. The source of the feedstock influences biofuel properties in addition to its conversion path.

Feedstock characteristics that have a significant influence on the energy extraction process are:

- ***Moisture content***

Moisture reduces the energy content of the feedstock because it takes energy to remove it. It also corrodes the metal in different equipment.

(47) https://www.intechopen.com/chapters/47727

• Energy content

It represents the energy available in the material per unit mass. Each material has a different value according to its chemical composition and moisture and ash content.

• Bulk density

The term bulk density refers to "the mass of the material divided by the total volume it occupies." The total volume includes external voids and internal pores of the material. The bulk density of biomass changes as the feedstock gets treated.

• Ash content

The amount of incombustible material is called the ash content and is given as a weight fraction of the dry biomass. At high temperatures, the ash might melt, causing the formation of clinker, which affects the performance of the boilers.

• Chemical composition

Carbon and hydrogen content determine the energy content of biomass. At the same time, oxygen supports the combustion process. Other elements such as sulfur, chlorine, and nitrogen assess the pollution level resulting from burning the material.

Conversion Pathways

Biomass can be converted into heat, fuel, gas, and power. Several factors influence the selection of a biomass conversion pathway. These parameters include biomass feedstock quality and quantity, availability, end-product choice, process economics, and environmental concerns.

• Biomass pre-treatment

In general, each of the conversion pathways requires the feedstock to be pretreated by upstream steps. The main pre-treatment technologies are used to increase the energy density of the biomass. The processing gets considerably easier if the feedstock is denser and more homogeneous. Pre-treatment may be as simple as cutting the biomass to a convenient size or processes like heat treatment and enzymatic action.

• Thermochemical Conversion

It involves heat application to change the main structure of biomass to produce intermediate energy carriers or heat.

• Combustion

The direct combustion of biomass is the most common Thermochemical Conversion pathway; the heat produced from the combustion is used for cooking, process and space heating, and power production.

• Thermal gasification

Heat is used to break down biomass feedstock like wood and forest products into synthesis gas. After that, the feedstock is partially oxidized or reformed with a gasifying agent (air, oxygen, or steam), producing synthesis gas (syngas).[49]

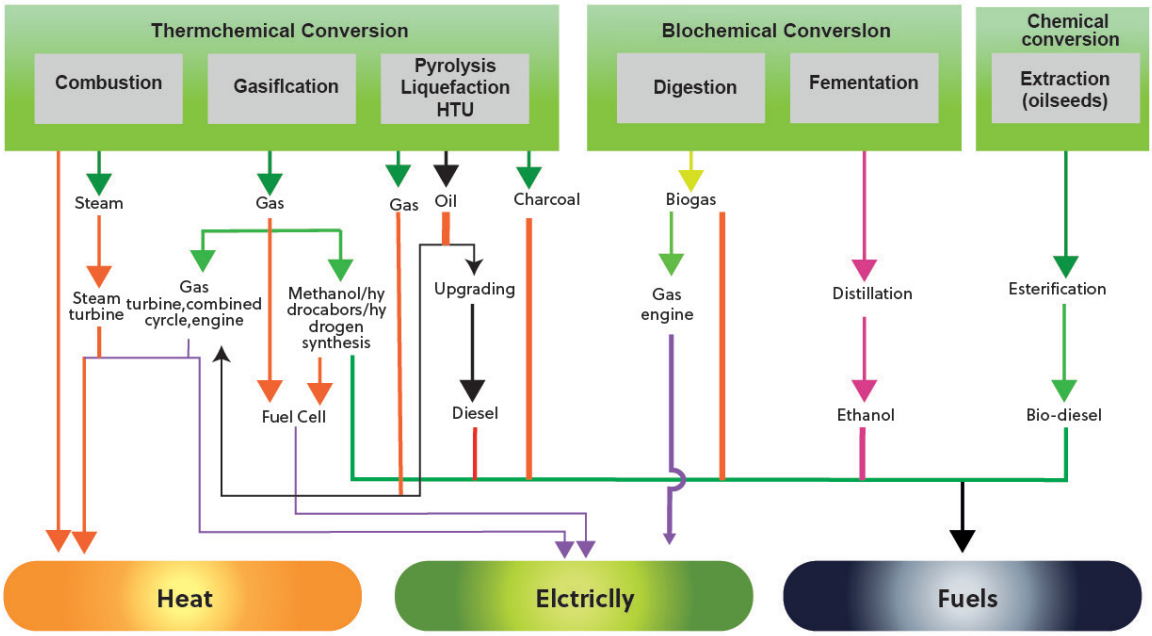

Figure 43: Main Biomass Conversion Routes[48]

(48) https://www.intechopen.com/chapters/73832
(49) https://www.energy.gov/eere/bioenergy/thermochemical-conversion-processes

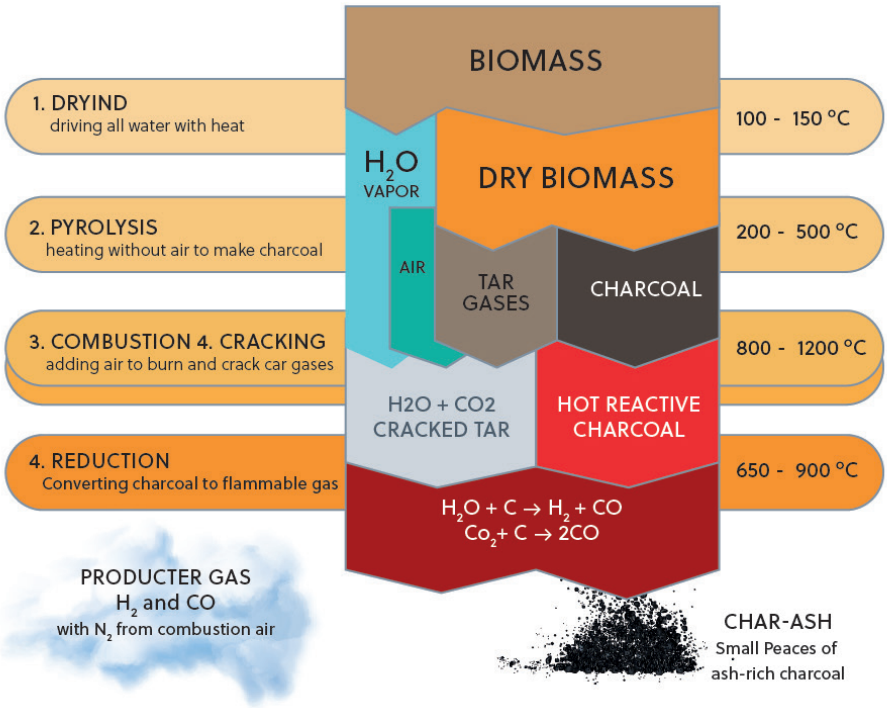

Figure 44: The five processes of gasification[50]

• *Pyrolysis*

Heat is used to break down biomass feedstock in the absence of oxygen, resulting in bio-oil, which can then be processed into a hydrocarbon product. Decomposition occurs at lower temperatures than gasification, and liquid oil is produced instead of synthesis gas.

• *Biochemical Conversion*

The main principle is to convert the carbohydrate portion of the biomass into an intermediate sugar stream, which can then be fermented or chemically catalyzed into a range of advanced biofuels, through the use of biocatalysts, such as enzymes, in addition to heat and other chemicals.[51]

• *Anaerobic Digestion*

Anaerobic digestion is a biological breakdown of the organic matter in which microorganisms do the work in the absence of oxygen. The organic matter came from animal waste, wastewater, biosolids, and food wastes. In order to produce biogas, anaerobic digestion takes place in a sealed vessel called a reactor. [52]

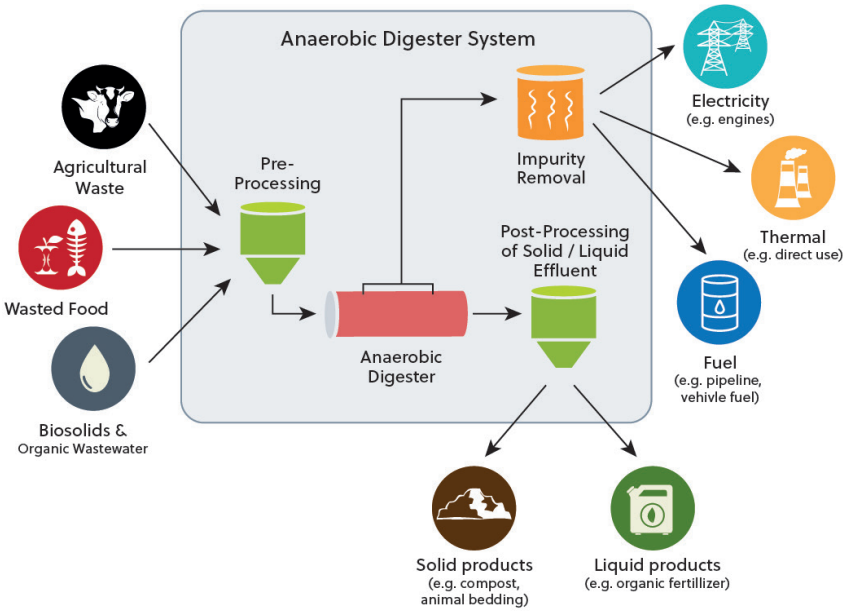

Figure 45: Anaerobic Digestion Schematic Diagram [53]

(50) All Power Labs (APL). How does Gasification Work; Available online at: http://www.allpowerlabs.com/gasification-explained
(51) https://www.energy.gov/sites/prod/files/2014/04/f14/biochemical_four_pager.pdf
(52) https://www.epa.gov/agstar/how-does-anaerobic-digestion-work
(53) https://www.tn.gov/environment/program-areas/sw-mm-organics/anaerobic-digestion.html

• *Fermentation*

Biochemical mechanisms could be used to convert biomass into alcohols during fermentation. These paths included a number of different schemes for carrying out the hydrolysis and fermentation processes.

Types of Biofuels [54]

• *Solid*

Organic, non-fossil material of biological origin may be used as fuel for heat production or electricity generation, such as fuelwood, wood residues, wood pellets, animal waste, vegetal material.

• *Liquid*

Includes all liquid fuels produced from biomass and the biodegradable fraction of waste, suitable to replace liquid fuels or blend with it, such as biogasoline, biodiesel, and bio-jet kerosene.

• *Gaseous*

The gas is produced from landfills, sewage sludge, anaerobic digestion thermal processes. It is composed principally of methane and carbon dioxide.

Fuel Standards

The European Union (EU) initiated the development of fuel standards, which are currently being converted into international standards. These standards should be implemented since this will affect the marketability of the products. Each country may have its standards depending on the national requirements. [55]

3.2 Design consideration

• *Feedstock Assessment and Analysis*

The identification and quantification of feedstock composition and key properties should be identified. These are:

• *Type of feedstock:*

If it is a by-product of a process or purpose-harvested such as energy crops.

• *Annual volume available*

• *Moisture content:*

The need for feedstock drying will be determined; Biomass with high moisture content is usually preferred for anaerobic digestion, pyrolysis, or biofuel production, whereas dry solid biomass is preferred for combustion or gasification.

• *Availability:*

If the feedstock is continuous, year-round, or seasonally available. In addition to the projection for the Long-term availability.

• *Feedstock Pre-treatment*

Depends on the composition of the feedstock, the conversion pathway requires specific properties which can be reached by designing the pre-treatment process. Pre-treatment is necessary to avoid process failures and to boost process efficiency.

• *Technology Selection*

Bioenergy carriers can range from simple firewood blocks for residential heating to a highly refined liquid transport fuel for blending in large volumes. The selection of location and feedstocks determine the specific technology needs.
The assessment and selection of the most suitable technology for each purpose and/or application must consider a number of factors:

• *The scale of operation:*

Design small scale systems consider fewer variables in comparison with medium and large scale.

• *The expected specification of the product:*

Each product must have a market. The production process must comply with the market standards and specifications.

• *Feedstock:*

The available feedstock may not match the specifications of the technology; it is essential to know the pre-requisites and specifications for the feedstock so the needed modifications are determined.

3.3 Advantages and disadvantages

Advantages

• A wide range of proven, mature technologies is available for converting biomass into heat, electricity, and biofuels.

• It is renewable since the organic matter used to produce biomass is infinite, the waste, wood, and manure are consistently produced.

• Diverting waste to biomass energy plants instead of landfills saves the environmental and economic costs of disposal and reduces contamination risks.

• Biomass energy power plants are dispatchable; the energy can be stored; bioenergy is not intermittent or variable, unlike other renewable energy sources.

• Bioenergy provides a use for waste streams, which adds value and revenue stream for different businesses.

(54) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Biofuels
(55) IRENA (2017), IRENA Project Navigator – Technical Concept Guidelines for Solid Biofuels from Woody Biomass, International Renewable Energy Agency, Abu Dhabi.

• Energy crops can be irrigated and fertilized with sewage water and grown in areas that benefit from the additional vegetation cover.
Disadvantages

• The use of waste increases the quantity of methane emissions released into the atmosphere, which is also harmful to the environment. Additionally, pollution produced by burning wood and other natural materials is comparable to the pollution produced by burning conventional fuels.

• Land intensive, bioenergy plants and energy crops have a large footprint and require a lot of space. Also, storing and processing biomass might need a large space.

• In specific cases, bioenergy may compete with food production or can lead to deforestation

3.4 Applications

Biomass for Heat Applications[56]

Producing heat from biomass is well established. Commercially available systems include small-scale systems for Residential applications and drying crops application, through to very large industrial systems for process and district heating.

• Residential application

The Direct combustion of woody feedstock has been practiced since the beginning of civilization and remains by far the most important biomass conversion technology in terms of global energy supply.

• Industrial and commercial systems

The industrial sector has the potential to be a significant market for biomass heating; the use of boilers in the 0.5 to 10 MW range is very common in industrial processes, and it can be fed with large amounts of biomass.

Power generation

Biomass can be converted into electricity through several methods. Direct combustion of biomass material is the most common. Similar to fossil fuel power generation systems, biomass has the advantage of dispatchability.

Pretreated biomass is the boiler fuel in a direct combustion system, creating steam to power the turbine and generator.

Using the generated steam for heating and power production at the same time, which is called combined heat and power, increases the overall energy efficiency of the process.

Transport

Ethanol, Methanol, Biodiesel, Biocrude, and Methane are – liquid and gaseous fuels that can be produced from biomass through different conversion pathways; in general, biomass is the primary renewable resource used to generate liquid fuels for transportation.

Figure 47: MENA Region's Largest Biodiesel Refinery in Dubai[58]

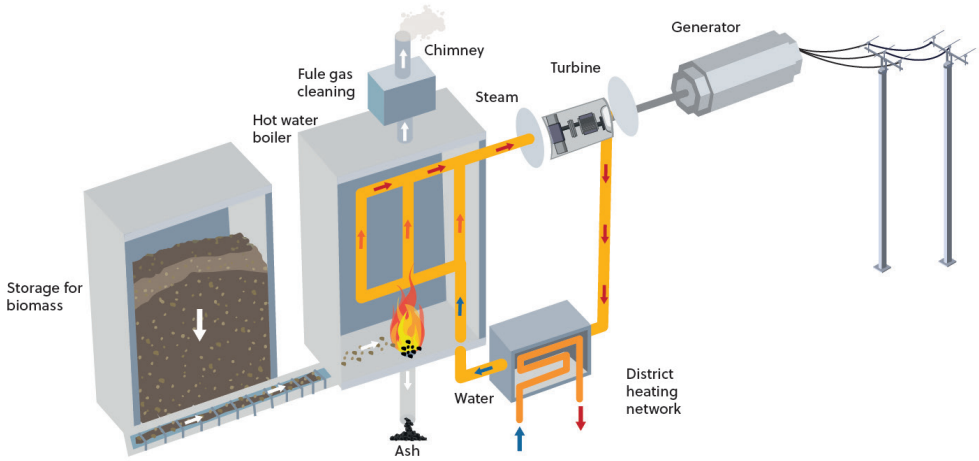

Figure 46: Large Scale Combined Heat and Power Application

(58) https://www.globenewswire.com/en/news-release/2021/09/07/2292776/0/en/MENA-Region-s-Largest-Biodiesel-Refinery-Starts-in-Jebel-Ali.html

Biofuels are usually classified into 'generations' based on their stage of development and the feedstocks they consume; however, there is no universally accepted classification.[59]

First-generation biofuels include mature technologies for producing bioethanol, biodiesel, biomethane from sugar, starch crops, and oil crops and animal fats, and wet biomass. Respectively.

Second-generation biofuels based on new and non-edible feedstocks. These include bioethanol and biodiesel produced from conventional technologies but based on novel starch, oil, and sugar crops such as Jatropha, and cassava and a range of conventional and novel biofuels (e.g., ethanol and butanol) produced from lignocellulosic materials (i.e., fibrous biomass such as straw, wood, and grass).

Third-generation or advanced biofuels generally include biofuel production routes at the research and development stage, such as biofuels from algae, hydrogen from biomass.

3.5 Projects

Biomass combustion for industrial process heating at Midabriq

Location: Morocco

Capacity:

Project Brief

- Midabriq has installed a biomass boiler that mainly uses olive pomace as a feedstock, replacing 100% of its fuel oil consumption.[60]
- The costs per MWh dropped by around 65%

Status: Operational

Small Biogas Pilot Unit in Zaatari Camp[61]

Location: Jordan

Capacity:

Project Brief

- Co-digestion is used in the biogas pilot unit, where organic waste from the solid waste separation plant is mixed with sewage sludge from the Waste Water Treatment Plant (WWTP).
- Movable unit

Status: Operational

3.6 Further Readings

Technology

Good Practice Guidelines, Bioenergy Project Development and Biomass Supply, IEA. 2007.
Link:*https://www.ieabioenergy.com/wp-content/uploads/2013/10/Good-Practice-Guideines-Bioenergy-Project-Development-and-Biomass-Supply.pdf*

IRENA (2019), IRENA Project Navigator-Technical Concept Guidelines for Biogas Projects, International Renewable Energy Agency, Abu Dhabi.
Link: *www.irena.org/navigator, free registration*

IRENA (2017), IRENA Project Navigator – Technical Concept Guidelines for Solid Biofuels from Woody Biomass, International Renewable Energy Agency, Abu Dhabi.
Link: *www.irena.org/navigator, free registration*

IRENA (2018), Solid biomass supply for heat and power: Technology brief, International Renewable Energy Agency, Abu Dhabi.
Link: *https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Solid_biomass_supply_2019.pdf*

(59) Bauen, Ausilio, Göran Berndes, Martin Junginger, Marc Londo, and François Vuille. 2009. Bioenergy – A Sustainable And Reliable Energy Source. IEA Bioenergy.
(60) https://www.beralmar.com/en/news/show/id/60
(61) http://www.fao.org/3/cb2340en/CB2340EN.pdf

RENEWABLE ENERGY TECHNOLOGY

BIOENERGY

TECHNOLOGY DESCRIPTION

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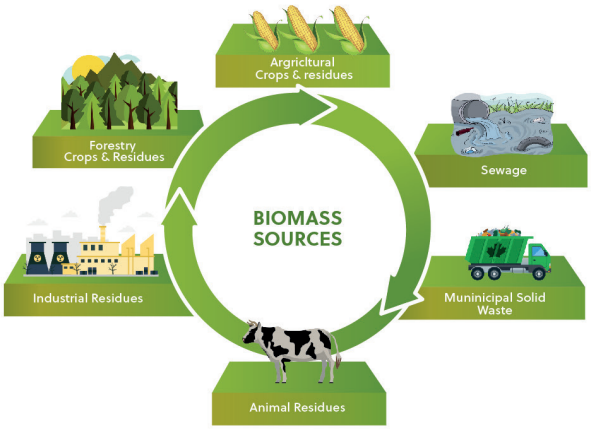
FEEDSTOCK SOURCES



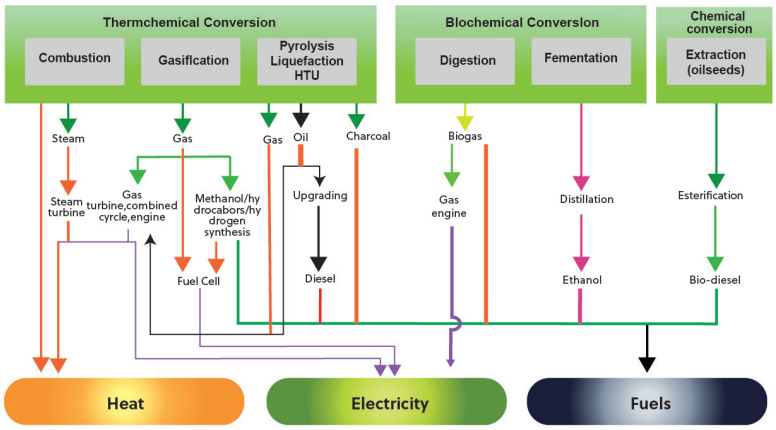
BIOMASS PROPERTIES

Feedstock characteristics that have a significant influence on the energy extraction process are:

- Moisture content
- Energy content
- Bulk density
- Ash content
- Chemical composition

CONVERSION PATHWAYS

Biomass can be converted into heat, fuel, gas, and power. Several factors influence the selection of a biomass conversion pathway. These parameters include biomass feedstock quality and quantity, availability, end-product choice, process economics, and environmental concerns.



TYPES OF BIOFUELS

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• Feedstock Pre-treatment

Depends on the composition of the feedstock, the conversion pathway requires specific properties which can be reached by designing the pre-treatment process.

• Technology Selection

The assessment and selection of the most suitable technology for each purpose and/or application must consider a number of factors:

- The scale of operation
- The expected specification of the product:
- The available Feedstock

ADVANTAGES	POINTS TO CONSIDER
• A wide range of proven, mature technologies is available for converting biomass into heat, electricity, and biofuels. • It is renewable since the organic matter used to produce biomass is infinite. • Diverting waste to biomass energy plants instead of landfills saves the environmental and economic costs of disposal and reduces contamination risks. • Biomass energy power plants are dispatchable. • Bioenergy provides a use for waste streams. • Energy crops can be irrigated and fertilized with sewage water and grown in areas that benefit from the additional vegetation cover.	• The use of waste increases the quantity of methane emissions released into the atmosphere. • Land intensive, bioenergy plants and energy crops have a large footprint and require a lot of space. • In specific cases, bioenergy may compete with food production or can lead to deforestation.

APPLICATIONS

- Biomass for Heat Applications
- Power generation
- Transport

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