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The Conversion of Biowaste and Residue to Biofuel: From History, Physics Principles, to the Current Status of Technology, Mitigation of Environmental Impact and Economic Challenges

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Abstract: As the most commonly-used renewable energy in the world energy consumption, the potential and popularity of biomass energy is significantly underestimated. In the United States in 2018, renewable energy accounted for 11% of the national energy consumption, with 44.5% contributed by biomass energy. This article will focus on one feedstock, bio-waste and residue, in biomass resources. Furthermore, this journal will include an overview of the history of the technique, explanation of the fundamental physical principles, along with the discussions regarding major technology implementation of the conversion technique, and finally end with an evaluation of the environmental impacts and economic opportunities and challenges. At the end of the journal, we will show that the development of bio-waste and residue conversion techniques will naturally benefit from biomass' carbon cycle and the variety of techniques available. Moreover, it has a large potential no matter environmentally or economically, along with technological advancement and the development of government regulations to minimize its harm.

Keywords: biomass, environment, biowaste conversion, renewable energy

1. Introduction

In the modern world in search of clean energy, the terms biomass and bioenergy are very prevalent. In fact, they account for 98% of renewable electricity generation. The term biomass refers to living or recently dead organisms and any by-products of these organisms. Strictly speaking, the term biomass encompasses all living things. In the context of biomass energy, it refers to crops, residues and other forms of biological material that can be used to replace fossil fuels in energy production. In recent years, biomass energy has

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received extensive attention for its capabilities in renewable power generation, green energy production, biofuels, and thermal energy [1].

The objectives of this paper are to raise public awareness of biomass energy because it is a relatively less well-known renewable energy resource, to discover some specific conversion processes from biomass to other energies, to discuss the environmental impacts and economic impacts of biomass energy.

In the following, the history of biomass energy in general comes first, and then followed by discussions of physical principles of how biowastes are transferred to other energies and descriptions of some detailed systems. Next comes the environmental and economic impacts of biomass energy both in general of those detailed systems. Finally, summary and conclusions are presented.

2. History

Biomass is by no means an alternative energy source discovered in recent years. It actually predates humans. There is substantial evidence to support the claim that biomass was used for energy supply between 230,000 and 1.5 million years ago. The first form of biomass as an energy source is the use of fire. Biomass is one of the most directly combustible carbon-renewable sources of energy globally, and is used by people to generate heat and cook food [2].

Combustion was and remains the primary form of converting biomass to energy. This is why biomass is still heavily used in developing countries that do not have the bioenergy generation systems that more developed countries use to create alternative energy sources.

Around the 19th century, attention began to focus on more modern uses of biomass materials. While fire is the oldest example of bioenergy in use, ethanol can be seen as the next big step in harnessing carbon for energy. Ethanol has been around for a long time. Humans have discovered and used the fermentation process long before civilization developed. Still, until the 12th century in Italy, there was no clear evidence that people distilled alcohol. Soon after people started making ethanol in the 1100s, it was quickly used for cooking and lighting. People started using ethanol to generate more energy.

From the 1700s to the 1960s, pine sap was a valuable renewable resource. Before oil, pine sap was a resource that nations competed for. In its original form, pine sap was used in the shipbuilding process. When distilled, the sap produced several extremely chemical substances at the time - the most important of which was turpentine. Turpentine has a variety of uses, but its most important use as an alternative energy source is lamp oil [3].

The geopolitical conflict felt in the 1970s brought about a fuel crisis. As a result, the Organization of the Petroleum Exporting Countries (OPEC) reduced oil exports. This has drawn attention from government and academia. Many people are starting to research and develop more renewable energy. This movement has brought many green energy improvements to solar panel power generation, geothermal power plants, offshore wind farms and hydroelectric power. During this time, scientists took a systems approach to energy and coined the term biomass.

Over time, the importance of bioenergy has been linked to issues such as pollution from fossil fuels. Several growing environmental concerns mark this period in biomass history. Scientists have turned their attention to studying climate change and reducing fossil fuels.

As it stands, modern biomass energy production is an important source of renewable energy. In fact, it has gone far beyond wind and solar in its search for renewable energy. It is a major source of alternative energy. Biomass feedstocks are processed and converted into energy in many different ways. While burning woody biomass (forest biomass material, wood pellets, etc.) remains the most popular way we use this renewable energy source, the field of biomass energy has come a long way. Innovation has brought us energy crops that are produced on a large scale and converted into biofuels and biogas, and landfills that use anaerobic digestion to convert biomass into biogas for daily use.

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3. Physical principles

3.1 Reason to select Bio-wastes to develop renewable energy

Although traditional biofuels are not suitable for modern industrial production due to their characteristics such as high water content and low heat value [4], today manufacturers already have mature techniques to convert biomass to other fuels like bio-methane and coal-like solid fuel. These fuels based on biomass can be easily accessed and cause limited to no environmental impacts, benefitting from its natural carbon cycle [4]. Therefore, following this philosophy, bio-methane is selected to be the one of the most widely used bio-fuel.

3.2 Bio-methane produce technique

In the rural areas of developing countries, biomass energy conservation technologies like the bio-methane production system are an efficient and substantial method to provide energy for local residents. In this chapter, we will introduce the principles of bio-methane producers.

The bio-methane producer is a system which employs the metabolic processes of anaerobic bacteria to decompose bio-wastes like livestock's dung and kitchen garbage. A bio-methane producer usually contains two main assembly units: the digester and the stove. In the anaerobic digester, different types of bacteria will speed up the process of anaerobic digestion [5].

In addition, there are three phases of anaerobic digestion. The first one is hydrolysis. Fermentation bacteria like cellulose decomposing bacteria and proteolytic bacteria would utilize extracellular enzymes to decompose biomass dissolved in water and disintegrate them into different products. Second is the acid production phase. Fermentation bacteria will utilize the intermediates of hydrolysis to decompose into volatile acids like acetic acid and lactic acid. This volatile acid will be the biggest part of methane source. Third is the methanogenic phase. In this phase, Methanogens will play a major role in anaerobic digestion. Methanogens would degrade the product of the second phase like acetic acid to methane and carbon dioxide.

After the three phases of anaerobic digestion, usable bio-methane will conduct to the stove and provide heat for people's cooking.

3.3 Micro-level methane production

Most bio-methane is generated by a specific bacteria called Methanogens, which uses anaerobic digestion to decompose biomass and release methane. In the process of anaerobic digestion, Methanogens utilizes several different enzymes to convert organics to bio-methane. And one of the following enzymes that play an important role is hydrogenase, which has vital functions in the acid production phase of anaerobic digestion. The hydrogenase in the methanogens catalyzes the hydrogen ion and electron to produce hydrogen. And hydrogen productivity has an important connection with the efficiency of methane production.

Under ideal conditions, catalytic efficiency of hydrogenase depends on pH value and environmental temperature. The research of hydrogenase efficiency points out the best pH value is within the limits of pH 7.0-7.5. It also suggests the optimum temperature range is limited in 40-50 Celsius [6], as can be seen in figure 1 and 2.

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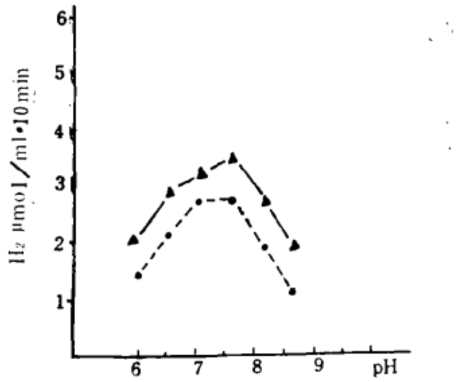

Figure 1. Test of optimum enzymatic release reaction [6]

▲Treatment of anaerobic sludge samples of liquor waste water

● Anaerobic sludge sample of limonitic acid wastewater disposed

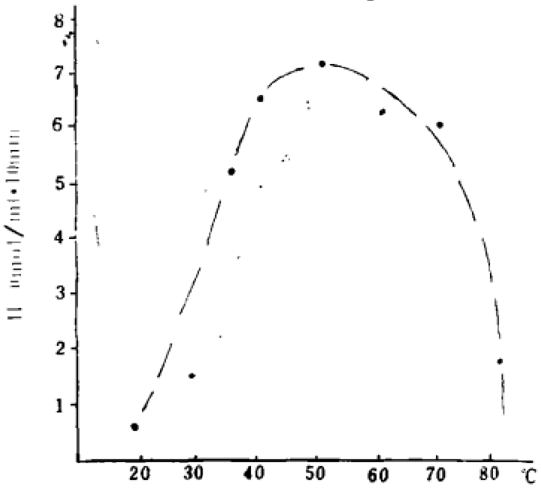

Figure 2. Optimum temperature for enzymatic release reaction [6]

4. Technology implementation and Typical system description

Bio-waste and residues have a variety of conversion techniques, including pre-processing combustion, transesterification or hydrogenation, hydrolysis fermentation, pyrolysis secondary processing, anaerobic digestion biogas upgrading, bio-photochemical routes, gasification secondary processing and a range of biological or chemical routes. Adding on to the last section around physical principles, in this section, we will explain the technique of hydrolysis fermentation and anaerobic digestion biogas upgrading in more detail.

As a widely used technology, hydrolytic fermentation is found especially suitable for processing solid biomass to ethanol. The process begins with the pre-treatment of the feedstock, followed by hydrolysis of the polymer into fermentable monosaccharides using enzymes or acids. Later, fermentation will be implemented to convert the six or five carbon sugars into ethanol, which leads to the final step of purification (distillation or filtration) and gasification of the residual solids and wastewater treatment (Figure.3 shows the general process of hydrolysis of biomass to fuel ethanol).

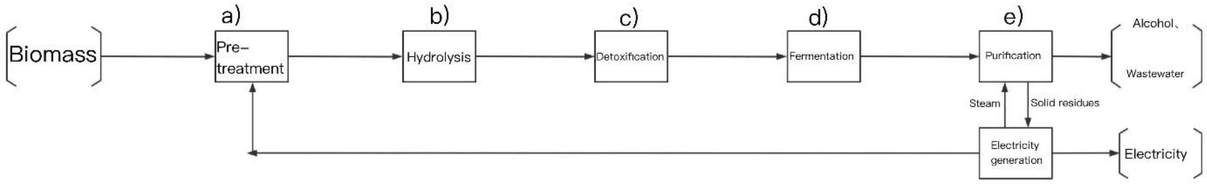

Figure 3. Process for the hydrolysis of biomass to ethanol

First of all, the pre-treatment process includes cleaning and crushing of the raw material. The smaller the particle size of the raw material, the larger the specific surface area, and the better it is for the catalyst to participate in catalysis and increase the reaction rate. Pre-treatments are categorized into mechanical, acidic, alkali, oxidative, fractionative, and biological [7].

The hydrolysis coming after is a reaction in which water reacts with another compound and breaks the compound down into two parts, with hydrogen atoms in the water being added to one part and hydroxyl groups to the other, resulting in the formation of two or more new compounds. The hydrolysis process converts biomass into more readily available energy storage material.

The plant hydrolysate contains inhibitors of subsequent ethanol fermentation, such as furfural, hydroxy methyl glyoxal, acetic acid, phenolic compounds, butyric acid, hydroxybenzoic acid, vanillin, and other toxic compounds. These compounds will reduce the yield of ethanol. Therefore, the detoxification process is needed prior to the fermentation of the hydrolysate. A common detoxification method used is diluting the hydrolysate, while this will reduce the concentration which increases the cost. After liquefaction, the pH value of the hydrolysates had to be brought back to ~4.5 which is optimal for fungal amyloglucosidase subsequently used in saccharification. TK-PUL is a commonly used choice to mitigate to the impact of this issue [8].

The fermentation of biomass is carried out by indirect fermentation, mixed strain fermentation, simultaneous saccharification fermentation (SSF), non-isothermal simultaneous fermentation (NSSF), and immobilized cell fermentation. The indirect fermentation method starts with the hydrolysis of cellulose by cellulase, and the enzymatic sugar solution is used as the fermentation carbon source. The mixture of monosaccharides and oligosaccharides such as glucose, xylose, and arabinose in the saccharification solution of fibrous raw materials, mixed strain fermentation method can use the mixture in the hydrolysis solution, this method can improve the conversion rate of raw materials. And the SSF process, pioneered in the 1970s, combines cellulase digestion and ethanol fermentation in the same reactor. In this method, yeast will use the glucose produced by cellulose digestion, so the concentration of cellulose disaccharide and glucose is very low, and the inhibitory effect of a high concentration of cellulose disaccharide and glucose on cellulase is removed, which improves the efficiency of digestion, saves production time, and increases the production efficiency.

Finally, in the purification process, the alcohol from the biomass conversion is extracted. The solid residue produced can be used to generate electricity, and the water vapor produced during the generation process can be re-involved in the purification process. This increases the utilization of biomass and saves costs while increasing the energy output.

Another popular conversion technique, anaerobic digestion (AD) is a natural biochemical process that converts organic materials into combustible biogas [9]. The AD process occurs through the action of microorganisms, which break down bio-waste and convert them into a gaseous mixture. The process can be divided into four stages (figure 4):

1) Hydrolysis
2) Acidogenesis
3) Acetogenesis
4) Methanogenesis

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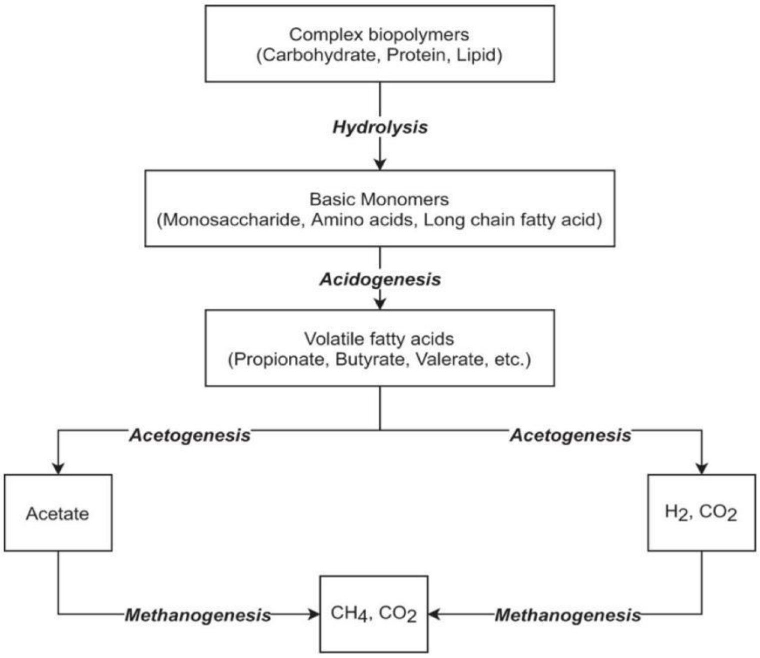

Figure 4. Anaerobic digestion (AD) biomass decomposition stages [9]

Hydrolysis is the first step in the digestion process. In this process, hydrolytic enzymes break down the complex structure of the biomass into monomers or oligomers. The general hydrolysis reaction is shown in the chemical equation (1). Hydrolytic enzymes include amylase, lipase, pectinase, and cellulase.

$$(C_6H_{10}O_5)n + nH_2O \rightarrow nC_6H_{12}O_6 \quad (1)$$

In the acidogenesis process, the products of hydrolysis are broken down by acid-producing bacteria. The majority of the products are converted into fatty acids, alcohols, and ketones. Equations (2) to (4) illustrate the chemical reactions in the acid-producing phase.

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH+2CO_2 \quad (2)$$

$$C_6H_{12}O_6+2H_2 \leftrightarrow 2CH_3CH_2COOH+2H_2O \quad (3)$$

$$C_6H_{12}O_6 \rightarrow 3CH_3COOH \quad (4)$$

After the acidogenesis process, the acetogenesis bacteria convert some of the fatty acids in the products of the hydrolysis and acid-producing stages into acetate, carbon dioxide, and hydrogen. Equations (5) to (7) illustrate the chemical reactions of the acetic acid-producing stage.

$$CH_3CH_2COO^- +3H_2O \leftrightarrow CH_3COO^- +H+HCO_3^- +3H_2 \quad (5)$$

$$C_6H_{12}O_6+2H_2O \leftrightarrow 2CH_3COOH+2CO_2+4H_2 \quad (6)$$

$$CH_3CH_2OH+2H_2O \leftrightarrow CH_3COO^- +3H_2+H^+ \quad (7)$$

The final stage, methanogenesis, is strictly anaerobic as methanogenic bacteria cannot survive in the presence of oxygen. The methanogenic bacteria use the products of the previous stages as feedstock to produce methane. The reactions in this stage are shown in equations (8) to (10).

$$CH_3COOH \rightarrow CH_4+CO_2 \quad (8)$$

$$CO_2+4H_2 \rightarrow CH_4+2H_2O \quad (9)$$

$$2CH_3CH_2OH+CO_2 \rightarrow CH_4+2CH_3COOH \quad (10)$$

5. Environmental impact

An important reason why biowaste and residue became a popular substitute for fossil fuel is that it reduces carbon emissions significantly, benefitting from its carbon neutrality. Biomass is carbon-neutral naturally

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since it follows a carbon cycle. For plants, they will take in CO_2 from the air through photosynthesis and then release it back into the atmosphere by respiration. For animals, they will consume plants to gain carbon, and then release CO_2 into the atmosphere by either respiration or decomposition. In both scenarios, the original carbon came from organic materials inside the organisms themselves. Throughout the whole process, no excess carbon is emitted; therefore, it is a carbon-neutral process.

Furthermore, using biowaste and residues as fuel can also reduce the emission of other harmful gasses threatening the environment. For example, methane is a major product in the anaerobic breakdown of biowaste, and it is 28-36 times as powerful as a carbon dioxide molecule in terms of trapping solar radiation in the atmosphere (i.e., it has a Global Warming Potential of 28-36). In addition, studies show that by using on-farm AD plants agricultural methane emissions could potentially be reduced by 0.6 Mt [10]. Furthermore, it can also reduce the release of sulfur dioxide (SO_2), which is the main source of acid rain. Since most biowaste includes extremely small amounts of sulfur, emissions of SO_2 will be significantly reduced if it can replace potentially high-sulfur fossil fuels like coal and oil. From an overall perspective, according to a life-cycle assessment (a form of analysis used to evaluate environmental impact) study done by the Prairie View A&M University in the W.A. Parish Power Plant in Texas, when 15% of coal is replaced by forest residue, the life cycle air emissions of CO_2, CO, SO_2, PM2.5, NOx (nitrogen oxides) could be reduced by 13.5%, 6.4%, 9.5%, 9.2%, and 11.6% respectively [11]. The study also mentioned that as a result of reducing emissions, potential life cycle impacts were mitigated in terms of aquatic toxicity, global warming, mineral extraction, and aquatic acidification. Considering biomass had only replaced 15% of coal, it is arguable that it had obtained a considerable percentage of reduction in the emission of harmful gasses. Therefore, compared to traditional energy resources such as fossil fuels, animal and plant residues are more eco-friendly as they release less detrimental gasses; consequently, if fossil fuels are replaced by biomass, it can avoid more serious environmental hazards and protect the ecosystem.

While the usage of biowastes can reduce carbon and other harmful gases' emissions in its process of production, the resources required in this process can experience a trade-off between the fuel produced and the land use. For instance, consuming biofuels can cause direct and indirect land use changes. Direct land use change occurs when non-agricultural land is changed to grow biofuel crops. Indirect land use change occurs after a direct land use change, where the "loss" of farmland urges farmers to react and turn the non-agricultural lands to replace the displaced cropland. This land-use change could cause greenhouse gas emissions (GHGs) due to the upfront cost of carbon stored in both above- and below-ground biomass lost when non-agricultural land is cleared. Moreover, it can also create an opportunity cost from the loss of the carbon sequestration service of converted land uses. To provide further context, experts estimated that to achieve a 56 bbl increase in corn-based bioethanol production in the US, a diversion of 12.8 million ha of existing cropland will be required for corn production for this bioethanol consumption. In addition, it is also argued that a decline in US agricultural exports (e.g., wheat by 31%) could then lead to agricultural expansion worldwide (Figure 5) As a result of this land use change, 3.8 billion megatonnes of CO_2-equivalent GHGs will be emitted; this is a biofuel carbon debt that would take 167 years for corn-based bioethanol use to repay [12].

Therefore, while using biowaste and residues as fuels can utilize its natural carbon cycle to reduce carbon emissions since it requires large areas of land, the land use change will cause negative environmental impacts and still emit GHGs.

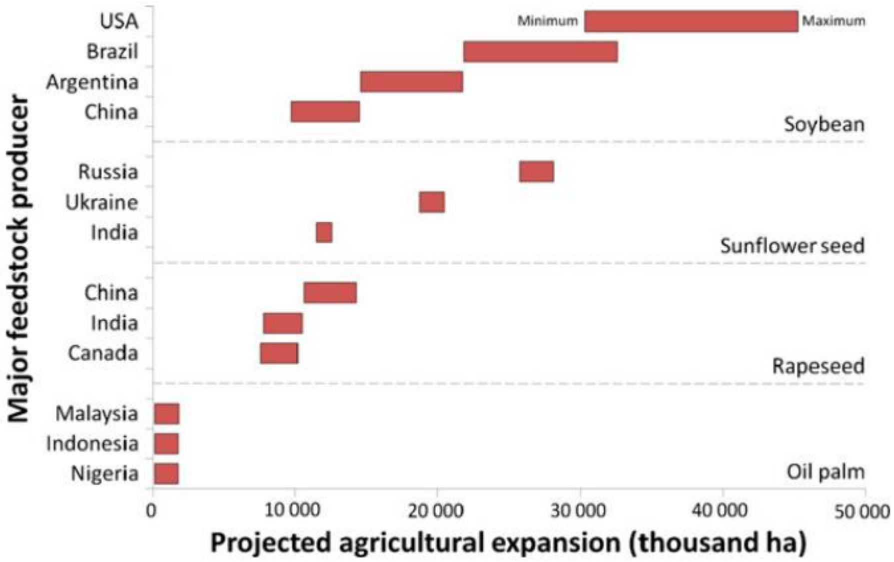

Figure 5. Major Feedstock Producer's Projective agricultural expansion

Other than the trade-off between fuel production and land use, biowaste used as fuels also will experience an opportunity cost which is the organic matter inside the soil that can be a natural fertilizer, which harms the soil. For instance, reducing agricultural-residue recycling for fertilization will cause a gradual reduction in the organic-matter content of the soil. This will bring two major consequences: firstly, it will influence the nutrient balance of the soil, which reduces the amount made attainable for plants annually by the natural processes of organic-matter decay; Secondly, as organic matter is vital in binding soil particles together, it will alter the soil's physical characters, which affects its ability to maintain structural integrity [13]. However, the severity of this impact varies among different scales of agriculture and types of fertilizers used. For example, in modern high-input farming systems, since chemical fertilizers have significantly replaced organic matter as a source of plant nutrients, organic matter is no longer necessary for agricultural production. On the other hand, for traditional upland agriculture, organic matter is the primary source of nitrogen, sulfur, and phosphorus which are fundamental for crop production. When residue recycling is reduced, crops output is mostly certain to fall. However, only considering the environmental perspective, the opportunity cost of burning residues and biowaste is a reduction in organic matter available in the soil, which harms the environment by affecting organic plant growth and the ecosystem.

To sum up, biowaste and residue used as fuel can reduce carbon emission and emission of other harmful gasses significantly, which supports sustainable development. Nevertheless, although biowaste and residues benefit from its natural carbon cycle and gain carbon neutrality, its excessive land use will bring a large opportunity cost, which will cause carbon emissions. In addition, as residues stop being recycled for fertilizers but instead being used as fuels, there will be a loss of organic matter in soils, harming the land. Therefore, biowaste and residue is a good renewable source for the reduction of carbon emissions, but for its problems, governments can impose stricter regulations among the land use and recycling of residues, to diminish the harm the plantation of plants may bring.

6. Economics of biofuel derived from biowaste and residues

The economics of biofuels derived from biowaste and residues has also been the focus of intense attention for several years, as it is not only related to the willingness of ordinary citizens to use biofuels as substitutes for fossil resources but also determines the profitability of industries that utilize biowaste and residues as raw materials into biofuels.

One of the drawbacks of biofuels is their price. According to statistics, biofuels have commanded higher prices than fossil fuels in Europe in recent years (figure 6).

Source: T&E analysis based on data provided by Stratas Advisors

Figure 6. Recent wholesale price developments (USD/toe) across the main fossil fuels and biofuels [14]

(FAME: Fatty Acid Methyl-Esters, PME: Palm Methyl Ester, SME: Soybean Methyl Ester, TME: Tallow Methyl Ester, UCOME: UCOME: Used Cooking Oil Methyl Ester, T1: EU bioethanol imports, T2: EU domestic bioethanol production).[15]

However, Biowaste and residues have significant price advantages over the other biofuels Feedstock. In the actual commercial production of biofuels, the overall cost of biofuels is composed of many aspects, such as the cost of raw materials, investment in new technology research and development, purchase of factory facilities, transportation costs and so on. At the same time, raw material cost is an important factor affecting the overall production cost. And for some of the same biomass energy, in particular Biowaste, the production plant can collect it at a lower price than other biomass raw materials on the market. In controlling the overall production cost, biological waste shows superiority over other biomass.

For example, we can compare the prices of different biowaste and other biomass in Table 1. The energy crops which are one of the main biomasses is about 80 Euro/ton, For the residues, though there is a fluctuation, some sorts of feedstock have a price lower than 80 Euro/ton, even negative. The negative cost of biological waste is largely influenced by government legislation. To protect the environment and reduce the impact of traditional waste disposal methods on the ecological environment and the quality of life of residents, relevant departments in different regions have issued different laws and regulations to limit the corresponding waste disposal and to reduce the cost of waste collection by factories that use waste as raw materials for biofuel production.

Landfills, as a form of urban waste disposal, have become increasingly problematic due to their land occupied by landfill, methane emissions, and impacts on groundwater and land, and cannot be considered as a sustainable way to treat urban waste. Part of the low cost of Biowaste and residues is the environmental protection benefits of the corresponding regional governments. For example, in order to achieve the goal of reducing the amount of waste sent to landfill, the EU environmental legislation imposes increasing landfill fees on the waste sent to landfill.[16] In the United States, the Energy Independence and Security Act (EISA) also provides financial incentives for biofuels, providing cash incentives, subsidies, and loans to institutions and factories that develop and produce biofuels. This means that in certain regions with relevant laws and regulations, waste conversion plants can even obtain raw materials at a negative cost [17].

Table 1. Result of the cost assessment for the countries of the consortium members [18]

	Austria	Finland	Germany	Greece	The Netherlands	Poland
Commodity	€/t free field side/forestry road/waste yard or producer					
Straw (minimal costs)	35	34	32	38	34	36
Straw (price)	80 to 180	not available	160	144	144	not available
Forestry residues (price)	30 to 80	25 to 80	30 to 80	30 to 80	30 to 80	30 to 80
Organic municipal waste (gate fee)	-15 to -60					
Surplus manure (price)	-	-	-10	-	-15 to -25	-
Waste wood (gate fee)	-60 to -25	-60 to -25	-60 to -25	-60 to -25	-60 to -25	-60 to -25
Land scape & roadside management (price	66 - 81					
Food processing residues (price)	0 to 180	0 to 180	0 to 180	0 to 180	0 to 180	0 to 180
Energy crops (price)	80	80	80 to 160	80 to 150	80 to 150	80

Many factors determine the cost of different biomass raw materials, such as region, trading volume, contract, transportation, etc., so the price in the market may fluctuate. For some biowastes, their commercial potential has already been demonstrated.

The Breakeven Point (BEP) is a parameter that compares the market price of a product with its original cost. The breakeven point is reached when the two prices are equal. In the case of diesel, the BEP for diesel is how much money it has to make in the market to offset the cost of production. Olkiewicz et al. [19] investigated and evaluated the break-even point (BEP) of 1232 $/t for biofuels produced from primary sludge. The price of commercial fuel in 2016 was $1,376 /t. This fully shows that biofuel produced by sludge has good economic efficiency and has good potential for commercial development.

In the biowaste to hydrogen-producing industry, by locating plants near agricultural processing plants that produce large amounts of waste, production costs can be reduced to below those of the most commercial hydrogen-producing industry. The most commercial hydrogen production from biomass sources costs about 1.4 to 5.2 US$/kg, while the cost of making hydrogen from biomass sources can be as low as 0.5 to 4.5 US$/kg using zero-cost materials [20-22].

Zhang et al. [23] Showed the economic benefits of two types of forestry leftovers and demonstrated the commercial potential and value, as shown in the Table 2.

Table 2. Economic benefits of forestry residues conversion to briquette fuel (based on per t of briquette fuel) [24]

feedstock	research methods	scale of production(t/y)	feedstock cost(¥/y)	operating cost(¥/y)	total cost(¥/y)	income(¥/y)	profit(¥/y)
saw dust	simulation	300,000	550.00	215.95	765.95	900.00	134.05
Forestry residues	simulation	27,500	571.42	219.85	791.27	935.00	143.73
average			560.71	217.90	778.61	917.50	143.73

The conversion of bio-waste to biofuel also has the advantage that it can be improved economically through technological innovation and optimized feedstock collection. Due to the low technological maturity of most waste biomass energy approaches, many process schemes are not mature. It has great prospects to reduce costs and improve the economy through more advanced technologies and reasonable mechanisms. Such as in the conversion of municipal sludge to biodiesel, for example, in the process of using solvent to extract fat from sludge, the solvent recovery efficiency is close to 99%, which can be recycled many times, thus saving a lot of costs. Mahamuni and Adewuyi (2009) reported that the use of high-frequency ultrasound can reduce the production cost of biodiesel. By reducing the amount of alcohol required for the reaction, a higher energy conversion rate is achieved for the same energy input [24].

We can also integrate bio-waste conversion plants with conventional fuel conversion plants to reduce costs by sharing certain processes and processing facilities. For example, in the production of waste-to-methanol, compared with the pure methanol produced from Refuse-derived-fuels (RdF), hybrid production model that integrate traditional methanol production and Refuse-derived-fuels can reduce costs more effectively. It is because it uses the excess hydrogen in syngas to supply the conversion of Refuse-derived-fuels (RdF) to methanol, thereby increasing the overall methanol productivity [25].

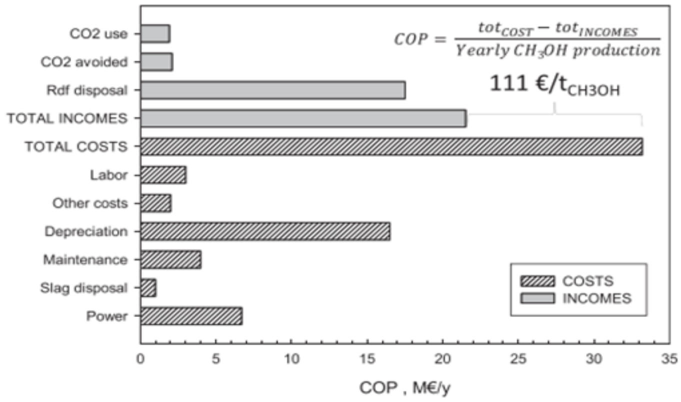

Figure 7. Breakdown of the estimated costs of production (COP) of methanol for a single unit (105,000 t/y) in a 300 t/d new WtM plant [25]

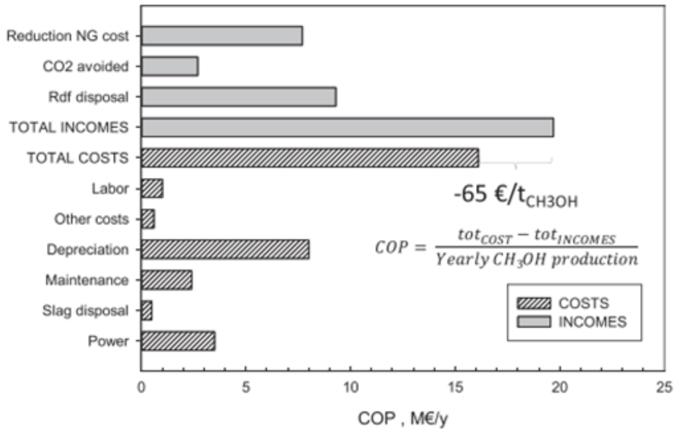

Figure 8. Breakdown of the estimated costs of production (COP) of methanol for a hybrid NG + RdF methanol plant.[25]

It is easy to see the profitability of the two models from Figure 7 and Figure 8. By integrating processing facilities, we can significantly reduce costs and improve profitability.

Optimizing machining parameters and process data through software simulation can also reduce production costs. More than 50 million m3 of Biogas and 13,000 ton of hydrogen can be produced annually through a case of Biogas to hydrogen production in the wastewater of a Turkish milk processing plant. The energy saving value of the process can reach 15 million US$/yr [20, 26].

In Li's study, they produced hydrogen from wastewater and agricultural waste and used ASPEN Plus software to estimate large-scale simulations. Their results showed that 100 cubic meters of wastewater and 400 cubic meters of agricultural waste working volumes would reap the largest annual profits, with 81% and 30% annual gains, respectively. After roughly converting fuel prices, hydrogen produced from wastewater can obtain 2.7 million US$/yr, and hydrogen converted from agricultural waste can obtain 2 million US$/yr [20, 27].

To summarize, Biowaste and residues have great prospects, and they have cost advantages over other biomass sources due to environmental legislation. For specific biowaste and residues, they have demonstrated the potential.

for commercial development. At the same time, through technological innovation, co-location, integration and parameter optimization, the cost of converting from biological waste to biofuel can be further reduced in the future.

7. Conclusions & future prospects

As a kind of energy supply source with a long history, the utilization of biomass energy has been accompanied by the progress and development of human civilization. Bio-waste, as an indispensable source of biomass, has great potential in environmentally friendly and commercial markets. One of the main methods for converting biological waste into biofuel is hydrolytic fermentation. The organic matter in biological waste is hydrolyzed into different products by bacteria and proteases, and further fermented into volatile acids. Finally, according to the corresponding products, different microorganisms are converted into different biofuels.

Using biological wastes and residues as a substitute for fossil energy sources can maintain carbon neutrality and reduce emissions of harmful gasses such as methane and sulfur dioxide. Meanwhile, biological wastes and residues demonstrate their price advantages over other biomass residues and the elimination regularity of residues in the marketplace. Through environmental legislation, many biological wastes and residues are extremely low in price and can be further reduced through technical innovation, integration, and optimization of parameters.

But at the same time, the conversion of biological waste is still accompanied by many issues. Converting bio-waste into biofuel rather than fertilizer which involves the recycling of organic matter in soils can disrupt the nutrient balance of the land and deeply change the physical properties of the land. There are still many types of biofuels from bio-waste that have higher prices than fossil fuels and do not break even. If government subsidies to Biowaste are excluded, the price of many biofuels will rise sharply as feedstock costs increase. In the future, through the development of new technologies, such as the discovery of new catalysts and other conversion mechanisms to achieve higher conversion efficiency, production costs may continue to decrease, thus achieving better commercial prospects.

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