DESUWOW

DEvelopment of professional Skills for the use of Urban solid Wastes and Organic Wastes in agricultural

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IO2

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Chapter 1 - Introduction Biomass-to-Energy

About

This chapter will provide some knowledge and information related to biomass and its conversion to energy. As biomass comes from sustainable sources, it is still necessary to have a better understanding on how to convert it sustainably. This chapter will provide introduction to biomass and all the processes involved to the system and project management.

There are some objectives in this chapter:

- Understand about what is biomass and its sources in general overview
- Understand the importance of the conversion of biomass-to-energy
- Understand the general concept of the biomass-to-energy
- Understand the sustainability approach in biomass conversion

Background

The Fit-for-55 package by the European Commission is a series of legislative proposals to deliver the European Union's increased climate target by reducing 55% of emissions by 2030. This package includes a higher target and new rules to support the expansion of renewables, including renewable energy resources. Also, the European Union (EU) has set ambitious climate and energy targets for 2030, including an EU-wide target for renewable energy from 32% to 40% of final energy consumption.

In 2020, the European Union renewable energy share is 21.3% (European Environment Agency, 2021). According to the European Environment Agency, that number means the EU has reached the target of 20% of renewable energy share for 2020. The constant improvement and progress on renewable energy production is a necessity as the new target of final energy consumption for renewable energy is 40% in 2030. According to the EU's Energy Factsheet, 75% of total greenhouse gases emissions in the EU comes from the energy sectors, so with the increase of renewable energy production will reduce the GHG emissions itself.

Sustainable bioenergy reinforced criteria in line with the EU Biodiversity Strategy for 2030 is:

- Prohibit sourcing biomass for energy production from primary forests, peatlands and wetlands
- No support for forest biomass in electricity-only installations as of 2026
- Prohibit national financial incentives for using saw or veneer logs, stumps and roots for energy generation
- Require all biomass-based heat and power installations to comply with minimum greenhouse gas saving thresholds
- Apply the EU sustainability criteria to smaller heat and power installations (equal or above 5MW)

Biomass

Biomass is organic, meaning it is made of material that comes from living organisms, such as plants and animals. Biomass comes from diverse resources which includes the residues of the wood working industry, energy crops, agriculture and agri-food effluents, organic fraction of municipal solid waste, household waste and sewage sludge from wastewater treatment plants.

Biomass from **agriculture** can include crop residues, bagasse, animal waste, energy crops, etc, **forestry** can include logging residues, wood processing by-products, black liquor from the pulp and paper industry, fuelwood, etc, and **other types of biological waste** which can include food waste, food industry waste, the organic fraction of municipal solid waste, organic household waste, etc.

Biomass for energy (bioenergy) utilisation must be produced, processed and used in a sustainable and efficient way in order to optimise greenhouse gas savings and maintain ecosystem services. The biomass utilisation especially for energy purposes must be implemented without causing deforestation or degradation of habitats or loss of biodiversity. The environmental performance of a bioenergy value chain and processes greatly depends on the different steps of the pathway, from the growing and harvesting of feedstocks, to the processing, conversion and distribution of bioenergy carriers, to the final energy use. Consequently, sustainability needs to be assessed on a case-by-case basis.

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The Importance of Biomass

Biomass has versatile characteristics which can be applied to several applications, such as heat, electricity and fuels. As biomass generated from renewable sources, it will make the biomass utilisation more sustainable. If the production of biomass is implemented in sustainable ways, it will reduce greenhouse gas emissions as it is a carbon-neutral carrier. Other than the impact of biomass to the environment, biomass will improve economy and energy security.

Bioenergy can play a significant role in achieving the EU targets in terms of renewable energies by 2030 and beyond. Opportunities to increase the utilisation of bioenergy are seen e.g. in the field using agricultural residues, by-products and waste. Bioenergy can also play an important role as a flexible energetic carrier to balance the power systems and thus allowing for higher shares of renewable energy sources such as wind and solar power. Also with sustainable practices, bioenergy can contribute to ensuring environmental aspects like securing biodiversity or maintaining ecosystem services, among other things; greenhouse gas savings, sustainability and rural development.

Biomass is also one of the important sources which can be used as a renewable energy resource which can support European Green Deals. In 2017 the European Commission released a final report for the sustainable and optimal use of biomass for energy in the EU. In 2021, the European Commission proposed a revision of the Renewable Energy Directive to strengthen the sustainability criteria of biomass utilisation to energy. There are targets which aim to achieve in national levels as it follows (European Commission, 2021):

- Buildings, a new benchmark of 49% renewables use by 2030
- Industry, a new benchmark of a 1.1 percentage point annual increase in renewables use
- Heating and cooling, the existing indicative 1.1 percentage point annual increase becomes binding on Member States, with specific indicative national top-ups
- District heating and cooling, an indicative 2.1 percentage point annual increase in the use of renewables and waste heat and cold (an increase from the current 1.0 percentage point increase)
- Transport sector, the proposal introduces a target for reducing the greenhouse gas intensity of transport fuels by 13% by 2030.

The advanced and more sustainable utilisation of biomass for energy is important to achieve those proposed targets by the European Commission.

Sustainability in Biomass Utilisation

Biomass is an attractive energy source which is continuously available on Earth. Bioenergy can become a clean, reliable and sustainable energy source. Also, bioenergy plays a key role towards delivering the EU climate and energy objectives. As a part of the European Green Deal, the European Commission raises the prospects of increased reliance on biomass sources for energy – and hence biomass use. There are some impacts related to bioenergy production. Bioenergy can help to reduce greenhouse gas emissions (GHG).

Also, it will provide economic benefits to society, like creating new jobs and as well as affordable energy sources. However, sustainability is not only about the environmental aspect, it is also about social and economic aspects.

Environmental Impact

According to Institute for European Environmental Policy (2021), environmental sustainability is therefore understood the context of two fundamental principles:

- The first is to recognise and reward biomass left in its living form (for ecosystem resilience and natural carbon sinks) as providing an important contribution to the EU's green deal objectives;
- The second is where biomass is harvested and used, to ensure the protection of the ecosystems from which that biomass arises and without which there would be no enduring supply.

Based on several existing assessments of understanding and estimating the sustainable biomass supply, the following conditions need to be considered when mobilising biomass resources in a sustainable manner:

- Land availability and competing land uses, as well as land management, such as intensity of production. This includes indirect land use changes through displacement. Areas dedicated to food, feed and fibre production should be excluded.
- Impact on carbon cycles, by removing biomass that would otherwise continue to accumulate carbon in situ.
- Impact on other environmental objectives (other than climate mitigation) through biomass cultivation and extraction, such as water requirements for growth, or loss of soil nutrients and structure where excess residues are removed.

The production of agricultural biomass can result in negative impacts on soils (e.g. loss of nutrients and soil organic matter, erosion, peatland drainage), water availability (in particular in water scarce areas) and biodiversity. The European Commission's study in 2013 concluded that "considerable potential risks to sustainability from biofuel cultivation exist, particularly risks to soils and to water quality and water availability". The use of agricultural residues (for example: straw) can also cause negative impacts on soils such as fertility and structure, and on biodiversity if extracted in excessive amounts. On the other hand, the use of waste to produce biogas can significantly reduce methane and other emissions. That is the reason why control and regulation is important to produce bioenergy.

However, to ensure sustainability in the bioenergy production reinforced criteria in line with the EU Biodiversity Strategy for 2030 is:

- Prohibit sourcing biomass for energy production from primary forests, peatlands and wetlands
- No support for forest biomass in electricity-only installations as of 2026
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Economic Impact

According to the European Commission (2016), there are some impacts of the economic aspect in the bioenergy production:

- Contribution to gross added value - This positive impact on gross added value is a combination of:
    - a positive "deployment effect": the increase in other renewable energy sources leads to more investments and therefore a larger positive impact in the economy as a whole
    - a positive "income effect": the additional jobs created by this shift leads to additional income for households, which is spent in consumption
    - a negative "indirect effect": other renewable energy sources require a higher level of public support, either directly through subsidies, or through feed-in tariffs. This can impact consumers, if the feed -in tariffs is directly passed on to them through an increase in energy prices, or if the subsidies are financed through an increase in taxation: in both cases, household consumption would go down. Increased support for other renewables can also be made available by giving less public support to other sectors, which will also have a negative economic impact.
- Impact on small and medium-sized enterprises (SMEs) - SMEs and micro-firms are widely represented in bioenergy production and use chain through, in particular, small forest owners and small bioenergy installations. In the baseline, SMEs in the forestry sector might be affected by national schemes. It is unlikely however that those SMEs would have to comply with several national schemes given their likely range of operations.
- Impact on rural development - Positive impacts on rural development can occur in cases where additional bioenergy demand incentivises more intensive harvesting of EU forests and use of EU agricultural feedstocks (rather than e.g. increasing imports or diverting industrial residues from other uses). This will be mostly driven by the market and/or by relevant subsidy schemes in each region. It can also be influenced at EU level by e.g. support to wood mobilisation under the Rural Development Programmes.
- Impact on the internal market and intra-EU trade
- Impact on external trade - decrease in imports from third countries for all options
- Innovation and research - While bioenergy has an important innovation angle (for example with regards to advanced biofuels for transport), the policy options are unlikely to make a fundamental difference to innovation and research since the sustainability requirements would only have an impact on well-established technologies (i.e. the use of solid and gaseous biomass for heat and power).

Social Impact

Social aspects of bioenergy systems, according to Segon and Domac (n.d.) can be divided into two categories:

- Relates with standard of living - Standard of living in this case was related to household income, education, surrounding environment, and health care while social cohesion and stability was defined in terms of peace and communal relationship, employment, rural population stability, infrastructure and support for related industries.
- Contribute to increased social cohesion and stability.

There are some impacts on social aspect (ERIA, 2008; EC, 2016):

- Employment generation - Employment in the bioenergy economy is most significant in the solid biomass sector, where 306,800 Europeans had a job in 2014. In addition, 110,350 people were employed in the biofuels sector, 66,200 in the biogas sector and 8,410 in the renewable urban waste sector. Employment impacts will also arise as a result of the small shift from bioenergy to other renewable energy in the policy options, due to a higher labour -intensity of other renewable energy sources.
- Health benefits - improved biomass techniques for cooking and home heating will improve quality of life for women and infants. Reduced incidences of diseases will also result in economic benefits due to less hospitalisation and work-days lost and less expenditure on medical care.
- Women empowerment - Development of bioenergy has the potential for engaging women in raising nurseries and collection of seeds, which could lead to their enhanced participation in the village economy.
- Possible improvement in the human development index (HDI) - As indicated earlier, development of bioenergy programmes are expected to increase employment, which will improve income of individuals. People may use extra income to spend on their basic needs such as education, health care and nutritious food.

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Chapter 2 - Biomass Resources and Supply

About

This chapter will provide an overview about the different sources of the biomass-to-energy and discuss how to make the supply more sustainable. Also, this section will provide an overview about the assessment of the resources' availability, characters, and type of biomass will determine the types of technologies appropriate for the specific biomass.

There are some objectives in this chapter:

- Understand and can determine the biomass resources
- Understand how to assess the availability, characters and types of the biomass resources
- Understand how to secure and create more sustainable the biomass resources' supply
- Understand the impacts of the resources management to the environment and sustainability

Biomass Resources

Feedstock is available biomass from renewable resources which are available for utilisation both direct use and processed to other forms of product to be used for energy source materials. Biomass feedstocks such as energy crops which are planted specifically for the biomass sources, agricultural activities residues, forestry residues, algae, wood processing residues, municipal waste, and wet waste which can come from wastewater treatment plants (organic sludge).

Wood and Agricultural By-Products

The supply of EU domestic biomass for energy purposes from the forestry sector amounted to over 60% in 2016, however 32.5% from the resources were constituted by direct supply of wood biomass from forests and other wooded land, and 28.2% by indirect supply of wood, agricultural crops and agricultural by-products accounted for 27%, waste (municipal, industrial, etc.) for 12% (European Commission's Knowledge Centre for Bioeconomy, 2019). Agricultural biomass is matter derived from biological organisms such as corn, straw, plants, animal waste, offal and perennial grasses.

The major wood and agricultural by-products biomass resources include the following:

- Firewood and wood biomass residues/wastes from forest harvesting operations (may occur as thinning in young stands or cutting in older stands for timber).
- Wood processing residues from wood and furniture industries (sawmilling, plywood, wood panel, building component, furniture, flooring etc.).
- Agricultural crops and agro–processing residues.
- Urban wood wastes (collected wood materials after construction or demolition projects, rejected wood pallets and any other construction and demolition wastes made from timber).

However, based on the EU Biodiversity Strategy for 2030, the sourcing of biomass for energy production directly from primary forests - like direct wood supply, also biomass from peatlands and wetlands are prohibited.

Waste

Waste-to-energy (WtE) conversion processes, as a source of renewable energy, are expected to play an increasingly important role in sustainable management of MSW at global level. Improved solid waste management (recycling, waste diversion from landfill and energy recovery from waste) estimated to reduce about 10–15% in the global GHG emissions.

According to the Frontline BioEnergy (2021) there are some waste types which are potentially used as feedstock for bioenergy, such as:

- Municipal solid waste, such as yard trimmings, paper and paperboard, plastics, rubber, leather, textiles, and food wastes
- Refuse-derived fuel (RDF) from sorted municipal solid waste (MSW)
- Wood derived from construction and demolition (C&D) waste
- Crude glycerin from biodiesel production
- Waste paper
- Paper sludge
- Dried distiller's grains and soluble (DDGS)
- Poultry litter
- Cow manure
- Meat and bone meal from animal rendering operations

The use of waste or residual streams of biological or organic materials could have a significant contribution on bioenergy production also, it will minimise impacts associated with landfilling.

Biomass Assessment

With various biomass resources, there is more flexibility to produce bio-based products. However, the economy, environment, energy and also climate issues are important aspects of biomass availability assessment. According to Walsh (2014), there is still a lack of biomass resource assessment, methodology and units which can deliver the results.

There are two main approaches to biomass resource assessment (Walsh, 2014):

1. Quantity (Inventory) Approach
2. Economic Approach

Quantity (Inventory) Approach

Quantity approach is only to estimate accountable and physical quantities but not the economical aspects, such as cost and prices. According to Walsh (2014), quantity (inventory) assessments are highly useful in establishing upper bounds (theoretical quantities) of biomass resources and can be adjusted using appropriate constraints (e.g., available lands, environmental/ecological needs, existing uses of the material) to provide estimates of the resource quantities that can be technically available.

There are 4 main assessments in the quantity approach based on material types:

Forestry Assessment

The forestry assessment includes the estimation of the potential surplus of forest materials, wood processing residues, and as well dead materials. Most studies regarding the forestry assessment for biomass utilisation is about processing residues. According to Walsh (2014), the residue quantity estimation can be further refined by some parameters, such as:

- Diameter
- Stem volume
- Height
- Tree species or types (hardwood or softwood)
- Age
- The efficiency of different harvesting methods

Processing residues are estimated below:
"**Quantities of wood used to produce wood products multiplied by a residue generation factor.**"

The Table 1 below explains the residue generation factors from all forestry operations.

Table 1. Residue fraction per unit merchantable wood removed (%) for each forest and management type (Daioglou, 2015)

Forest Biome	**Management Type**		
	Clear Cut	**Selective Cut**	**Wood Plantation**
	Residue production per wood production (%)		
Boreal Wooded Tundra	69	NA	78
Cool conifer Temperate mixed Temperate deciduous	53	NA	63
Savanna Warm mixed Tropical woodland Tropical forest	39	18	52

Other leftover trees, such as small diameter, non-commercial type of trees, dead or diseased trees also have potential bioenergy resources.

Agricultural Residues

According to Walsh (2014), agricultural crop residues typically estimated by:

“**Multiplying the crop yields by a harvest index (ratio of non-grain plant material to grain material)**”

Example:
Assume wheat production averages 3.0 dry metric tons (dMT) of grain/hectare, and has a harvest index of 1.3, then 3.9 dMT of straw are produced per hectare.

According to the Australian Society Plant Scientists (ASPS) (2017), the term “harvest index” is used in agriculture to quantify the yield of a crop species versus the total amount of biomass that has been produced. Potential values for the harvest index of various crop and horticultural species are shown in Table 2.

Table 2. Harvest index (dry mass of harvested component/total shoot dry mass) varies with crop species. Plant breeders have selected for high HI as their part of crop improvement strategies and have achieved some substantial gains (ASPS, 2017)

Crop Species	Harvested Component	Harvest Index (HI)
Wheat, barley	Grain	0.55
Rice	Grain	0.50
Maize	Grain	0.52
Sunflower	Seeds	0.50
Bean (Phaseolus)	Pods	0.25
Peanut	Pods	0.50
Cotton	Bolls	0.33
Sugar beet	Root	0.50
Potato	Tuber	0.82
Sweet potato	Tuber	0.65
Chrysanthemum	Flowers	0.46
Tulip	Flowers	0.20

So, by multiplying the hectares with yield provides an estimation of the total quantity of straw produced. Residue quantity estimates can be further refined by accounting for factors that might limit their quantities. Technical constraints might include limits to collection machinery efficiency. However, according to Haberl et al. (2011), there are alternative uses of the residues, as crop residues play an important role in limiting soil erosion and maintaining soil organic matter.

Energy Crops

According to Walsh (2014), there are several types of feedstocks, such as 1st generation feedstocks which there are extensive production nd available data like corn, wheat, sorghum, sugarcane, sugarbeets, soybeans, rapeseed and palm oil which can be used to produce biofuel like ethanol and biodiesel, and other bioproducts; also, there is 2nd (or 3rd) feedstocks generation like short rotation woody crops or herbaceous crops which not yet commercially produced.

For this, both expected yields and suitable lands (area) where the crops can be grown must be considered. For yields, the simplest approach is to assume potential yields based on expert opinion, possibly supplemented by results of field trials.

According to Ecofys (2016), the crop yield data for all crops for EU-27, Ukraine, Russia and Belarus was collected mainly from Eurostat and FAO. However, the data about management practices for a specific region was collected from peer reviewed published literature.

Residue yield (t/ha) = crop to residue ratio × actual crop yield (t/ha)

The residue yield gives the quantity of residue generated from one hectare in a specific region. For the calculation of total residue yield for a specific crop in a specific region, the following equation was used:

Total residue yield (t/region) = crop to residue ratio × total production (t/region)

Total residue yield was defined as: “The total amount of residue produced from a specific crop in a specific region (e.g. total wheat residue production in Bulgaria).”

Other Biomass Resources

The assessment of other biomass resources such as: municipal solid waste, demolition waste, construction waste, animal wastes, food processing wastes etc usually use a simpler methodology.

For smaller areas, the assessment is usually surveys to assess the quantities available. For larger areas, the resource quantities are often estimated by multiplying a defined base unit by a waste generation per base unit factor.

According to Walsh (2014), For urban wastes, the base unit can be population (for MSW), housing starts (for residential construction), or expenditures (for industrial construction/renovation wastes). Further refinements might include adjustments for waste composition, housing type (e.g., single family, multifamily units) and size (e.g., square feet), type of remodel (e.g., major kitchen remodel, addition of wood deck), quantities recycled, or regional differences in construction materials used. Animal manure quantities (and potential methane production) are estimated by multiplying manure generation factors (quantity manure/day/defined animal unit) by the quantity of defined animal units.

Economic Approach

Economic approach in biomass resource assessment is by providing detailed economic considerations. This approach can include cost-quantity estimation and also estimation of resource supply curves - quantities available and price.

Quantity Cost Approach

According to Walsh (2014), The quantity and associated cost approach includes an inventory component, but extends the assessment to include biomass cost estimates in addition to physical quantities. Costs (prices) can be obtained by interviewing potential suppliers about the price they expect to be paid, by compiling data from existing studies, or by using prices for materials paid for alternative uses as a proxy. For new energy crops, costs (prices) are usually estimated since these crops are not currently produced. Additionally, some studies estimate machinery costs using purchase price and engineering specifications, while other studies use custom harvest rates (e.g., hay mowing or baling rates for switchgrass) to estimate harvest or collection costs. Crop residue costs are estimated using a similar approach.

Supply Curve Approach

In the supply curve approach, biomass resource quantities are estimated as a function of the price that can be paid for the resources. Estimates of several such price/quantity combinations can be used to construct the supply curve. Supply curve estimates can use simple approaches based largely on the quantity-cost approach for several quantity/cost combinations (the cost based methodology). Alternatively, supply curves can be estimated using economic models. Economic models are complex and data intensive, and typically not very transparent, but they provide maximum flexibility to examine changes in any given variable and if conducted in a dynamic framework, allow variables within a model to change in response to each other and as a function of time.

Cost-based Supply Approach

A simple supply curve for energy crops can be estimated by knowing the yields, the area on which the yields occur, and the production costs for several areas. For example, assume that in a defined region, there are 10 000 total hectares and that yields of 5 dMT ha^{-1} can be achieved on 1000 ha (total of 5000 dMT), 7.5 dMT ha^{-1} on 2000 ha (15 000 dMT), 10 dMT ha1 on 4000 ha (40 000 dMT), 12.5 dMT ha^{-1} on 2000 ha (25 000 dMT), and 15 dMT ha on 1000 ha (15 000 dMT). Further assume the corresponding production costs are $US 50, 45, 40, 35, and 30 per dMT. A typical return to the producer (profit) and/or a typical transportation cost (for defined distances) may be added to the production cost estimates but will be excluded from this example. The supply curve is constructed by ordering the costs from lowest to highest value ($US 30 to 50 per dMT) and using cumulative quantities at each price level. Thus for $US 35 per dMT, the total quantity is that at $US 30 per dMT (15 000 dMT) plus that between $US 30 and 35 per dMT (25 000 dMT) for a total of 40 000 dMT. Figure 1 illustrates the supply curve for this example.

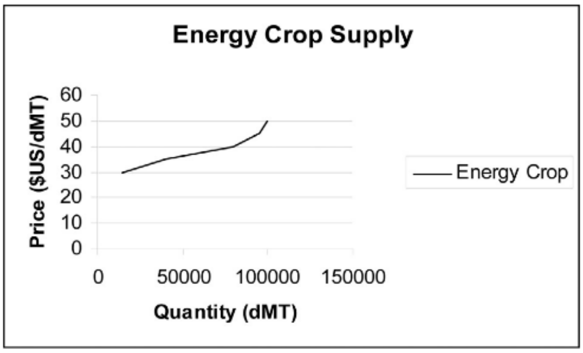

Figure 1. Example supply curve for energy crops using cost based methodology (Walsh, 2014)

Biomass Resource Data

European data can be found in the EUROSTAT database (Statistical Office of the EU) (http://epp.eurostat.ec.europa.eu). EUROSTAT does not collect the data – the member states do that. Rather it consolidates the data and ensures that it is comparable (consistent between the data provided by individual countries). EUROSTAT includes data on land use (agriculture, forest, recreation, residential) and land cover (crops, grasslands, forests, built-up areas). Agricultural statistics include farm structure, utilisation of farm land, labour, production, supply/use, prices, and agricultural income. Data is available at both national and regional levels. It also includes information on nutrient and pesticide use and organic farming. Forestry data includes production and trade of wood and wood products, and forestry and logging employment. It has access to data from the Ministerial Conference for the Protection of Forests in Europe (deadwood, biomass, and carbon in biomass and forest soils) and to the FAO Forest Resources Assessment data where all countries in the world are asked to report and forecast forest area, wood resources, and removals.

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Chapter 3 - Biomass Utilisation

About

This chapter will provide an overview about the utilisation of biomass-to-energy. This section will include the benefits of biomass utilisation, particularly to society and environment. Also, this section will provide the overview of the biomass-to-energy utilisation processes which will be created to easy-to-understand by the readers who are not familiar with the biomass-to-energy topic.

There are some objectives in this chapter:

- Understand about what is biomass utilisation
- Understand about the utilisation processes of biomass
- Understand about how biomass provides energy and electricity
- Understand the importance of the utilisation of biomass
- Understand how biomass utilisation can give the positive impacts to the society

Biomass Utilisation

Bioenergy can play a significant role in achieving the EU targets in terms of renewable energies by 2030 and beyond. Opportunities to increase the utilisation of bioenergy are seen e.g. in the field using agricultural residues, by-products and waste. Bioenergy can also play an important role as a flexible energetic carrier to balance the power systems and thus allowing for higher shares of renewable energy sources such as wind and solar power. Also ensuring environmental aspects like securing biodiversity or maintaining ecosystem services, bioenergy can contribute to, among other things, greenhouse gas savings, sustainability and rural development.

The EU's demand for renewable energy is set to increase considerably in the gradual phase-out of fossil fuels in the EU's energy mix and the targets set for renewable energy sources. The energy sector is by far the largest user of EU internal wood processing residues and by-products, and the heating and cooling sector the largest end-use of bioenergy in general, using about 75% of all bioenergy consumed. Bioelectricity and transport fuels account for 13% and 12% respectively (Banja et al., 2019). According to Andersen et al. (2021), by 2050, energy consumption from biomass is expected to rise at a sustained rate with estimates varying from a near doubling to a tripling. When material use is included, the consumption figure rises further with a 50% increase in material consumption alone expected as they replace other more carbon-intensive materials.

Bioenergy production can also bring significant opportunities to deliver social, environmental and economic benefits and contribute to rural development. Possible alternative uses of biomass (e.g. for food, feed, wood products, etc.) also need to be considered to ensure the sustainability of feedstock supply from an overall bioeconomy perspective.

There are 3 main converting methods of biomass conversion to useful thermal energy, electricity and fuels for power, as it follows:

1. Direct combustion
2. Gasification
3. Liquidation of biomass.

Biomass Pretreatment Methods

The primary objective of the pretreatment process is to deconstruct the complex biomass structure comprising lignin, hemicellulose, and cellulose so that each biopolymer can be effectively utilised to produce fuels, power and as well chemical materials. Several biomass pretreatment methods are available, including physical, chemical, physico-chemical, and biological some of them are listed as follows:

1. Physical methods which consisted of extrusion, ball milling, wet-disc milling, microwave pretreatment.
2. Chemical methods which consisted of acid pretreatment, alkali pretreatment, organosolv pretreatment, ozonolysis pretreatment.
3. Physicochemical methods which consisted of steam explosion, ammonia fibre explosion, liquid hot water, carbon dioxide explosion, wet oxidation.
4. Biological methods which consisted of white-rot fungi, brown-rot fungi, soft-rot fungi.

Extrusion Pretreatment

Extrusion processing is one of the promising physical pretreatment methods for deconstruction of lignocellulosic biomass. Extrusion is defined as an operation of creating objects of a fixed, cross-sectional profile by forcing them through a die of the desired cross-section. The material will experience an expansion when it exits the die.

There are some advantages and limitations of the extrusion pretreatment of the biomass,
Advantages:

- Easy on process monitoring and control.
- No inhibitory compounds formation due to sugar degradation.
- Adaptability for process modification.
- Continuous and high throughput.
- No need for washing of pretreated biomass if extrusion is performed without chemical addition.
- Can be combined with other methods of pretreatment for better results.

Limitations:

- Lack of data for economic analysis.
- Energy intensive process.
- Poor flow during continuous processing leading to burning of material.

Acid Pretreatment

Acid pretreatment is the most extensively studied and widely used for lignocellulosic biomass pretreatment process. The main objective of the acid pretreatment process is to hydrolyze the hemicellulose fraction of the lignocellulosic biomass. The effectiveness of this pretreatment method is usually enhanced with the increase in the proportion of hemicellulose and extractive fractions in the biomass.

There are some advantages and limitations of the acid pretreatment of the biomass as it follows:
Advantages:

- High reaction rate to solubilize the hemicellulose fraction of biomass thereby making the cellulose fraction accessible for cellulase enzymes.
- A method of deconstruction can be designed for biomass processing to generate separate hemicellulose hydrolyzates (after pretreatment) and cellulose hydrolyzates (after enzymatic hydrolysis).
- Cost saving for xylanase enzymes: Hemicellulose is extensively hydrolyzed during pretreatment depending upon the feedstock type and processing conditions; therefore, high-cost xylanase enzymes are not generally required for hydrolysis.

Limitations:

- Inhibitors, such as furfural and hydroxymethylfurfural (HMF), produced from sugar degradation require an additional detoxification step to make the released sugars fermentable.
- Need expensive stainless-steel vessels due to the corrosive nature of acid.
- Additional cost for alkali to neutralise acid after pretreatment.
- Environmental concern due to excessive use of chemicals.

Alkali Pretreatment

Alkali pretreatment is another extensively studied and widely used lignocellulosic biomass pretreatment method. This process is like an acid pretreatment process, but usually carried out at a lower temperature. While acid pretreatment solubilizes hemicellulose fraction of the biomass, the goal of alkali pretreatment process is to solubilize lignin fraction of the lignocellulosic biomass. Like in acid pretreatment process, alkali pretreatment process also solubilizes most of the biomass extractives.

There are some advantages and limitations of the alkali pretreatment of the biomass
Advantages:

- Effective delignification.
- Lower sugar degradation compared to dilute acid pretreatment due to the lower processing temperature; possible to pretreat at room temperature using longer time.
- Lignin and other extractives can be separated before enzymatic hydrolysis without loss of carbohydrate; high possibility of getting reactive lignin for high value application.

Limitations:

- Excessive phenolic compounds due to lignin degradation, which are potential inhibitors for enzymatic hydrolysis of sugar polymers.
- Additional cost for hemicellulose hydrolytic enzymes in addition to cellulase enzymes.
- Additional cost for acid to neutralise alkali after pretreatment.

Organosolv Pretreatment

Organosolv is a promising biomass pretreatment method, in which biomass is mixed with a selected organic solvent, with or without additional catalyst (acid or alkali) and heated at an appropriate temperature and time duration. Various organic solvents or solvent mixtures can be used; including low boiling point solvents, such as ethanol, methanol and acetone; high boiling point solvents, such as glycerol, ethylene glycol and tetrahydrofurfuryl alcohol; and other classes of organic solvents, such as organic acids, phenols, ketones and dimethyl sulfoxide.

There are some advantages and limitations of the organosolv pretreatment of the biomass
Advantages:

- Extracted lignin is relatively of high purity, low molecular weight and sulphur free making it possible for the high value application of lignin.
- All three biopolymers—cellulose, hemicellulose and lignin—can be separated into different streams.
- It can be combined with other pretreatment processes for effective biomass hydrolysis.

Limitations:

- High cost of solvent: Recycling process is also energy intensive. Additional solvent is required to avoid lignin precipitation due to washing with water.
- Formation of inhibitory compounds, such as furfural and HMF, due to sugar degradation when acid catalyst is used.
- Residual solvent will be inhibitory for enzymatic hydrolysis and fermentative organisms.
- Environmental and health concerns due to the use of volatile organic liquids at high temperature.

Ionic Liquid Pretreatment

This is a relatively new approach for biomass pretreatment, in which the whole biomass is dissolved in a selected ionic liquid and the carbohydrate polymers are precipitated by adding appropriate anti-solvents; thereby, separating lignin and carbohydrates.

There are some advantages and limitations of the ionic liquid pretreatment of the biomass
Advantages:

- Ionic liquids, considered as green solvent, are stable up to 300 °C; have extremely low volatility with minimum environmental impact.
- Possible to separate each of the biopolymers—cellulose, hemicellulose and lignin.
- Ionic liquid with desirable properties can be synthesised.

Limitations:

- Cost of ionic liquids is still very high.
- Many ionic liquids are toxic to the hydrolytic enzymes and the fermenting organisms.
- Cost of solvent recovery is tedious and expensive.
- Difficult to handle the viscous biomass slurry with ionic liquid during pretreatment at temperature beyond 150 °C.

Steam Explosion Pretreatment

Steam explosion pretreatment is a widely studied physicochemical pretreatment process. In this process, the ground and preconditioned biomass is treated with saturated steam at high temperature (160–290 °C) and high pressure (0.7 and 4.8 MPa) for a few seconds to several minutes before the pressure is explosively released. This method is more effective in hardwood and herbaceous biomass but needs addition of acid catalyst for effective pretreatment of softwood due to the presence of lower amount of acetyl groups in softwood hemicellulose.

There are some advantages and limitations of the steam explosion pretreatment of the biomass,

Advantages:

- No use of chemicals and hence no recycling and environmental costs.
- Relatively less dilution of released hemicellulose.
- High particle size biomass can be used, leading to significant energy savings. Size reduction accounts to around one third of the entire pretreatment process.

Limitations:

- Incomplete de-construction of lignin-carbohydrate complex may lead to condensation and precipitation of soluble lignin; thereby resulting in reduced biomass hydrolysis efficiency.
- High temperature (around 270 °C) is the best to enhance cellulose digestibility; however, this leads to the formation of inhibitory compounds—furfural and HMF.
- Weak acids and phenolic compounds, such as acetic, formic and levulinic acids, generated during this process are inhibitory for subsequent enzymatic hydrolysis and fermentation.

Ammonia Fibre Explosion Pretreatment (AFEX)

The AFEX method is an alkaline physicochemical pretreatment process. Its processing method is similar to that of steam explosion but operates at lower temperature. In this process, the biomass is mixed with liquid anhydrous ammonia (0.3 to 2 kg/kg dry biomass); cooked at 60–90 ◦C and at pressure above 3 Mpa for 10–60 min. The optimum ratio of ammonia to biomass, and cooking temperature, pressure and time depends on the type of lignocellulosic biomass materials. The AFEX method is very effective for herbaceous crops and agricultural residues, but relatively less effective for woody biomass. AFEX is also considered as a feasible method for the pretreatment of herbaceous biomass to extract protein for animal feed along with sugar generation for biofuels production.

There are some advantages and limitations of the ammonia fibre explosion pretreatment of the biomass,

Advantages:

- No formation of inhibitory compounds like furfural and HMF from sugar degradation due to low temperature operation.
- High selectivity for delignification.
- Easy for recycling due to the volatile nature of ammonia; 99% ammonia recovery is possible.
- Residual ammonia can serve as a nitrogen source for the organisms during fermentation.

Limitations:

- Excess water requirement because the phenolic fragments of lignins must be washed to avoid inhibition during enzymatic hydrolysis and fermentation.
- Ammonia recycling is very costly for commercial scale processing.
- Inefficient for high lignin content biomass, such as softwood and newspaper waste.

- Environmental concern due to the use of volatile chemicals.

Liquid Hot Water (LHW) Pretreatment

Different terminologies are used in literature to describe this process, including solvolysis, hydrothermolysis, aqueous fractionation, and aquasolv. This process is comparable with dilute acid pretreatment without using acid. In this process, biomass slurry in water is cooked at elevated temperature (160–240 °C) for various time periods, depending on biomass type, to solubilize hemicellulose fraction of biomass leading to cellulose enriched portion.

There are some advantages and limitations of the liquid hot water pretreatment of the biomass,
Advantages:

- No use of additional chemicals.
- No need to use expensive and corrosive-resistant materials for pretreatment reactors.
- Relatively large size particles can be used leading to energy saving, which is required for size reduction of biomass to fine particles.
- Possible to recover separately the cellulose and hemicellulose streams.
- Minimum formation of inhibitory compounds.

Limitations:

- The xylose stream is of very low concentration and hence needs an additional cost-intensive evaporation of water operation to get appropriate sugar concentration for fermentation.
- High cost since high pretreatment temperature is required.
- Not suitable for biomass with high-lignin content.

Biological Pretreatment

Biological pretreatment involves use of microorganisms to degrade biomass lignin and make carbohydrate polymers susceptible for enzymatic hydrolysis. Among various organisms capable of producing enzymes to degrade lignin and carbohydrate polymers of biomass, white-rot, brown-rot, and soft-rot fungi are important. The white-rot fungi are the most effective for biomass pretreatment because of their enzymatic efficiency and economy. The brown-rot fungi degrade cellulose, whereas white-rot and soft-rot fungi degrade both lignin and cellulose. The ligninolytic enzyme system of white rot fungi primarily consists of lignin peroxidase (LiP), manganese peroxidase (MnP) and laccase.

Based on enzyme production patterns, the white rot fungi could be categorised into three groups:

- Lignin-manganese peroxidase group - P. chrysosporium and Phlebia radiata.
- Manganese peroxidase laccase group - Dichomitus squalens and Rigidoporus lignosus.
- Lignin peroxidase laccase group - Phlebia ochraceofulva and Junghuhnia separabilima.

There are some advantages and limitations of the biological pretreatment of the biomass,
Advantages:

- No inhibitory compounds are produced.
- The process is environmentally friendly.

Limitations:

- Very slow process; residence time is usually between 10 to 14 days.
- Large space is required to perform the process.
- Strict temperature control is required, leading to increased processing cost.
- Cellulose crystallinity could not be reduced.

Biomass Conversion Methods

Direct Combustion

Combustion is the most common and traditional way to produce heat from biomass. In developing countries, the thermal efficiency of direct biomass combustion is 10% - 15% generally. After transformation the thermal efficiency of stoves in rural China are about 30%, and the best can reach up to 50%. The stove is composed of a combustion chamber, fire fencing ring, smoke circulation passage, chimney, stove door, grate and air inlet. The key design points are to increase the intensity of thermal radiation and reflection in the combustion chamber and reduce the loss of complete combustion in the inner stove and the thermal loss of smoke.

Some advanced European countries adopt high-efficiency combustion equipment such as sulphurized-bed combustion equipment. In the equipment, wood is cut into small pieces which then cross the sulphurised bed in a very short time. After combustion, the incompletely burned wood pieces are returned to the sulphurised bed from the smoke exhaust system. The commercialised small- and middle-sized boilers developed by these countries take wood and residues as fuel. Their efficiencies can reach 50% - 60%. In Holland, there are about 1.75 million sets of wood stoves with specifications of 5 - 20 kW and 600, 000 wood fireplaces for domestic heating and hot water supply. Their thermal efficiencies can reach over 50%. The thermal efficiency of fixed bed model boilers burning grass and manufactured by England and Denmark are 60%.

Gasification

Pyrolysis

Pyrolysing gasification of biomass is one of the optimum biomass utilisation technologies. In gasification equipment, biomass is transferred to high-grade combustible gas through thermal chemical action at high temperature. The gas can be used for drying, heating, thermal insulation and electricity generation.

Using gasification equipment, almost all biomass can be transferred to gas fuel which mainly consists of CO, CO_2, H_2 and CH_4. The other part of energy of biomass is used to carry out gasification action. The gasification efficiency of wood is 60% - 80%. Pyrolysis enables the energy recovering rate of rice to reach over 94% and the thermal value of the combustible gas obtained is 2.5*10 kJ/m³. The thermal value of combustible gas obtained from cattle manure pyrolysis is $1.7*10^4$ kJ/m³. The gasification efficiency of multiple waste is over 80%.

The thermal value of combustible gas can be increased by adding hydrogen during pyrolysis processing of biomass.

Since the 1970's, some European countries began to study gasification equipment with multiple functions, suitable for different requirements and adopting high temperature pyrolysis techniques. There were two kinds of gasification equipment developed:

- **Sliding bed gasification chamber**

Biomass slides slowly from the top of the gasification chamber while gasifying. Oxidizer is flowed upwards from the bottom of the gasification chamber and crosses the biomass to gasify it. The temperature of output gas can reach 600 ^{o}C and there is no tar in the gas.

- **Sulphurised bed gasification chamber**

The ground biomass (with a size of a few mm) is fed to the gasification chamber and gasified while crossing the float material. The gas produced has a high temperature that reaches to about 800 ^{o}C. The sulphurised bed gasifier is mostly suitable for biomass.

Anaerobic Digestion

With the anaerobic digestion technology, the combustible gas is obtained while organic waste is treated and the residue digested can be processed into fodder or fertiliser, which is commonly developed because of obvious economic, environmental and ecological benefits.

Some developing countries like China and India are extending and using this technology in rural areas. The family-sized digester technology of China is in the leading position in the world. Up to now, there are 4.75 million small-sized digesters which produce 1.04 billion cubic metres of biogas annually. In addition, all the middle and large scale biogas plants with an electricity capacity of 2077 kW in China can produce 29.1 million cubic metres of biogas annually.

On the aspects of treating multiple industry waste water and organic rubbish, some countries adopt highly efficient techniques, such as: anaerobic filter, UASB and sulphurised bed. France and Japan use and extend high efficiency anaerobic digestion equipment that adopt high density adhering technology to treat organic waste water to the international market. Its efficiency is ten times higher than that of traditional methods. Dry digestion technology and two-step anaerobic digestion techniques have been widely researched in recent years, and these can be used to treat solid waste.

|| Fact:

According to the present technology level, 10 m^3 of biogas can be produced from one ton of rubbish, 35 m^3 of biogas from one ton of human excrement and urine and 5 - 50 m^3 of biogas from one ton of organic waste water with high concentration.

Liquefaction

There are 2 different types of liquefaction methods for biomass conversion to biofuels:

1. Indirect Liquefaction
2. DIrect Liquefaction, which consisted to 2 different types of methods:
    a. Hydrolysis - Fermentation Liquefaction

b. Thermodynamic Liquefaction, which separated to 2 different types of methods:
    i. Pyrolysis method
    ii. Hydrothermal method

Indirect Liquefaction

Indirect liquefaction is a promising technology, which is divided into two stages. The first stage is a thermochemical gasification process. In this process, the syngas is produced after the raw material reacts with air or steam. In the syngas, the primary substances are CO, CO_2, H_2, and H_2O. The second stage is the well-established Fischer–Tropsch (F–T) process. During the F–T process, the mixture would be used to produce a range of chemicals, including methyl alcohol, dimethyl ether, and ethyl alcohol, while there is little research on the higher alcohols derived from the biomass syngas. The biggest challenges are the design of the novel catalytic reactor for the typically smaller scale of biomass conversion processes and catalysts for specific chemicals according to the molar ratio of H_2 to CO. We take the synthesis of ethyl alcohol as an example to introduce the indirect liquefaction process.

Direct Liquefaction

Hydrolysis - Fermentation Liquefaction

In the last few decades, ethyl alcohol has attracted a great deal of attention as a potential alternative to fossil fuels. Currently, fermentation of biomass is the main industrial technology to produce ethyl alcohol, of which the primary raw materials are glucose (obtained from corn) and sucrose (obtained from sugar cane and beets). There are the same negative effects on ethyl alcohol production using starch or sugar as the raw material, which would compete with food production directly. Up to now, corn straw has been considered as a possible raw material for ethyl alcohol production.

Once the biomass is transported to the production plant, it would be stored in the warehouse to prevent fermentation and bacterial contamination. Then, the raw material would be pre-treated to make it more accessible for extraction. In the fermentation process, hydrolysate, yeasts, nutrients, and other ingredients would be added. The fermentation is usually executed at 25–30 ◦C and the suitable reaction time would last for 6-72 h.

Thermodynamic Liquefaction

In general, there are two types for thermodynamic liquefaction of biomass depending on the operating conditions: pyrolysis liquefaction and hydrothermal liquefaction.

Pyrolysis

In pyrolysis liquefaction, it could be divided into slow pyrolysis, fast pyrolysis, and flash pyrolysis. Slow pyrolysis is usually executed at a low reaction temperature, heating rate, and a long residence time, which produces a little bio-oil. In the flash pyrolysis process, the reaction time is only or less than several seconds with a very high heating rate and small particle size, and the primary product is syngas. Fast pyrolysis also proceeds at a high heating rate (less than in flash pyrolysis) and short residence time of the vapor. The favourable product in the process is bio-oil. The pyrolysis bio-oils could be directly burned in boilers, or upgraded to produce valuable fuels and chemicals using the following methods:

Extraction, emulsification, esterification/alcoholysis, supercritical fluids, hydrotreating, catalytic cracking, and steam reforming.

Hydrothermal

Hydrothermal liquefaction of biomass is one of the effective methods to treat the biomass with high water content compared to pyrolysis liquefaction. This liquefaction of biomass is not affected by the level of water content and the types of biomass with high conversion and relatively pure products. The suitable properties for liquefaction of biomass are demonstrated, including a high density, good heat, mass transfer capability, fast decomposition, and extraction under hydrothermal conditions. This is an environmentally friendly technology, and the heteroatom in biomass could be converted into undesired by-products.

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Chapter 4 - Biomass Energy (Bioenergy) Conversion Processes

About

This Chapter will provide the information about recent practices and applications of the biomass-to-energy conversion. This section will give a better and deeper understanding of the readers about the technical conversion processes including the pros and cons in terms of economics and environment.

There are some objectives in this chapter:

- Understand what is the energy in general
- Understand the importance of the energy conversion in the lens of biomass utilisation
- Can do impacts assessment about the pros and cons of the processes
- Understand the different methods of the biomass-to-energy conversion

Bioenergy

Bioenergy is a type of energy which develops from living organisms like plants, animal manure, household sewages, waste etc. There are different types of bioenergy, there are direct combustion, biofuel, and biogas which can be used as electricity, heat, gas and fuel for some purposes.

Biofuel

Biofuel or also called as agrofuel is liquid fuels derived from agricultural or forestry biomass, either fresh biomass or organic waste. Although fossil fuels have their origin in ancient biomass, they are not considered agrofuels by the generally accepted definition because they contain carbon that has been out of the carbon cycle for a very long time. Agrofuels are mainly used in the transport sector, especially biodiesel (agrodiesel) and bioethanol (agroetanol).

- **Biodiesel** or also called as agrodiesel made from vegetable oils extracted from rapeseed, soy, oil palm, sunflower and algae, among others. Animal fats from the meat industry as well as used cooking oil from restaurants and the by-products of the production of Omega-3 fatty acids from fish oil can also be used as feedstock for agrodiesel. Agrodiesel can be used as a fuel for vehicles in its pure form, but is usually blended with fossil diesel. Agrodiesel is the most common liquid agrofuel in Europe, where it is used to meet the mandatory targets for renewable energy in the transport sector. It is also used in heat and power plants as a substitute for fossil oil. Rape seed, soy and oil palm are the mostwidely used crops to produce agrodiesel at an industrial scale.
- Ethanol (as well as propanol and butanol) are produced by fermenting sugar into alcohols that can be used as fuel, mainly in vehicles. **Bioethanol** or agroetanol is the most widely used. A range of crops with a high sugar and/or starch content such as

sugarcane, maize, sugar beet, wheat, cassava and sweet sorghum are used as raw material for producing agroetanol, with sugar and maize being the most popular for industrial use. Agroetanol produced from easily degradable sugars and starches is referred to as **first generation**. This is usually derived from food crops and therefore competes directly with food production. In order to avoid the competition with food, many experiments have been carried out to produce enzymes able to break down the cell walls of lignin, cellulose or hemi-cellulose from e.g. trees or straw. Agroetanol based on these non-food sources is referred to as **second generation**. This is not economically viable at present although the industry has claimed to be (nearly) ready to produce it for the last decade.

Biogas

Biogas produced when microorganisms digest organic material in anaerobic conditions (i.e. in the absence of oxygen). Biogas is made up of approximately ⅔ methane and ⅓ carbon dioxide and possibly small amounts of other gases. Animal manure, slurry, organic waste from households and industry, and residues from agriculture are the primary sources for biogas production. In industrial agriculture, biogas is seen as a viable way to avoid nuisance odours and reduce methane emissions from slurry tanks while at the same time producing energy and providing additional income to farmers. However, for economically viable production, plant material from waste crops or crop residues must be added. When crops such as maize are added (which is frequently the case in Europe) life cycle emission accounting has shown that the production is problematic in terms of greenhouse gas emissions. Biogas can be used as a transport fuel or as a replacement for natural gas in heat and electricity production. The by-products may be used as fertiliser on agricultural soils.

Production Flow of Bioenergy

There are different methods that can be used in bioenergy production. The methods are up to the utilisation of the biomass itself, to produce biofuel has different methods on producing biogas, vice versa.

The methods also can be different based on the materials used in the production. As there are different types of pretreatment methods for different biomass types or characteristics. As explained on Chapter 3, there are also different types of conversion methods on biomass utilisation to energy, there are direct combustion which used to create heat, gasification which used to create biogas, and liquefaction which used to create biofuel.

Simply, the bioenergy production flow can be explained like this:

Biomass >>> **Preparation (Pre-treatment & Conversion Process to Product (trade forms) like biofuel, and biogas)** >>> **Product** >>> **Selling and Distribution** >>> **Conversion (biodiesel, bioethanol, biogas) to Energy** >>> **Bioenergy (Heat and Power)**

Heat and Electricity Production

Direct combustion is the most common method for converting biomass to useful energy. All biomass can be burned directly for heating buildings and water, for industrial process heat, and for generating electricity in steam turbines. Direct combustion is the simplest and oldest way to generate electricity from biomass. Direct combustion (or "direct-fired") systems burn biomass in boilers to produce high pressure steam. The steam turns a turbine connected to a generator-the same kind of steam-electric generator used in fossil fuel power plants. As the turbine rotates, the generator turns, and electricity is produced.

Biomass >>> Boiler >>> Steam >>> Turbine >>> Electricity

Some advanced European countries adopt high-efficiency combustion equipment such as sulphurized-bed combustion equipment. In the equipment, wood is cut into small pieces which then cross the sulphurised bed in a very short time. After combustion, the incompletely burned wood pieces are returned to the sulphurised bed from the smoke exhaust system. The commercialised small- and middle-sized boilers developed by these countries take wood and residues as fuel. Their efficiencies can reach 50% - 60%.

The devices used for direct combustion of solid biomass fuels range from small domestic stoves (1 to 10 kW) to the largest boilers used in power and combined heat and power (CHP) plants (>5 MW). Intermediate devices cover small boilers (10 to 50 kW) used in single family houses heating, medium-sized boilers (50 to 150 kW) used for multi-family house or building heating and large boilers (150 to over 1 MW) used for district heating. However, co-firing in fossil fired power stations enables the advantages of large size plants (>100 MWe) that are not applicable for dedicated biomass combustion due to limited local biomass availability.

According to the European Biomass Industry Association, there are most frequently used furnaces for biomass combustion:

Table 3. Frequently used furnaces for biomass combustion

Type	Typical Size Range	Fuels	Ash (%)	Water Content (%)
Wood stoves	2 - 10 kW	Dry wood logs	<2	5 - 20
Log wood boilers	5 - 50 kW	Log wood, sticky wood residues	<2	5 - 30
Pellet stoves and boilers	2 - 25 kW	Wood pellets	<2	8 - 10
Understoker furnaces	20 kW - 2.5 MW	Wood chips, wood residues	<2	5 - 50
Moving grate furnaces	150 kW - 15 MW	All wood fuels, most biomass	<50	5 - 60

Pre oven with grate	20 kW - 1.5 MW	Dry wood (residues)	<5	5 - 35
Understoker with rotating grate	2 - 5 MW	Wood chips, high water content	<50	40 - 65
Cigar burner	3 - 5 MW	Straw bales	<5	20
Stationary fluidised bed	5 - 15 MW	Various biomass, d < 10 mm	<50	5 - 60
Circulating fluidised bed	15 - 100 MW	Various biomass, d < 10 mm	<50	5 - 60
Dust combustor, entrained flow	5 - 10	Various biomass, d < 5 mm	<5	<20

Understoker furnaces are mostly used for wood chips and similar fuel with relatively low ash content, while grate furnaces can also be applied for high ash and water content. Stationary or bubbling fluidised bed (SFB) as well as circulating fluidised bed (CFB) boilers are applied for large-scale applications and often used for waste wood or mixtures of wood and industrial wastes e.g. from the pulp and paper industry.

Biofuels Production

Biodiesel

Biodiesel is an alternative diesel fuel obtained from renewable sources. The biodiesel is mono alkyl ester which is derived from animal fat or some types of oils, including cooking vegetable oils. Substances of animal and vegetable origin are classified as biomass energy sources. According to Rajaluigam (2016), The carbon will be neutral when biodiesel is used as a fuel, because during the combustion process, the amount of carbon emission is equal to an animal or plant absorbed during it whole life time. So the emission will be low in green combustion of biofuel.

According to Aktas (2020), biodiesel is produced by reacting vegetable or animal oils with an alcohol and catalyst. It is also a non-toxic, biodegradable and renewable diesel fuel. As the biodiesel are mono alkyl esters, so biodiesel does not contain oil, however can be used as a fuel, either pure or mixed with diesel oil of any proportion (Ölmez, 2005).

According to Aktas (2020), there are some oil sources that can be used in biodiesel production:

- Vegetable Oils: Sunflower, Soybean, Rapeseed, Safflower, Cotton, Palm Oils
- Recovery Oils: Vegetable Oil Industry By-Products
- Urban and Industrial Waste Origin Recovery Oils

- Animal Oils: Frost Oils, Fish Oils and Poultry Oils
- Waste Vegetable Oils: Used Cooking Oils

Biodiesel Production Technologies

There are some mainstream technologies that enable the use of oil and fat feedstock types as fuel in diesel engines which are usually called biodiesel. The technologies are direct use or blending of oils, pyrolysis, micro emulsion, and transesterification. Transesterification is the method that is preferable by various researchers to use for biodiesel production due to better quality production.

Direct Use (Dilution) or Blending

Dilution process is a process of thinning vegetable and waste oils by mixing with a solvent or a diesel fuel in certain proportions. Direct uses of vegetable oils have generally been considered not satisfactory and impractical for both direct and indirect diesel engines. Oils used in the dilution method of biodiesel production; peanut oil, rapeseed oil, sunflower oil and waste oils. The high viscosity, acid composition, free fatty acid content, as well as gum formation due to oxidation and polymerization during storage and combustion, carbon deposits and lubricating oil thickening are obvious problems.

To avoid such problems the alternative fuel sources are directly blended with conventional fossil fuels. This kind of blending will improve the fuel quality, reduces the fossil fuel consumption, etc., so it is also preferable as a most convenient way to use an alternative fuels such as biofuels. The bio oil and diesel blends will be in different ratios like 10:1,10:2, 10:3, etc., (Mendhe, 2015).

Pyrolysis

The word “pyrolysis” is derived from pyro (which can be interpreted as "fire") and lysis (which is being interpreted as "separating"). Hence, pyrolysis can be simply defined as the decomposition or disintegration of organic compounds at very high temperatures, aided either by the presence of a suitable catalyst or absence of air. Pyrolysis is conducted at a temperature range of 400–600 °C. The process produces gases, bio-oil, and a char depending on the rate of pyrolysis. According to Gebremariam (2017), based on the operating conditions, the pyrolysis process can be divided into three subclasses: conventional pyrolysis, fast pyrolysis and flash pyrolysis. Fast pyrolysis is the one used for production of bio-oil.

Table 4. Classification of pyrolysis methods

Method	Temperature (°C)	Residence Time	Heating Rate (°C/s)	Major Products
Conventional/slow pyrolysis	Med-high (400-500)	Long 5-30 min	Low 10	• Gas • Char • Bio-oil (tar)
Fast pyrolysis	Med-high (400-650)	Short 0.5-2 s	High 100	• Bio-oil (thinner) • Gases • Char

Ultra-fast/flash pyrolysis	High (700-1000)	Very short < 0.5 s	Low 10	• Gases • Bio-oil

The organic materials that can be pyrolysed include animal fats, vegetable oils, natural triglycerides. The liquid components of the pyrolysed fats and triglycerides include biodiesel which functions in the same manner as petroleum diesel in diesel engines. Abbaszaadeh (2012) also reported that biodiesel fuel produced through a pyrolysis process or known as bio-oil is suitable for diesel engines.

Micro-emulsification

According to IUPAC definition, micro-emulsion is dispersion made of water, oil, and surfactant(s) that is an isotropic and thermodynamically stable system with dispersed domain diameter varying approximately from 1 to 100 nm, usually 10 to 50 nm. Ma et al. (1999) explained that the formation of micro-emulsion is one of the potential solutions for solving the problem of vegetable oil viscosity.

The components of a biodiesel micro-emulsion include diesel fuel, vegetable oil, alcohol, and surfactant and cetane improver in suitable proportions. Alcohols such as methanol and ethanol are used as viscosity lowering additives, higher alcohols are used as surfactants and alkyl nitrates are used as cetane improvers. Micro-emulsions can improve spray properties by explosive vaporisation of the low boiling constituents in the micelles. Micro-emulsion results in reduction in viscosity, increase in cetane number and good spray characteristics in the biodiesel. However, as indicated by Parawira (2010), continuous use of micro-emulsified diesel in engines causes problems like injector needle sticking, carbon deposit formation and incomplete combustion.

Transesterification

Transesterification is the method which is most convenient to produce biodiesel from oil and fat feedstock types, which chemically resembles petroleum diesel. With this method, oils and fats (triglycerides) are converted to their alkyl esters with reduced viscosity to near diesel fuel levels. This product is thus a fuel with properties similar to petroleum based diesel fuel, which enable it to be used in existing petroleum diesel engines without modifications.

Generally, transesterification is a reversible reaction, which simply proceeds essentially by mixing the reactants usually under heat and/or pressure. However, if some kind of catalyst is added to the reaction, the process will be accelerated. There are a number of ways to produce transesterification, like acid catalysed, base catalysed, lipase catalysed, supercritical, nano catalysis, and ionic liquid catalysis.

Acid Catalysed Transesterification

Acid catalysed transesterification was the first method ever in history to produce biodiesel (ethyl ester) from palm oil using ethanol and sulfuric acid. The acid catalysed process is due to the reaction of a triglyceride (fat/oil) with an alcohol in the presence of an acid catalyst to form esters (biodiesel) and glycerol. This method is convenient and economically viable in producing biodiesel from oil or fat resources with high free fatty acid content. However, the acid catalysed reaction requires a longer reaction time and a higher temperature than the alkali catalysed reaction.

Acid catalysed transesterification starts by mixing the oil directly with the acidified alcohol, so that separation and transesterification occur in a single step, with the alcohol acting both as a solvent and as esterification reagent. The acid catalysed transesterification should be carried out in the absence of water, in order to avoid the competitive formation of carboxylic acids which reduce the yields of alkyl esters. Since transesterification is an equilibrium reaction, there should always be more alcohol than the oil to favour the forward reaction for complete conversion of the oil to alkyl ester. However, more alcohol beyond the optimum will also cause some extra cost on separation of more produced glycerol from the alkyl ester and that is why there should always be an optimization of the ratio for efficient production.

Sulphuric acid, sulfonic acid, and hydrochloric acid are the usual acid catalysts but the most commonly used is sulphuric acid. There are advantages and disadvantages of the acid catalysed transesterification method.

The advantages are:

- Gives relatively high yield
- Insensitive to FFA content in feedstock, thus preferred-method if low-grade feedstock is used
- Esterification and transesterification occur simultaneously
- Less energy intensive

The disadvantages are:

- Corrosiveness of acids damage equipment
- More amount of free glycerol in the biodiesel
- Requires higher temperature operation but less than supercritical
- Relatively difficult separation of catalyst from product
- Has slower rate of production (relatively takes longer time)

Base Catalysed Transesterification

The alkaline or base catalysed transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol in the presence of alkaline catalysts such as alkaline metal alkoxides and hydroxides as well as sodium or potassium carbonates to form esters (biodiesel) and glycerol. Base catalysed transesterification is much faster than acid catalysed transesterification and is less corrosive to industrial equipment and therefore is the most often used commercially. However, presence of water and high amount of free fatty acid in a feedstock gives rise to saponification of oil and therefore, incomplete reaction during alkaline transesterification process with subsequent formation of emulsion and difficulty in separation of glycerol. The main disadvantage resulting due to saponification reaction is the consumption of catalyst and increased difficulty in separation process, which leads to high production cost.

Generally, base catalysts manifest much higher catalytic activity than acid catalysts in the transesterification reaction, but are selectively suitable for deriving biodiesel only from refined oils having low content of free fatty acids (FFA) usually less than 0.5%. The efficient production of biodiesel using base catalysed transesterification is not only dependent on the quality of the feedstock, it is also dependent on the crucial reaction operation variables such as alcohol to oil molar ratio, reaction temperature, rate of mixing, reaction time, type and concentration of catalyst and also on the type of alcohol used (usually methanol).

Sodium hydroxide, potassium hydroxide and sodium methoxide are catalysts usually used in base catalysed transesterification. Sodium hydroxide is mostly preferable owing to its intermediate catalytic activity and a much lower cost. There are advantages and disadvantages of the base catalysed transesterification method.

The advantages are:

- Faster reaction rate than acid catalysed transesterification
- Reaction can occur at mild reaction condition and less energy intensive
- Common catalysts such as NaOH and KOH are relatively cheap and widely available
- Less corrosive

The disadvantages are:

- Sensitive to FFA content in the oil
- Saponification of oil is the main problem due to quality of feedstock
- Recovery of glycerol is difficult
- Alkaline wastewater
- Generated requires treatment

Lipase Catalysed Transesterification

The lipase catalysed transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol in the presence of lipase enzyme as a catalyst to form esters (biodiesel) and glycerol. Lipase catalysed transesterification is the other way of transesterification of oils and fats for biodiesel production using enzymes in which there is no problem of saponification, purification, washing and neutralisation so that it is always a preferred method from these perspectives. However, the problems associated with enzyme catalysts are their higher cost and longer reaction time.

Lipases for their transesterification activity on different oils can be found from different sources. Ability to utilise all mono, di, and triglycerides as well as the free fatty acids, low product inhibition, high activity and yield in non-aqueous media, low reaction time, reusability of immobilised enzyme, temperature and alcohol resistance are the most desirable characteristics of lipases for transesterification of oils for biodiesel production. Enzymes are usually immobilised for better enzyme loading, activity and stability. Selecting and designing the support matrix are important in enzyme immobilisation. With this respect, there are a number of ways to immobilise enzymes.

There are advantages and disadvantages of the lipase catalysed transesterification method.

The advantages are:

- Insensitive to FFA and water content in the oil, thus preferred when low grade feedstock is used
- It is carried out at low reaction temperature

- Purification requires simple step, by enabling easy separation from the by-product, glycerol
- Gives high purity product (esters)
- Enables to reuse immobilised enzyme

The disadvantages are:
- The cost of enzyme is usually very high
- Gives relatively low yield
- It takes high reaction time
- The problem of lipases inactivation caused by methanol and glycerol

Ionic Liquid Catalysed Transesterification

Ionic liquids are organic salts composed of anions and cations that are liquid at room temperature. The cations are responsible for the physical properties of ionic liquids (such as melting point, viscosity and density), while the anion controls its chemical properties and reactivity. Their unique advantage is that while synthesised, they can be moderated to suit required reaction conditions.

Among the different possible types of ionic liquids for catalysis of transesterification reaction for biodiesel production, Ionic liquids composed of the 1-n-butyl-3-methylimidazolium cation are the most widely studied and discussed compounds. Guo et al. (2014) concluded that ionic liquid catalysed transesterification proved to be efficient and time saving for the preparation of biodiesel from soybean oil.

The advantages of this method are:
- Easy to separate final products due to formation of biphasic.
- Efficient and time saving
- While preparing catalysts their properties can be designed to suit a particular need
- Catalyst can be easily separated and reused many times
- High catalytic activity, excellent stability

The disadvantages of this method are:
- High cost of ionic liquid production
- Requires relatively more alcohol for effective yield

Bioethanol

Bioethanol is considered a potential substitute for the conventional gasoline and can be used directly in vehicles or blended with the gasoline, thereby reducing greenhouse gas emissions and consumption of gasoline. Bioethanol (E100) can be used for direct application. However there is a difficulty in starting the engine as the engine will start in low temperature or cold weather, because E100 needs higher heat for vaporisation.

Advantages of bioethanol include high-octane rating resulting in increased engine efficiency and performance, low boiling point, broad flammability, higher compression ratio and heat of vaporisation, comparable energy content, reduced burning time and lean burn engine.

There are some sources that can be used in bioethanol production:

- The first generation source comes from edible feedstock:
    - Corn
    - Sugar cane
- The second generation source comes from lignocellulose as the feedstock:
    - Switchgrass
    - Cornstalks
    - Wood
    - Herbaceous crops
    - Waste paper and paper products
    - Agricultural and forestry residues
    - Pulp and paper mill waste
    - Municipal solid waste
    - Food industry waste
- The third generation source comes from algae as the feedstock, there are types of algae with high productivity:
    - Nannochloropsis Oculata
    - Tetraselmis suecica
    - Scenedesmus dimorphus
    - Porphyridium cruentum (seawater)
    - Porphyridium cruentum (fresh water)
    - Padina Tetrastromatica

Bioethanol can be used in some applications such as:
- Fuel for transportation
- Fuel for power generation from thermal combustion
- Feedstock in the chemicals industry
- Fuel in the cogeneration systems

Bioethanol Production Process

Bioethanol production included pretreatment, hydrolysis and fermentation. There are some types of pretreatment processes which are usually used in bioethanol production such as traditional pretreatment and advanced pretreatment methods for lignocellulose. In the hydrolysis process the lignocellulosic biomass can be catalysed either with enzymes or acid. In the fermentation technologies there are some types of it, such as batch fermentation process, continuous fermentation process, fed-batch fermentation process, separate hydrolysis and fermentation (SHF), simultaneous saccharification and fermentation (SSF), simultaneous saccharification and co-fermentation (SSCF), and consolidated bioprocessing (CBP).

Lignocellulosic biomass >>> Pretreatment >>> Hydrolysis >>> Fermentation >>> Distillation >>> Bioethanol/Ethanol

Pretreatment Process

The pretreatment process of the lignocellulosic biomass will help to separate cellulose which is usually located in a matrix of polymers that consist of hemicellulose and lignin. This cellulose separation helps the process of hydrolysis - as it becomes more accessible and easier to produce sugar monomers in hydrolysis. If there is no pretreatment, the hydrolysis process will be not effective as the enzyme will just bind on the surface of the lignin.

There are some advantages on pretreatment process include:

- Helping to prevent degradation of sugars (pentoses)
- Ensuring viability of the bioethanol production, like reactor size, heat and power requirements
- Minimise the formation of inhibitors which can reduce the yield of the hydrolysis and fermentation from sugar to ethanol

Traditional Pretreatment

There are 4 different pretreatment methods such as:

- Physical pretreatment - In the physical pretreatment, the lignocellulosic biomass breaks down to the small size, this pretreatment involves milling, grinding, extrusion and irradiation. This method will increase the surface area and pore size of the biomass which can increase the efficiency of the enzymatic hydrolysis. Physical pretreatment can be combined with the chemical pretreatment to increase the efficiency of deconstruction of the lignocellulose (Edeh, 2020).
- Chemical pretreatment - The chemical pretreatment includes acid, alkali (base), and oxidative methods. However, the chemical pretreatment is highly sensitive and selective with the feedstock's types. Chemical pretreatment is very effective but it needs particular working conditions and environment, and as well by product from this method needs particular disposal.
- Physicochemical pretreatment - In the physicochemical treatment is actually combining both physical and chemical pretreatments.
- Biological pretreatment - In the biological pretreatment involves microorganisms like white-rot, brown-rot, soft-rot fungi and bacteria to breakdown the lignocellulosic biomass for further hydrolysis.

Advanced Pretreatment

This treatment is usually called lignocellulose fractionation pretreatment (Edeh, 2020). This treatment aimed to reduce the cost of the pretreatment process in the bioethanol production. This process is achieved by using cellulose solvents which are able to enhance the separation of the cellulose, hemicellulose, and lignin in the lignocellulose biomass.

There are 2 different advanced treatment methods:

- Acid-mediated fractionation - this method uses cellulose solvent like phospholic acid, acetone or ethanol, and operates at 1 atm and 50 ^{o}C to separate lignocellulosic biomass. This method is effectively used to pretreat some lignocellulose such as bamboo, corn stover, sugarcane, switchgrass and elephant grass (Sathisuksanoh, 2011).
- Ionic-liquid based fractionation (ILF) - Ionic liquids are simply salt solutions which consist of a significant quantity of organic cations and a small quantity of inorganic anions in the form of liquid in room temperature. This method is used to fractionate lignocellulose to obtain specific, purified and polymeric raw materials which are intact and are easily separated and used as value-added co-products (Edeh, 2020).

Hydrolysis

Hydrolysis is an important process in bioethanol production. Hydrolysis used to be done after pretreatment of the lignocellulosic biomass which had already broken down to polymeric carbohydrates (cellulose and hemicellulose). This stage will break down the polymers carbohydrate to sugar monomers. Hydrolysis process can be used with acid or enzyme catalysis.

The acid-catalysed hydrolysis is the method which is commonly used in bioethanol production. The acids which are frequently used in this hydrolysis are H_2SO_4 and HCl with high concentration and low temperature. The result of this method is 90% sugar recovery in a short period of time. However, this method has some advantages such as high cost, difficulty in acid recovery, control and disposal.

The enzyme-catalysed hydrolysis is another method in the hydrolysis process for bioethanol production. This process uses enzymes such as Clostridium, cellulomonas, Erwinia, Thermonospora, Bacteroides, Bacillus, Ruminococcus, Acetovibrio, and Streptomyces. Others include fungi such as Trichoderma, Penicillium, Fusarium, Phanerochaete, Humicola, and Schizophyllum sp. (Edeh, 2020). And the most commonly used microbial enzyme is Trichoderma sp. (Imran, 2016). This method has advantages such as high sugar recovery. However, there are some factors which affect the result, such as pH, enzyme loading and time, temperature and substrate concentration. The disadvantage of this method is high production cost, as the enzymes are expensive.

Fermentation Process

Fermentation is a biological process which converts monomeric sugar products from hydrolysis into ethanol, acids and also gases. This method is using yeast, fungi and bacteria. In this process, the most commonly used microorganism is yeast especially Saccharomyces cerevisiae as this microorganism has high yield of ethanol and high tolerance limits (Surendhiran, 2019).

There are some technologies on fermentation process to produce bioethanol such as batch, fed-batch, continuous and solid-state fermentation, simultaneous saccharification and fermentation (SSF), simultaneous saccharification and co-fermentation (SSCF), non-isothermal simultaneous saccharification and fermentation, simultaneous saccharification, filtration and fermentation, and consolidated bioprocessing (CBP).

Batch Fermentation Process

This is the most basic fermentation process in the bioethanol production, as it’s easy to control and has multi-vessel. The process involves adding the substrates, microorganism, culture medium and nutrients at the beginning of the operation in a closed system under favourable conditions at a predetermined time. The products are only withdrawn at the end of the fermentation time. However, the disadvantages of this process are low yield, long fermentation time and high labour, so this process is unattractive for commercial production.

Continuous Fermentation Process

This process involves adding substrates, culture medium and nutrients into a fermentor which contains active microorganisms and continuously withdrawing the products. The advantages of continuous fermentation process are high productivity, small fermenter volumes, and low investment and operational cost (Jain, 2014). Long cultivation time is the disadvantage of this process as it is a potential decline in yeast capability to support ethanol. The advantages are low capital investment, high productivity and small fermenter volumes.

Fed-batch Fermentation Process

According to Edeh (2020), Chandel (2007), and Xiao (2019), the fed-batch fermentation process is the combination of batch and continuous fermentation processes involving charging the substrate into the fermenter without removing the medium. Compared with other fermentation processes, the fed-batch process has higher productivity, more dissolved oxygen in the medium, shorter fermentation time and lower toxic effect of the medium. The disadvantage is that ethanol productivity is limited by cell mass concentration and feed rate.

Separate Hydrolysis and Fermentation (SHF)

According to Edeh (2020), Azhar (2017), and Tavva (2016), the enzymatic hydrolysis is separated from fermentation allowing enzymes to operate at high temperature and the fermentation microorganisms to function at moderate temperature for optimum performance. Since the hydrolytic enzymes and the fermentation organisms operate at their optimum conditions, it is expected that the productivity of ethanol will be high. The disadvantages of SHF are high capital cost especially as two reactors are required, requirement of high reaction time, and possibility of limiting the cellular activities by sugars released during the hydrolysis step.

Simultaneous Saccharification and Fermentation (SSF)

The simultaneous saccharification and fermentation (SSF) where the saccharification of cellulose and the fermentation of monomeric sugars are carried out in the same reactor simultaneously (Rastogi, 2018). According to Edeh (2020), the disadvantage of SSF is the variation in the optimum temperature required for efficient performance of the cellulase and microorganisms during hydrolysis and fermentation, respectively.

Simultaneous Saccharification and Co-fermentation (SSCF)

This involves carrying out the hydrolysis and saccharification in the same unit with co-fermentation of pentose sugars. Usually, genetically modified Saccharomyces cerevisiae strains that can ferment xylose are used since normal Saccharomyces cerevisiae cannot ferment pentose sugar (Bondesson, 2016). Like SSF, SSCF has the advantages of lower cost, higher ethanol yield and shorter processing time (Chandel, 2007).

Consolidated Bioprocessing (CBP)

According to Hasunuma (2012), this process requires the enzyme production, hydrolysis and fermentation to be carried out in a single unit. The microorganism mostly used in this process is Clostridium thermocellum as it has the capacity to synthesize cellulase which degrades lignocellulose to monomeric sugars and produces ethanol. Although, CBP is still at its nascent stage, the following advantages have been identified: less energy intensive, cheaper cost of enzyme, low cost of investment, less possibility of contamination (Edeh, 2020).

Biogas Production

According to the European Environment Agency, biogas is a type of gas, rich in methane, which is produced by the fermentation of animal dung, human sewage or crop residues in an air-tight container. Simply, biogas is a fuel in the form of gas which is produced by anaerobic process from biomass. Anaerobic process in biogas production is the process of methanogenesis (methane production) without the presence of oxygen.

Methane is a greenhouse gas and also a hydrocarbon which is a primary component of natural gas. However, methane can be produced in anaerobic process from biomass sources like wastes and sewage - so, it's not only come from natural gas (fossil fuel).
On average, biogas contains:

- 55-80% methane (CH_4)
- 20-40% carbon dioxide (CO_2).
- Trace gases, including toxic hydrogen sulphide and nitrous oxide.

In methane production, there are 4 essential steps such as hydrolysis, acidification, acetogenesis, and methanogenesis. These steps consist in the anaerobic digestion process. In the anaerobic digestion process, there are 2 different methods, including single-stage operation and two-stage operation. However, single-stage is less efficient, but it is simple. Many researchers recommended the two-stage operation, as it is more efficient in terms of retention time of biogas production.

According to the European Commission (2017), in Europe energy crops (mainly maize) provide about half of the biogas production (318 PJ, 7.6 Mtoe), followed by landfill (114 PJ, 2.7 Mtoe), organic waste (including municipal waste) (86 PJ, 2,0 Mtoe), sewage sludge (57 PJ, 1.3 Mtoe) and manure (46 PJ, 1,1 Mtoe).

Below is the simple biogas production flow scheme:
Feedstock >>> Pretreatment >>> Anaerobic digestion process >>> Raw Biogas >>> Purification >>> Storage >>> Distribution

Pretreatment Process

Similar to the bioethanol production process, pretreatment is needed in the biogas production. In biogas production, pretreatment aims to open up the structure of substrate which can increase the biogas yield. Pretreatment will improve the efficiency and quality of the anaerobic digestion result. There are 5 different pretreatment methods, such as physical, chemical, thermal, biological, and combination.

Physical Pretreatment Methods

In the physical pretreatment, the structure of biomass will be broken down by using physical force. This pretreatment is used to make the biomass easily processed in the anaerobic digester as the biomass is susceptible to microbial and enzymatic processes. There are different types of physical pretreatment methods such as:

- Milling
- Cavitation
- Microwave irradiation
- Extrusion

Thermal Pretreatment Method

According to Edeh (2020), thermal pretreatment improves hydrolysis, with increased methane yield during subsequent anaerobic digestion. A wide range of temperatures has been studied, ranging from 60 to 270°C, but temperatures above 200°C have been found responsible for the production of recalcitrant soluble organics or toxic/inhibitory intermediates during the pretreatment process (Wilson, 2009).

Chemical Pretreatment Methods

There are some types of chemical pretreatment methods that can be used in the biogas production process, such as:

- Acid PretreatmentAlkali Pretreatment
- Oxidative Pretreatment
- Ozonation Pretreatment

Biological Pretreatment Method

The biological mediated pretreatment process is based on the function of multiple forms of heterotrophic microbes (Edeh, 2020)**.** Fungal pretreatment improves degradation of lignin and hemicellulose and hence results in increased digestibility of cellulose, which is preferably essential for anaerobic digestion process. Several fungal classes, including brown-, white- and soft-rot fungi, have been used for pretreatment of lignocellulosic biomass for biogas production, with white-rot fungi being the most effective.

Combined Pretreatment Methods

There are different types of combined pretreatment methods such as:

- Steam explosion
- Physicochemical
- Ammonia fibre expansion

Anaerobic Digestion Technologies

Multiple-stage anaerobic digestion system is more efficient in terms of product quality and performance. The standard multi-stage anaerobic digestion system is a two-stage acid/gas (AG)-phased system, in which the acid-forming steps (hydrolysis and volatile acid fermentation) are physically separated from the gas-forming step (methane formation) by being conducted in separate digestion tanks. In order to design any anaerobic digester, we need to solve three principal requirements such as: to produce a high volume of high-quality biogas - able to continuously handle a high organic loading rate; and to have a short hydraulic retention time in order to have smaller reactor volume.

The first stage, known as the primary or acid phase digester, consists of the hydrolysis and the first acid-production step, in which acidogenic bacteria convert organic matter into soluble compounds and volatile fatty acids. The second stage, known as the secondary or the methane stage digester, consists of further conversion of organic matter to acetic acid through acetogenesis, as well as the methane formation step, in which methanogenic bacteria convert soluble matter into biogas.

According to EPA (2006), there are advantages of multi-stage anaerobic digestion versus single-stage anaerobic digestion processes include:

- Multi-stage systems require less digester volume to handle the same amount of input volume because they have lower retention times and allow higher loading rates than single-stage systems.
- Multi-stage systems have achieved VS reduction, which provides better odor control.
- A multi-stage system can be configured to reduce foaming problems.
- Multi-stage systems reduce the short circuiting of solids by separating the stages and optimising the retention time in each stage.

Disadvantages:

- The piping requirements for a multi-stage system, operation, and maintenance are more complex than those for a single-stage system.

There are various types of digesters, which are mostly used in the industry involving multistage systems:

- Continuous flow stirred-tank reactors (CSTRs)
- Anaerobic plug-flow reactors (APFRs)
- Anaerobic contact reactor (ACR)
- Biofilms
- Batch reactors
- Anaerobic baffled reactor (ABR)
- Hybrid bioreactor
- Upflow anaerobic sludge blanket (UASB)

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Chapter 5 - Biomass Project Development Processes

About

This Chapter will present an overview of the development process from the point of view of both project owners and professional project developers. It will provide the concept of a biomass project, describe the complexity of such projects, present the stakeholders involved, and discuss the stages of project development and implementation.

There are some objectives in this chapter:

- Understand the basic of the project development of the biomass-to-energy
- Able describe the complexity of the project development
- Understand the stages of the biomass-to-energy project
- Understand what types of stakeholders and other professionals who can involved in the project

Biomass-to-energy Project Concept

Biomass is one of the most promising resources for renewable energy production. According to the World Bank (2017), biomass utilisation have some advantages such as:

- Supply cheaper and more stable energy resources - like electricity, steam and heat for an industrial process or any kind of operation which needs constant energy supply.
- Develop and improve the economy of the business and operations by exporting surplus of the energy - electricity, heat or steam produced from biomass.
- Provide renewable energy options which can be a solution for the environment, local community and/or the industry itself.
- Reduce the greenhouse gas emissions by substituting fossil based energy resources like oil, coal and natural gas with biomass.
- Reduce potential waste from industrial and agricultural to be disposed of to the landfill by utilising them as energy feedstock.

With biomass-to-energy projects can bring positive impacts on the energy demand. There are two types of energy us from the bioenergy production:

- Use for electricity, heat or steam generation for in-house consumption
- Use for in-house consumption and the surplus for business purposes - like exporting electricity, heat or steam for other energy use.

The most important point for the biomass project development is biomass supply sufficient or not for long-term production. Also, the project developer has to explain the financial viability - because it will give a big impact to investors. If the project developer fails to ensure the biomass availability and financial viability of the bioenergy project, they will never get to obtain the project in an effective financial phase.

However, to calculate the availability and financial viability, below on Table 5.1. explained the technical viability for the bioenergy production based on minimum amount of the biomass needed and available technology based on COWI

Table 5. Biomass Minimum Input Amounts and Plant Technology Sizes (COWI)

Technology	**1-1.5 MWe**	**5-10 MWe**	**10-40 MWe**
	Minimum Biomass Input (tons/day)		
Combustion plants using a water/steam boiler	20-100	100-200	200-900
Combustion plants using ORC technology	50-200	200-500	n/a
Biogas production with gas engine	40-200	n/a	n/a

Project Stages

There are two different project stages such as project preparation and implementation. According to the World Bank (2017),

Preparation Stage

There are 4 different phases of the preparation stage of the bioenergy project development, as it follows:

1. Project Idea

   Preparing the detailed concept idea before other studies and development of the project is necessary. The project ideation is needed to make sure the main idea is feasible for the implementation - including environmentally, social, and financially. The biomass resources, local issues, national regulations and use of the bioenergy can be part of the main consideration of the project ideation. The detailed overview of the project idea and concept are explained above (previous section).

2. Pre Feasibility Study

   The pre-feasibility study aims to initially measure the potential of the implementation and investment of the project. There are some points needed to be considered in the pre-feasibility study, such as:
   1. Description of the biomass fuel resource (amount, characteristics, price, transport, logistics, need for supplementary fuel, etc.)
   2. Barriers for the project
   3. Potential technical concepts (several concepts may be identified and briefly assessed)

4. Calculation of expected energy production (electricity, steam, heat)
5. Preliminary layout
6. Possibility to connect to the electrical grid (distance to grid, voltage level, costs for connection, etc.)
7. Preliminary assessment of energy sales (PPA, electricity price, heat price, steam price, etc.)
8. Preliminary assessment of alternative sites (access to site, size, connection to grid, sewer, etc.)
9. Preliminary assessment of alternative locations
10. Preliminary assessment of environmental and social risks and impacts
11. Preliminary assessment of construction costs (CAPEX) and operating costs (OPEX)
12. Preliminary financial analysis
13. Preliminary risk assessment
14. Preliminary assessment of necessary permitting and licensing
15. Planning and project implementation, including tentative time schedule.

To develop pre-feasibility study document, it can be developed with contents highlight below (World Bank, 2017):

1. Introduction
2. Conclusion and recommendations
3. Description of the project
4. Expected energy production
5. Power and heat demands
6. Preliminary environmental impact assessment
7. Assessment of alternative sites
8. Layout
9. Civil engineering design
10. Electro-mechanical equipment
11. Grid connection
12. Cost estimation (CAPEX/OPEX)
13. Permitting and licensing process
14. Planning and project implementation
15. Preliminary financial analysis
16. Preliminary risk analysis
17. Appendices

3. Feasibility Study

When the analysis and outcomes of the project from pre-feasibility study is favourable, detailed feasibility study can be developed. The aim of the feasibility study in the project is to create details for the interested parties and stakeholders to make a commitment to proceed with its development. Also, it will help the project to be more organised and realistic. This feasibility study can help to gain investment from financial institutions - as they are required to do this study in the project development.

There are 3 different feasibility study stages according to the World Bank (2017), such as:

1. Conceptual Design
    a. Definition of fuel characteristics, such as composition and heating value
    b. Description of applied technology
    c. Evaluation of suitable technologies, including fuel handling, combustion system, boiler, ash handling and disposal, flue gas treatment technologies to meet applicable and relevant air emission standards, energy recovery system, etc.
    d. Assessment of potential plant location(s) following an evaluation of technical, environmental, and economic aspects, and local acceptability
    e. Initial assessment of capital costs (CAPEX) and operational expenditures (OPEX)
    f. Assessment of potential use of steam and/or heat. Is it possible to use the heat for industrial purposes, perhaps as steam? Is there a market for district heating/cooling?
    g. Examination of the connections to the electrical grid, other external off take customers, water and wastewater services, etc
2. Bankable Feasibility Study
    a. The conceptual design and required investment
    b. Secured long-term supply of biomass (volume, heating value/properties, and price)
    c. Financial and economic analysis including cost-benefit calculations, calculations of net present value (NPV) and internal rate of return (IRR), and similar analyses
    d. Overview of current regulatory and policy framework relevant to the project
    e. Assessment of potential additional sources of financing, sensitivity analyses, and risk analyses important to financing institutions
    f. Assessment of potential risks to the financial viability of the project and suggestions of mitigation measures
    g. Environmental and social impact assessment, including identification of mitigation measures
    h. Organisation studies of potential O&M service companies
    i. Procurement plan and identification of potential equipment suppliers and contractors
    j. Implementation plan, including time and financing schedule.
3. Authority Permits
    The following elements are normally part of the permitting process:
    a. Environmental permit based on the environmental impact assessment prepared as per regulatory requirements
    b. Planning permission
    c. Building permit
    d. Power grid connection approval, if relevant
    e. District heating system, if relevant
    f. Approval for wastewater discharge, if any.

Note: If the feasibility study indicates that the project is viable, the next stage of the project can be started.

4. Contracts and Financing

   The contracts and financing stage takes the project from the feasibility study to final investment decision (FID) by the project owner. This involves moving the project forward on a number of fronts, including outline design and selection of contractor(s).
   Selection of contractors can be done several ways via public procurement, including competition among qualified potential bidders, or via a dialogue-based procurement process with one or several potential contractors.

Project Implementation

After the project preparation stage and if the outcome is viable, there is the next stage which is project implementation. The project implementation based on the project preparation documents developed initially. According to the World Bank (2017), there are 5 stages in the project implementation, such as:

1. Preparation and review of the detailed design of the system
2. Construction
3. Commissioning
4. Operations and testing stage
5. Decommissioning

Project Development

There are some components of bioenergy project considerations, as it will affect the development of the project. According to the World Bank (2017), there are some barriers in the bioenergy project development such as:

- Is a site with proper access and size available at reasonable cost?
- Does the project owner have sufficient strength to run the project?
- Is financing available at reasonable terms and conditions?
- Is a well-defined market available for export of energy (electricity and/or steam/heat), offering long-term secure prices and making the project feasible?
- Is a grid connection available within a short distance, and is connection possible at reasonable terms? (This is not relevant if the project is developed only for self-supply of electricity and/or heat/steam.)
- Is national (and any regional or international) legislation in favour of this type of project, and can environmental approval be expected?

Those questions need to be answered before moving forward to the project development implementation. Other than that, there some other points and considerations in the project development as it follows:

1. Site Identification

Site is an important point to place to be considered at si the system and all operations in more sustainable ways - environmental, financial and social. There are some questions which can help to identify suitable site identification such as:

- What is the cost of suitable and available sites?
- Are there any restrictions on their use?
- Is the potential site large enough for the biomass plant and for the necessary biomass storage area?
- How is the infrastructure of the area? For example, connection to grid (if relevant), connection to heat/steam customers (if relevant), road/railway access (if relevant), power supply, sewer connection, raw water supply, etc.
- What is the distance from the biomass resource?
- Is sufficient storage space available to accommodate interruptions in external fuel supply (rainy season, blocked roads, etc.)?

2. Biomass Supply and Resources

In the project development, it is important to know the supply and resources of biomass for long-term projection. It will help to project the production in sustainable ways of production. There are some questions which can be used by the project owner to consider the feasibility of the project:

- Is sufficient biomass available, and from whom/where?
- Is seasonality or the rainy season an obstacle?
- How is the biomass stored until delivery to the plant (at the biomass supplier's place)?
- Who delivers the biomass, and what is the contractual setup?
- How is the quality of the biomass verified?
- What is the price and the payment mechanism (weight, moisture content)?

3. Technical Considerations

Apart from the biomass supply and resources, the technology used should be considered before making any decision towards it. After answering the questions related to the biomass supply and resources, the project owner can make considerations about the technicality. There are some questions which will help the technical considerations, such as:

- Is biomass waste appropriate as a fuel for energy production?
- Is potential corrosion behaviour of the fuel acceptable for technology providers?
- If supplementary biomass fuels are needed, can the biomass plant operate without limitations on both on-site and off-site sourced fuels? (Fuel handling, steam boiler, and flue gas cleaning are important points to consider.)
- Is it technically and economically feasible to convert the biomass waste to electricity/heat?
- Is sufficient biomass fuel available, and, if not, are supplementary fuel sources available, and at what cost and terms?

- Is a connection to the grid possible at the correct voltage (if export of power is relevant)?
- Is a connection for the supply of steam and/or heat to nearby industries or district heating networks accessible (if export of heat and/or steam)?
- Who will pay for the transmission line to the grid connection point and for the heat/steam connection?
- How is biomass handled and stored at the site?
- How is backup energy supply secured (in case of plant breakdown, lack of biomass supply, etc.)?

4. Project Operation and Maintenance

In project development, the considerations of how everything works and maintain are important, as it will help to figure out how the project can work sustainably and in the long term. After answering questions related to the site, biomass supply and technicality, there are other questions to consider how the project operate and maintain including the human resources and technology, such as:

- Will the plant's own staff carry out maintenance, or will it be outsourced?
- Are staff with required skills locally available to manage and operate the plant?
- Will the plant have a high degree of automation, thus reducing the need for manpower? (This may require more highly skilled staff.)
- Are disposal routes for ashes available?

5. Legislation

One of the most important parts of the bioenergy production project development is legislation. It is important to keep making sure the project aligns with all the regulations and standards by each country. There are some main questions which can be answered to make sure the feasibility of the project, such as:

- Is national (and any regional or international) legislation in favour of this type of project, and can planning and environmental approvals be expected?
- Does legislation allow such facilities?
- What are the local and national emission limits that need to be met? What is the associated cost?

6. Project Economy and Financing

After all the points above answered, project economy and financing can be calculated. The project economy and financing is important to keep the project running and implemented efficiently in the longer term. There are some questions which can be answered on calculating and plan the project economy and financing such as:

- Who will be the owner and operator of the project?
- Is the project financially viable, and are potential risks identified and adequately mitigated?

- Does the project have access to sufficient financing from internal sources, or will external financing from financial institutions be necessary for implementation?
- Is financing available at acceptable terms and costs?
- Is the project dependent on external sale of energy? If yes, is there a market for the sale of electricity, process steam, or heat to outside customers?
- What terms can be obtained for connection to and sale of electricity to the grid, including available support mechanisms for renewable energy such as feed-in tariffs, clean energy certificates, etc.?
- Is there a tariff for the sale of heat and/or steam?
- Can the feed-in tariff be guaranteed, and what are the commercial terms and timeframe?
- Is the anticipated project revenue sufficient to generate a return on investment (ROI) commensurate with project risks?

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Chapter 6 - Commercial Aspects of Biomass-to-Energy

About

This Chapter will provide the information about the regulation and framework of the commercialisation of biomass-to-energy. It will present a better understanding about the regulation from the EU about biomass supply agreements, power purchase, steam/heat supply agreement, and residue disposal from the bioenergy production agreement.

There are some objectives in this chapter:
- Understand the the structure of agreements in the biomass supply
- Understand the the difference processes of agreements in the bioenergy project development
- Understand EU regulation and framework about biomass-to energy commercialisation
- Understand how to implement the regulation and framework to the real work

Background

Commercial aspects of bioenergy are important to be considered. Those aspects are important in the projects which rely on the external supply - from its biomass, production, selling and waste treatment. To make sure the project is financially viable, formalising the agreements with suppliers and third parties is a necessity.

The agreements in the project development and implementation will help the developer, supplier and also third parties to have concrete knowledge and realistic financial analysis to establish the project effectively and more organised. In the biomass to energy commercialisation aspects, there are some considerable aspects to have, as it follows:
1. Biomass supply agreements - which can include onsite biomass supply and external biomass supply (from suppliers)
2. Financial and loan agreements - which include equity for the project, loans from bank
3. Authority approvals
4. Construction agreements - which include consultants, technical constructor and also insurance company to cover the risk possibility
5. Consumption and purchase agreements - which include inhouse energy consumption and external sell to customers.

Biomass Supply Agreements

Biomass supply agreements are important in the project implementation. In the bioenergy project, biomass plays the main role to keep the project going. If the biomass supply fails, the project will fail too and consequences are high especially in the financial aspect.

According to the World Bank (2017), the most important factors to incorporate in a biomass supply agreement are the following:

- Quantity of biomass (tons per day, delivered on-site) and what happens if the supplier does not supply biomass in accordance with the agreement
- Quality of biomass (typically weight and moisture content), how quality is determined, and what happens if the specifications are not met
- Price of biomass (Euros per ton) and how the price varies with quality parameters
- Place of delivery (ideally on site)
- Rejection criteria and consequences of late delivery.

There are main outline structure in the biomass supply agreement (World Bank, 2017), as it follows:

1. **Explanation of the between supplier and end user** for the biomass supply to which site or project
2. **Purpose**
   "The supplier agrees to supply to the end user, and the end user agrees to purchase from the supplier, biomass to the specifications, in the quantities, for the period, at the price, and on the terms and conditions set out below."
3. **Duration of contract**
   "This contract is for a period of [XX MONTHS/YEARS] and will commence on [DATE] and end on [DATE]."
4. **Quantity**
   "The minimum monthly quantity of biomass supplied during the defined contract will be [XX] cubic metres [OR XX TONS]. In case of a shortfall in the biomass available to the supplier, the supplier shall be responsible for [SOURCING FROM THIRD PARTIES/PAYING COMPENSATION]."
5. **Source and delivery**
   "The biomass will be derived from the following sources: [insert as appropriate].
   Biomass will be supplied in [BAGGED/BALED/LOOSE] form and delivered to the end user by a suitable vehicle for delivery into the end user's fuel store."
6. **Quality and specifications**
   "Regulating key quality parameters such as, for example, moisture content.
   The target moisture content on a wet basis shall be [XX%] by weight based on the [relevant standards] but in any event shall not exceed [YY%]. In case of delivered biomass not meeting the minimum specifications as determined through sampling, the supplier shall be responsible for [COMPENSATION]."
7. **Weights, sampling and analysis**
   "The end user may at any time send representative samples of biomass for evaluation, analysis, testing, and approval. All samples must meet the specification."
8. **Price**
   "The price for biomass delivered into the fuel store of the end user will be based upon the following tariff up until [DATE] $ [XX] per cubic metre of biomass; [OR: $ XX PER TON OF BIOMASS]. For biomass complying with minimum specifications but with a moisture content above [ZZ%] the price shall be [ADJUSTED PRICE]."
9. **Invoices, billing and payment**
   "The supplier will invoice the end user on a monthly basis. This will be based upon the number of loads recorded (by weight or volume) and will be assessed on the XX day of each month."

10. **Insurance**
    "The supplier will have adequate public liability insurance for handling and transport of the specified quantities of biomass. The responsibility for insuring the end user against the economic consequences of a possible inability of the supplier to meet the contractual obligations shall be with [END-USER/SUPPLIER]. Irrespective of this, the supplier shall in case of default of the obligations under this contract pay the end user a penalty defined as [definition of penalty upon default]."
11. **Event of dispute**
12. **Termination**
13. **Force majeure**
14. **Representation**
15. **Governing law and jurisdiction**

Power Purchase Agreements (PPA)

When the project produces more energy than the project owner's energy needs, they can prepare PPA. This agreement can work between the project owner - an independent energy producer and power purchase which is often a state-owned electricity utility company. The PPA isa a long term agreement which uses commercial provisions for energy prices and quantities during the given period. Also, this agreement will provide both producer and purchaser a security and stability in the power purchasing process. The commercialisation aspect will help to keep a stable revenue stream to secure the project implementation in the long-term period.

According to the World Bank (2017), there are key elements of PPA, such as:

1. Required quality of the power (frequency, voltage, planned outage)
2. Quantities of capacity and energy sold (MWh per year)
3. Price of electricity output (Euros per MWh) and available capacity (if the project is perceived as baseload), the price may reflect special feed-in tariffs for renewable energy and renewable energy credits
4. Flexibility for producer to make third-party sales (if allowed by the purchaser)
5. Compensation to producer in case of production limitations (by purchaser or transmission system operator) due to constraints in transmission system
6. Compensation to purchaser in case of delays in completion of project or underperformance of delivery (may include sanctions or liquidated damages for projects being perceived as baseload)
7. Timeframe of the agreement (typically five years or more)
8. Dispatching rules, including potential restrictions.

There are key structures of the PPA, as it follows:

1. Purpose
2. Facility description
3. Interconnection facilities and metering
4. Obligation to sell and purchase energy output
5. Payment for energy output
6. Supporting regulatory framework (feed-in tariff, purchase obligations, etc.)
7. Billing and payment

8. Operation and maintenance
9. Default and termination
10. Contract administration and notices
11. Dispute resolution
12. Force majeure
13. Representations and warranties
14. Insurance and indemnity
15. Regulatory jurisdiction and compliance
16. Assignment and other transfer restrictions
17. Confidential information
18. Miscellaneous

Steam/Heat Supply Agreement

Similar to the power purchase supply agreement, this agreement focuses on the excess of steam/heat (hot water) which can supply a nearby industry. This activity helps to sustain revenue of the project. According to the World Bank (2017), the heat supply agreement should include and define the following elements, such as:

1. Steam/heat parameters (temperature/pressure) and maximum variations
2. Quantities of heat sold (MWh per year)
3. Price of heat (Euros per MWh)
4. Responsibility for investment costs for the heat transfer infrastructure between the heat supplier and the heat user
5. Timeframe of the agreement (years).

Bio-Residue and Waste Disposal Agreement

As the biomass-to-energy process results in residues and waste, the disposal agreement is a necessity. The waste can come from combustion process, biogas production and other bio-work in the project which must be disposed of. The result of disposal can produce other products which are useful for re-use purposes, like fertiliser - even if the quality is good, it can be another revenue in the project.

There are some key elements in the bio-residue disposal agreement, as it follows:

1. Quantities of the bio-residue (tons per day)
2. Quality of the bio-residue (nutrient value)
3. Price (or cost of disposal) of the bio-residue (Euros per ton).

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Chapter 7 - Economical Evaluation

About

This Chapter will provide an overview about the cost analysis and evaluation of bioenergy production. This section can give deeper understanding about how to calculate and evaluate the economical aspects of bioenergy production.

There are some objectives in this chapter:

- Understand the basic of economical evaluation of the biomass-to-energy conversion
- Able to calculate the economical aspects of the bioenergy production
- Understand important points in the economical calculation and evaluation of the bioenergy production

Background

Economical evaluation of the project is a necessity to be analysed. The evaluation consists of financial and economic analysis. Financial analysis should be done in detail to keep the project working effectively and realistically. The analysis of the project can help project implementation in the long term. Economic analysis will help the project owner to evaluate the impacts on society by calculating cost and benefits.

Financial analysis can help the project owner, investors and also bank - loan management to be able see the feasibility of the project and its management. It will be an important element to keep the owner, investors and other relevant stakeholders to feel secure and realistic about the project and understand about the costs and benefits of the project.

About the financial analysis in a business, there are elements which can support to develop scenario in the project, such as:

1. Latest cost of the energy, it can be another type of the energy and resources. It will help to compare the current energy available and in-the-project produce energy costs.
2. The stability of the energy supply.
3. Storage and disposal analysis which can include the costs and any other technical risks and issues.

There are key elements which differentiate financial and economic analysis, such as:

1. Financial analysis
    a. The evaluation based on the investor's perspective
    b. Market prices is important to be considered
    c. Taxes, tariffs, etc are important to evaluate which can help to manage the project costs and benefits
    d. Focus in internalities
2. Economic analysis
    a. The evaluation based on the society's economic perspective
    b. Value of taxes, tariffs, subsidies, etc of the project to society
    c. Consideration of external factors both negative and positive, like reduction of greenhouse-gas emissions, etc.

According to the World Bank (2017), there are key elements to ensure the biomass project is financially sustainable such as:

1. Availability of the biomass feedstock supply is stable and secure.
2. Stable market which can provide easy access to distribution for the produced electricity or heat.
3. Availability of the biomass volume is sufficient for the operation and technology used in the project.
4. All the processes like biomass collection, storage and transportation, pretreatment processes, waste and residue treatment process of the project can be well financed in the project.
5. Acceptable rates and affordable rates in the financing phase.

About the economic analysis, there are some key elements to keep the project economically viable and sustainable, such as:

1. The biomass resources for the energy production will not cause negative social impacts, like food crisis, biodiversity loss, etc.
2. Supply of the biomass feedstock comes from secondary or tertiary sources, like residual biomass which can be beneficial for climate and environment.

Financial Analysis

As already mentioned above, financial analysis will help project owners, investors and relevant stakeholders to evaluate the project in terms of financial viability. An investor will be interested to invest in the project if the internal rate of return is higher than the weighted average capital cost. Simply, the investment should generate a profit.

There are some risks associated with the financial viability of biomass-to-energy projects, such as:

1. Supply of the biomass feedstock is unstable.
2. Quality of the biomass is insufficient compared to the technology used in the project.
3. Market access for the products is low.
4. Unfamiliarity with investments of the biomass and bioenergy projects.
5. The limitation of the collection, transport and other technical processes of the biomass feedstocks.

According to the World Bank, there are typical benchmarks for key financial parameters in biomass projects, such as:

1. Internal rate of return (IRR) of the project: >10 percent
2. Net present value of the project: > 0 percent, dependent on the risks related to the project
3. Payback period: <10 years
4. Debt service coverage ratio: 1.2 to 1.5

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Note: *The above-mentioned estimates are generalised results and will differ across borders and project-specific conditions. Domestic benchmarks for these criteria often depend on the economy's underlying interest rate, country risk, and general level of economic development and are subject to changes over time.*

Below is approach to financial analysis (the World Bank, 2017):

(Revenues from energy production) - (CAPEX) - (Cost of Financing) - (OPEX) = (Net Value)

To get better understand about the approach to financial analysis, there are key methodologies used in a financial analysis applied for the biomass-to-energy projects, as it follows:

1. Weighted Average Cost Capital (WACC)

WACC is a calculation of cost of capital in which each category of capital is proportionately weighted. Therefore, WACC is the appropriate discount rate for a financial assessment. The discount rate of the project is very important, as it affects the present value of future costs and benefits.
The WACC is calculated using the following formula:

WACC = (Share of Equity x Cost of Equity) + (Share of Debt x After-tax Cost of Debt)

2. Revenue

In the implementation of the project, revenue is needed to evaluate and assess. The revenue must consider the demand of the market for the produced products - it can include tariff and how it has an effect on the cash flow. The output amount and prices are important to be evaluated for the financial viability of the project.

In the biomass-to-energy revenue, there are 2 different resources as it follows:

a. On-grid, which includes:
    - Electricity
    - Heat
    - Gas
    - Residues which potentially can be converted to other products, like fertiliser
b. Off-grid, which includes:
    - Savings from external sources, like coal, natural gas and oil
    - Residues which potentially can be converted to other products, like fertiliser

3. Cost of Biomass Supply

Biomass supply of the project is crucial to assess. The calculation of the biomass supply will help the project implementation secure and stable. There are some key cost elements which important to calculate biomass supply, especially if the biomass comes from different sources, such as:

a. Cost of collection
b. Cost of transport
c. Cost of pretreatment
d. Cost of storage

4. Capital Expenditures (CAPEX)

In the biomass-to-energy project financial analysis, CAPEX is a total investment cost which is needed to develop and procure the project plant, including property, buildings, equipment, machinery and other needed technologies.

A capital expenditure must be capitalised. This requires the owner to spread the cost of the expenditure (the fixed cost) over the useful life of the asset.

5. Economic Lifespan

According to the World Bank, The average lifespan of a biomass-to-energy plan is assumed to be 20 to 30 years, which also is the length of the financial analysis. It is important to include the residual value of the energy plant if a shorter analysis period is selected.

Economic Analysis

An economic analysis is usually conducted based on a request from the public authorities (for example, in connection with an investment grant request), to provide knowledge about the impacts that the project will have on society. The importance of this type of analysis varies significantly with the project size. An economic analysis estimates the net benefit of the project by incorporating all benefits and costs, including external effects, which are quantified and expressed in monetary terms.

- Smaller biomass projects in developing countries, decoupled from the national grid, will have mainly a local economic impact. The social and environmental impacts also are of local scale.
- Larger biomass projects, connected to national energy grids, will have a bigger economic impact on society as a whole. The larger amounts of biomass applied in the project, the larger the environmental and potentially social impact.

Below is approach to economic analysis (World Bank, 2017):

(Revenues from energy production) + (External benefits to society) - (Investment costs and O&M costs) - (External costs to society) = (Net benefits to society)

1. Local Economic Benefits and Costs

A biomass project potentially can have important impacts on the local economy, or it might function without affecting the local area at all. The potential positive and negative local effects of a biomass project are as follows:

Benefits:

- A possible increase in income for local farmers as a result of local demand for biomass
- A local source of stable energy from the biomass plant
- The creation of local jobs (either at the plant or in the agricultural sector)
- Possible infrastructure improvements, such as grid connection or improved roads for biomass transport.

Costs:

- Negative environmental effects due to emissions from plant
- Social effects should be carefully considered. If the biomass to be used for energy production is currently used by locals for human consumption, animal consumption, or income generation, removing the biomass may cause social problems.

2. Public Economic Benefits and Costs

Biomass projects may have an impact on the macroeconomy, and can provide several other macroeconomic benefits, such as:

Benefits:

- A stable energy supply
- Fewer subsidies for fossil fuels in public budget
- Improved opportunities for industrial production, and thereby job generation, due to the stable energy supply
- National increased security of energy supply, making the country less dependent on import of foreign energy Reduction of greenhouse-gas emissions, as energy from bio-waste implies less emissions compared to alternative fossil-based energy sources
- More environmental benefits from reducing alternative fossil fuel-based electricity generation
- Reduced health costs and better overall air quality from pollution externalities.

Costs:

- No negative environmental effects, unless primary biomass is used for energy generation. This would undermine the sustainability of the project, causing an overall global increase in greenhouse-gas emissions.
- Negative economic effects: Capital expenditures and operation and maintenance costs, potential risk posed by foreign currency exposure to exchange rate volatility

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Chapter 8 - Environmental and Social Evaluation

About

This Chapter will give the introduction and provide an overview about the methodology of the screening and assessing environmental and social (E&S) risks and impacts of the biomass-to-energy processes.

There are some objectives in this chapter:

- Understand the environmental and social risks and impacts of the bioenergy production
- Understand how to assess the environmental and social impacts of the energy production

Background

Environmental and social issues could arise from biomass-to-energy production projects and plants. The environmental and social assessments are important to be developed in the project development.

Biomass can provide alternative energy which can substitute fossil fuels regarding the greenhouse gas emissions benefits. However, the use of biomass for energy can have an impact on the social and local environment, such as air quality, biodiversity, water consumption and also land use at the local level. Also, in social perspective, it can impact local livelihoods, food security, employment and also poverty.

According to the World Bank (2017), there some examples of environmental and social impacts of biomass projects, as it follows:

1. Environmental impacts, such as:
    - Air quality: Emissions from combustion of bio-residues can lead to air pollution.
    - Nutrients: Removal of residues from the agricultural ecosystem can lead to depletion of nutrients in soil if the ashes are not returned to the soil.
    - Biodiversity: If demand for residues increase beyond supply, new agricultural areas can be created from conversion of, for example, wetlands, shrub land, or forest, which can negatively impact biodiversity.
    - Water: Both water quality and quantity can be affected, for example by discharge of wastewater or increased use of groundwater for production of biomass.
    - Land: If only secondary resources are used, local impacts on land are probably small. However, if other users already utilise the feedstocks, environmental consequences could arise if these users pursue other feedstocks

2. Social impacts, such as:
    - Employment: The bioenergy plant can generate employment in the region.
    - Economy: The plant can benefit the local economy.
    - Food security: Depending on existing uses of the feedstock, potential food security issues can arise if food or feed crops are used for energy generation.

There are several policies and tools which can be used to assess environmental and social impacts, as it follows:

- IFC Performance Standards: Environmental and Social Performance Standards and Guidance Notes define IFC clients' responsibilities for managing their environmental and social risks.
  Available at:
  http://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/IFC+Sustainability/Our+Approach/Risk+Management/Performance+Standards/
- Equator Principles: A risk management framework, currently adopted by 83 financial institutions in 36 countries, covering 70 percent of international project finance debt in emerging markets. The principles are used to determine, assess, and manage environmental and social risk in projects, primarily intended to provide a minimum standard for due diligence to support responsible decision making.
  Available at:
  http://www.equator-principles.com
- Bioenergy Decision Support Tool: Planning Strategically and Assessing Risks in Investment Choices, developed by UN-Energy, the UN Food and Agriculture Organisation, and the UN Environment Programme.
  Available at:
  http://www.bioenergydecisiontool.org
- RASLRES Bioenergy Tool, developed by the EU European Regional Development Fund.
  Available at:
  http://www.raslres.eu
  Note: that this tool is developed for the Nordic region and is mainly applicable in similar settings.

Environmental Assessment

The main topics of the environmental impact assessments in the biomass-to-energy project are water, biodiversity, soil and land, and air.

1. Water

With unsustainable use of water remaining a threat to environment and human development alike, the use of water for bioenergy projects must be sustainable and must not compromise water quality and quantity.

According to the World Bank, there are key questions to assess water use in the biomass-to-energy project, such as:

- Will the use of water for biomass production or feedstock conversion affect water availability or security of supply in the watershed?
    - If additional or new irrigation is needed to produce the bioenergy crop, a local water balance should quantify how the project impacts local water resources.
    - If biomass or feedstock producers that are connected to local water distribution networks plan to increase their water use, the impact on security on water supply may be substantial and should be assessed.

- Will the use of water for production of biomass or conversion of feedstock affect water quality?
    - Consider, for example, if production of the crop drives changes in land management, clearing of land, or removal of trees. If so, there may be a risk of loss of topsoil through erosion, which could end up having an impact on streams and rivers.
    - If additional or new fertilisers or pesticides are to be used, this may have implications for water quality. Consider both groundwater and surface water resources.
    - If the biomass or feedstock producer will use additional or new water resources because of the project, the capacity and quality of local water treatment systems should be evaluated and taken into account in the design.

- Will the use of water for biomass production or feedstock conversion change water flows and water availability for downstream users?
    - If any streams, pipes, or reservoirs are impacted or changed because of biomass or feedstock production, this could affect local water supply.

Note: If the answer to any of the above questions is “yes” one or more issues of concern will need further investigation and assessment.

2. Biodiversity

Development of bioenergy can have adverse impacts on biodiversity by causing habitat loss, fragmentation of areas, and loss of species. Biodiversity not only has value as a provider of services to humankind (for example, food, medicine), but also has value in itself. Furthermore, diverse, connected, and well-functioning habitats are most resilient against external threats such as climate change or pollution. It is important to assess, prevent and minimise the impacts of projects in ecosystems and biodiversity.

According to the World Bank, there are key questions to assess biodiversity in the biomass-to-energy project, such as:

- Will the biomass project affect rare or threatened species?

  - The risk to any rare or threatened species should be assessed. This is particularly critical if natural habitats (forests, wetlands, etc.) are modified or if production is intensified on currently farmed areas. At the global level, rare or threatened species are listed on the IUCN Red List of Threatened Species, which can be accessed at: http://www.iucnredlist.org.
    Consideration of regional-level lists of threatened species should also be included in the assessment.

- Will the biomass project affect threatened ecosystems or habitats, for example through degradation, conversion, loss, or fragmentation?
  - If land is cleared for cultivation, there is a risk that ecosystems or habitats can be lost or fragmented, which can have adverse impacts on species in those regions.
  - Intensification of production, loss of nutrients, or excessive pollution can lead to degradation of natural habitats surrounding the project area.

- Will the biomass project lead to the introduction of non-native and/or invasive species?
  - The risk of invasive species should be considered in those situations where non-native flora (such as a new energy crop) is introduced to the region.

- Will the biomass project affect or change ecosystem services in the area?
  - Ecosystem services comprise a host of different services, and modifications to natural landscapes generally put one or more of these at risk. It is therefore necessary to assess for impact on ecosystems.
  - Care should be taken that ecosystem services that provide vital services to the region are not put at risk (for example, protection against flood or water purification performed by mangrove forests).
  - Ecosystem services are often not part of the formal economy (that is, the value provided by these services is not valued in economic terms), but they provide important functions for the local region and the affected communities. Care therefore should be taken to ensure free, prior, and informed consultation and participation by the affected communities.

Note: If the answer to any of the above questions is “yes,” one or more issues of concern will need further data collection and assessment.

3. Soil and Land

Land is a scarce resource, its use becomes important for social, environmental, and economic reasons. Sustainable use of productive areas is important for food production and for the delivery of a range of ecosystem services, such as purification of water, carbon storage, protection against erosion, and as habitat for plants and animals.

According to the World Bank, there are key questions to assess soil and land in the biomass-to-energy project, such as:

- Will the biomass project lead to the conversion of land uses, for example, the conversion from wetlands and/or forest to agricultural land, to meet demand for the bioenergy feedstock selected for the project?
    - If the project involves a call for suppliers in the local area, landowners may be enticed to change land use, for example by clearing shrub land or forests to make way for a plantation or other productive land. In such cases, there could be a risk of loss of biodiversity and carbon.
    - The sourcing of primary or secondary biomass or feedstock may cause a risk of land conversion. For waste-based systems, this risk should be minimal.

- Will anticipated changes in the land management, the use of the land, or intensified use of the land to produce biomass or feedstock for the project affect neighbouring or more distant areas or landowners (for example, if current production shifts to other lands)?
    - If the project entails increased demand for a primary or secondary biomass in the host region, landowners may shift from food or feed crops, resulting in decreasing supply of these. This may lead to the conversion of new land elsewhere to supplement the lost production. In such cases, due care should be taken, and impacts on supply and demand in the region should be subject to further analysis.

- Will production of biomass affect the soil quality or lead to degradation of soil and land?
    - Consider if the provision of biomass for the project entails changes in land management, for example, increased tillage or the use of heavy machinery. This may impact the soil, possibly resulting in degradation.
    - When secondary biomass resources are used, soil degradation and loss of nutrients can occur if ash and other residues are not returned to the soil.
    - If the project is linked to the production of cattle or other grazing animals, additional demand may lead to farmers increasing the number of animals. This, in turn, can lead to overgrazing, which in some areas can cause erosion, and, in other areas, can start desertification processes.

- Are artificial fertilisers or pesticides needed in order to grow the feedstock in sufficient quality and quantity?
    - The use of fertilisers or pesticides may negatively impact soil and water quality, soil productivity, and soil biodiversity.

Note: If the answer to any of the above questions is “yes,” one or more issues of concern will need further data collection and assessment.

4. Air

Clean air is important for humans, animals, and the environment, and air pollution is detrimental for health and food production, among others. Care therefore should be taken to avoid air pollution from the production or conversion of feedstock for bioenergy production. Air pollution can be biological (pollen, fungi), physical (smell, thermal, radiative), and chemical (ozone, nitrogen oxides, sulphur oxides) and could result from plant emissions and changes of management practices (such as intensification) on agricultural land or in forests.

According to the World Bank, there are key questions to assess air in the biomass-to-energy project, such as:

- Will production, conversion, or transport of the feedstock cause emissions of air pollutants, such as nitrogen oxides, particulate matter, sulfur oxides, ozone, aerosols, soot, or volatile organic compounds?
    - Use of heavy machines or some types of trucks for transport of biomass or feedstock (or other necessary inputs) may result in pollutant emission.
    - Burning of field residues or waste at the biomass production site may lead to pollutant emission.

- Will production, conversion, or transport of the feedstock cause emission of smell and odorous emissions, thermal heat, or radiation?
    - If the feedstock for the project is manure, chicken litter, or waste from food industry treatment, storage and transport of the feedstock may lead to nuisance or pollution if not handled well.

- Will production, conversion, or transport of the feedstock cause emission of biological air pollutants, such as pollen, fungi, or bacteria?
    - If the feedstock is biological waste or if the digested remains from biogas production are used on fields as fertiliser, there may be risk of spread of bacteria and pollutants.
    - If the feedstock is biological waste, then transport, treatment, and storage must be organised so that the risk of spreading bacteria is minimised.
    - Some agricultural systems, mostly where livestock are involved, can spread spores, which in rare cases may cause health risks if concentrations are high.

Note: If the answer to any of the above questions is "yes," one or more issues of concern will need further data collection and assessment.

Socioeconomic Assessment

Alongside environmental issues, the development of a biomass project may entail social risks and impacts, especially on local communities affected by the project. This can include impacts on livelihoods, cultural heritage, access to or ownership of land, and access to natural resources. In summary, issues to be examined include (World Bank, 2017):

- Food security
- Land acquisition, titling, and tenure
- Access to assets and natural resources
- Community health and safety
- Energy security and access
- Gender and vulnerable groups
- Labour issues, labour rights, employment, wages, and income.

The project developer should systematically screen for socioeconomic issues linked to the type of biomass concerned (primary, secondary, tertiary), as the socioeconomic impacts may vary depending on the feedstock type.

Adequate engagement with affected communities throughout the project cycle on issues that could potentially affect them and to ensure that relevant environmental and social information is disclosed and disseminated should be actively sought and implemented by the project proponent. In addition to affected communities, a preliminary list of other potential stakeholders includes:

- Central government authorities and ministries
- Representatives of regions, local governments, and regulatory bodies
- Nongovernmental organisations, including conservation organisations
- Labour organisations, trade organisations, farmers groups, and community-based organisations
- Private sector, research agencies, universities, and consulting firms
- Financing institutions, small-scale finance providers, and insurance companies
- Religious and cultural organisations.

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