Yuanhang Wang

UTILIZATION AND DEVELOPMENT PROSPECT OF BIOMASS ENERGY IN INDUSTRY

Thesis
CENTRIA UNIVERSITY OF APPLIED SCIENCES
Environmental Chemistry and Technology
June 2020

ABSTRACT

Centria University of Applied Sciences	Date June 2020	Author Yuanhang Wang
Degree programme Environmental Chemistry and Technology		
Name of thesis UTILIZATION AND DEVELOPMENT PROSPECT OF BIOMASS ENERGY IN INDUSTRY		
Instructor		**Pages** 33
Supervisor Yue Dong		

This paper mainly focuses on the utilization of biomass energy in industry. Biomass energy is an important clean and environmental new energy. Countries in the world are increasing their efforts to develop biomass energy.

In this thesis work, the technologies, principles and applications of biomass energy in industrial utilization are briefly stated from three aspects of biomass biochemical conversion, chemical conversion and thermochemical conversion.

Finally, the current situation and development prospect of biomass energy in the world and the significances of developing biomass energy are also introduced.

In addition, although biomass energy has great development potential, there are still many difficulties in the development of biomass energy, such as imperfect system, imperfect policies and insufficient marketization.

Key words
Biochemical conversion, chemical conversion, microbiological fuel cells, prospect, status, significances, thermochemical conversion

CONCEPT DEFINITIONS

List of abbreviations

C	Carbon
CO	Carbon monoxide
CO_2	Carbon dioxide
CH_4	Methane
$C_6H_{12}O_6$	Glucose
$(C_6H_{10}O_5)_n$	Polysaccharide
H	Hydrogen element
H_2	Hydrogen
H_2O	Water
H_2S	Hydrogen sulfide
K	Potassium
MFC	Microbiological Fuel Cells
N	Nitrogen element
N_2	Nitrogen
NH_3	Ammonia
NH_4^+	Ammonium ion
O	Oxygen element
O_2	Oxygen
P	Phosphorus
S	Sulfur

ABSTRACT
CONCEPT DEFINITIONS
CONTENTS

FIGURES

1 INTRODUCTION

Energy is an important material basis for the survival and development of human society. Throughout the history of the development of human society, every major progress of human civilization was accompanied by the improvement and replacement of energy. The development and effective utilization of energy is one of the important symbols of production technology, living standard and social development. How to protect the Earth environment and ecology while developing and using energy has become a major global issue. Vigorously developing and using new energy is the only way out for human beings. (Zhang 2015.)

Compared with solar energy, wind energy, water energy and tidal energy, biomass energy has unique advantages. Biomass is the only energy in the form of substance and also the only renewable energy that can be stored and transported. With the development of science and technology, the utilization technology of biomass energy is gradually improved. The biomass energy has become a conventional energy. (Chen, Yang & Yang 2018, 1-2.)

Biomass energy is the energy provided by living plants in nature. Solar energy is stored in biomass in the form of chemical energy. It belongs to renewable energy like wind energy and solar energy. It is rich in resources and can ensure the sustainable use of energy. Biomass energy refers to the energy that plant chlorophyll converts solar energy into chemical energy and stores in biomass. Through thermochemical conversion technology, solid biomass is converted into combustible gas and tar. Through biochemical conversion technology, biomass is converted into biogas, alcohol. It is directly or indirectly derived from the photosynthesis of green plants and can be converted into conventional solid, liquid and gas fuels which are inexhaustible. It is renewable energy and the only renewable carbon source. (Zhang & Liu 2009.)

In terms of chemical composition, biomass is a complex composed of a variety of complex polymer organic compounds with a variety of components. It mainly includes cellulose, hemicellulose, lignin, a small amount of starch, protein and lipid. Different kinds of biomass have different components. In the aspect of element composition, except for a small amount of inorganic matter and a certain amount of water, most of biomass fuel is combustible organic matter. The basic elements of biomass fuel are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), phosphorus (P), potassium (k). (Zhang & Liu 2009.)

In this paper, the technologies, principles and applications of biomass energy in industrial utilization are briefly stated from three aspects of biomass biochemical conversion, chemical conversion and thermochemical conversion. The current situation and development prospect of biomass energy in the world and the significances of developing biomass energy are also introduced. Moreover, the problems encountered currently in the development of biomass energy are summarized.

2 CLASSIFICATIONS AND SIGNIFICANCES OF DEVELOPING BIOMASS ENERGY

There are different standards for the classification of biomass energy. According to whether it can replace conventional fossil energy on a large scale, it can be divided into traditional biomass energy and modern biomass energy. The traditional biomass energy mainly includes the rural domestic energy such as firewood, straw, straw, rice husk and other agricultural wastes and livestock manure, etc. The modern biomass energy is the biomass energy that can be applied on a large scale, including the waste of modern forestry production, bagasse and urban solid waste. According to different sources, biomass suitable for energy utilization can be divided into five categories: forestry resources, agricultural resources, domestic sewage and industrial organic wastewater, urban solid waste and livestock manure. (Shi & Hua 2007.)

Forestry biomass resources refer to the biomass energy that provides biomass energy in the process of forest growth and forestry production. It includes firewood forests and scattered wood, residual branches, leaves and sawdust in forest tending and thinning operations, waste of forestry by-products such as shell and fruit core. Agricultural biomass energy resources refer to agricultural crops and energy plants and waste from agricultural production, such as crop straws (corn straw, sorghum straw, rice straw). Energy plants generally refer to all kinds of plants used to provide energy, usually including herbaceous energy crops, oil crops, hydrocarbon plants and aquatic plants. (Shi & Hua 2007.)

Domestic sewage is mainly composed of various kinds of drainage for urban residents' living, business and service industries such as cooling water, bath drainage, toilet drainage, laundry drainage, kitchen drainage, fecal sewage, etc. Industrial organic wastewater is mainly the wastewater discharged in the production process of alcohol, wine making, sugar making, food, pharmaceutical, papermaking and slaughtering industries, which are rich in organic matters. Urban solid waste is mainly composed of domestic waste, commercial waste, service waste and a small amount of construction waste. Its composition is relatively complex, affected by the average living standard of local residents, energy consumption structure, urban construction, natural conditions, traditional habits and seasonal changes and other factors. Livestock manure is the transformation form of other forms of biomass (mainly grain, crop straw and grass), including excrement, urine discharged by livestock and poultry and their mixture with grass. (Shi & Hua 2007.)

Biomass energy is ubiquitous. The process of taking materials is relatively easy and the production process is relatively simple. Moreover, the price of biomass is low and there is a huge amount of biomass from forest to ocean on the Earth. Biomass energy as a new energy is converted from solar energy.

Through the photosynthesis of plants, solar energy is converted into chemical energy. Biomass energy is environmentally friendly in use process. For example, the sulfur content and nitrogen content of biomass are low and the sulfur oxide and nitrogen oxide generated in the combustion process are fewer. Therefore, it can effectively reduce the greenhouse effect. Biomass energy has high volatile components and high carbon activity. Most of the volatile components can be released at a temperature of about 400 °C. Therefore, it is easy to produce gas fuel. Biomass energy has less ash after combustion. Therefore, the ash removal equipment can be simplified. Biomass energy can exist in the form of biogas, compression molding solid fuel, gasification for gas production, gasification for power generation, fuel alcohol production and thermal cracking for biodiesel production. Therefore, it can be applied in various fields of industry. Biomass energy is the only energy that can be stored and transported. Therefore, it provides convenience for its process and conversion compared with other renewable energy. (Shi & Hua 2007.)

Biomass energy as clean energy, the content of harmful substances (such as sulfur and ash) in biomass are only about 10 % of that in coal. At the same time, the emission and absorption of biomass carbon dioxide (CO_2) constitute the natural carbon cycle, and its energy utilization can achieve zero CO_2 emission. Therefore, increasing the development and utilization of biomass energy are significant in improving energy efficiency, reducing greenhouse gas emissions, protecting the environment, and achieving sustainable development. (Chen, Yang & Yang 2018, 10-12.)

The development and utilization of biomass energy is in favor of resolving the world's energy crisis. Energy is the key to a country's economic and social development. Traditional fossil energy mainly includes coal, oil and natural gas. However, fossil energy has been overexploited in a very short period of time, and the reserves have been sharply reduced, which also promotes its price to rise continuously. Moreover, the harmful gases such as greenhouse gases emitted by burning fossil energy will not only lead to environmental problems, but also lead to climate catastrophe. Therefore, people must turn to new renewable and environment-friendly energy and reduce the dependence on traditional fossil energy. The advantage of renewable energy lies in its renewability and recycling, which can effectively reduce energy consumption and improve energy utilization structure. Biomass fuel ethanol and biodiesel can supersede and partially supersede gasoline and diesel for vehicles, so as to reduce oil consumption and dependence on oil import. The electricity provided by biomass power generation can reduce the coal consumption of thermal power generation and economize coal resources. The promotion and use of biogas can solve the source problem of household fuel and economize natural gas use. (Li, Yuan & Ma 2011.)

At present, the problems of environmental pollution have become serious, and the pollution problems such as haze have become the focus of the society. Because of the air pollution and water pollution caused by many factors such as heating, industrial coal, automobile exhaust, people have paid more attention to it. The three main sources of air pollution are fuel combustion, industrial production and transportation. Fuel combustion and transportation pollution are closely related to the traditional fossil energy consumption. However, the environmental problems caused by air pollution, such as ozone layer destruction, acid rain and greenhouse effect are very common. Biomass energy is a kind of clean green energy. It can not only economize the traditional fossil energy consumption, but also reduce the emissions of greenhouse gases and other harmful gases, which has the effect of emission reduction. First, take the biofuel ethanol as an example, because the oxygen content of gasoline added with ethanol increases, which makes carbon monoxide and hydrocarbons burn more fully. These two indexes in automobile exhaust can be reduced obviously. Taking biodiesel as an example, because of its low sulfur content, the emission of sulfur dioxide and sulfide after combustion can be reduced by more than 30 %. In addition, biodiesel does not contain aromatic alkanes, and its impact on the environment and human health is much lower than that of petroleum diesel. (Chen, Yang & Yang 2018, 10-12.)

Rural areas are relatively weak in economic development, and the living standards of most rural areas are relatively backward. Many rural areas still use biomass energy inefficiently, such as the traditional burning of firewood and straw. Rural areas are rich in land resources, so reasonable use of the rich biomass resources in rural areas and planting more energy plants (plants with energy utilization value) can not only bring more income to farmers and improve their lives, but also make full use of waste resources to improve the rural environment. At the same time, it also broadens the prospects for agricultural development and increases business opportunities. (Zhang 2015.)

3 THE UTILIZATION OF BIOMASS ENERGY IN INDUSTRY

The main forms of biomass in industrial utilization are biomass biochemical conversion, biomass chemical conversion and biomass thermochemical conversion. The biochemical conversion technologies of biomass include biogas fermentation technology and bioethanol technology, which are the main methods to produce methane and ethanol in industry. The chemical conversion technologies of biomass include biodiesel technology and biomass hydrothermal technology. Thermochemical conversion technologies of biomass include biomass combustion technology and biomass gasification. This is also the most direct way to use biomass in industry. Next, the technologies, principles and current applications based on these three conversion forms as the core will be introduced. (Chen, Yang & Yang 2018 .)

3.1 Biochemical conversion of biomass

Depending on the function of microorganism or enzyme, the biomass can be biochemically transformed to produce liquid or gas fuels such as ethanol, hydrogen (H_2), methane (CH_4). It mainly focuses on the biomass of agricultural production and processing process, such as crop straw, livestock manure, domestic sewage, industrial organic wastewater and other organic waste. (Chen, Yang & Yang 2018 .)

3.1.1 Biochemical conversion principles of biomass

Biogas fermentation process is essentially the material metabolism and energy conversion process of microorganisms. In the process of catabolism, biogas microorganisms obtain energy and substance to meet their own growth and reproduction, while most of the substances are converted into CH_4 and CO_2. Nowadays, it is generally believed that the biogas fermentation principle can be divided into two-stage anaerobic fermentation theory and three-stage anaerobic fermentation theory. (Lin, Wang & Zhou 2007.)

Two-stage anaerobic fermentation theory is shown in FIGURE 1. The first stage is that complex organics, such as sugars, lipids and proteins, are decomposed into low molecular intermediates under the action of anaerobes and facultative anaerobes, mainly some low molecular organic acids (such as acetic acid, propionic acid, butyric acid, etc.) and alcohols, and H_2, CO_2, ammonium ion (NH_4^+) and H_2S are produced. In this stage, a large number of fatty acids are produced, which reduces the pH value of the fermentation liquid. Therefore, this stage is also called the acid fermentation stage. In the second stage, specific anaerobic bacteria will continue to decompose the intermediate products produced in the first stage into CH_4 and CO_2. At this stage, organic acids are continuously converted into CH_4 and CO_2, and NH_4^+ is present in the system, which makes the pH value of fermentation liquid increase continuously, so this stage is also called alkaline fermentation stage. (Lin, Wang & Zhou 2007.)

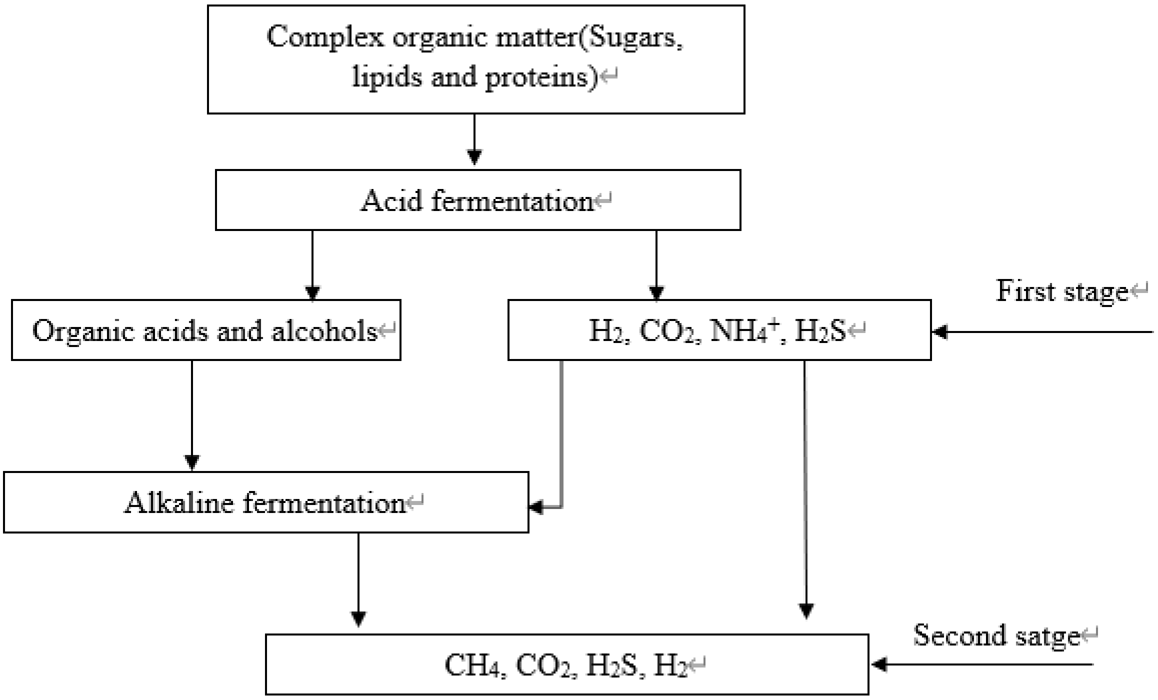

FIGURE 1. Theoretical diagram of two-stage anaerobic fermentation (Adapted from Chen, Yang & Yang 2018.)

Three-stage anaerobic fermentation theory is shown in FIGURE 2. The first stage is called hydrolysis and fermentation. In this stage, complex organics are hydrolyzed and fermented by microorganisms (fermentation bacteria). Polysaccharides are first decomposed into monosaccharides, and then fermented into ethanol and fatty acids through fermentation. Protein is hydrolyzed to amino acid first, and then it produces fatty acid and ammonia (NH_3) by deamination. Lipids are converted to fatty acids and glycerol, and then to fatty acids and alcohols. The second stage is called acidification stage. Under the action of synthetic acetogenic bacteria, intermediate products produced in the first stage（except formic acid, acetic acid, methylamine and methanol）such as fatty acids (propionic acid, butyric acid) and alcohols (ethanol), are transformed into acetic acid, H_2 and CO_2. The third stage is called CH_4 production stage. CH_4 bacteria transform formic acid, acetic acid, methylamine, methanol, H_2, CO_2 and other substrates into CH_4 through different routes, among which the most important substrates were acetic acid, H_2 and

CO_2. About 70 % of CH_4 comes from the decomposition of acetic acid and a little from the synthesis of H_2 and CO_2. In the actual biogas fermentation process, the above three stages are connected with each other, and they maintain a dynamic balance between them, so that the substrate continues to decompose and biogas continues to form. (Lin, Wang & Zhou 2007.)

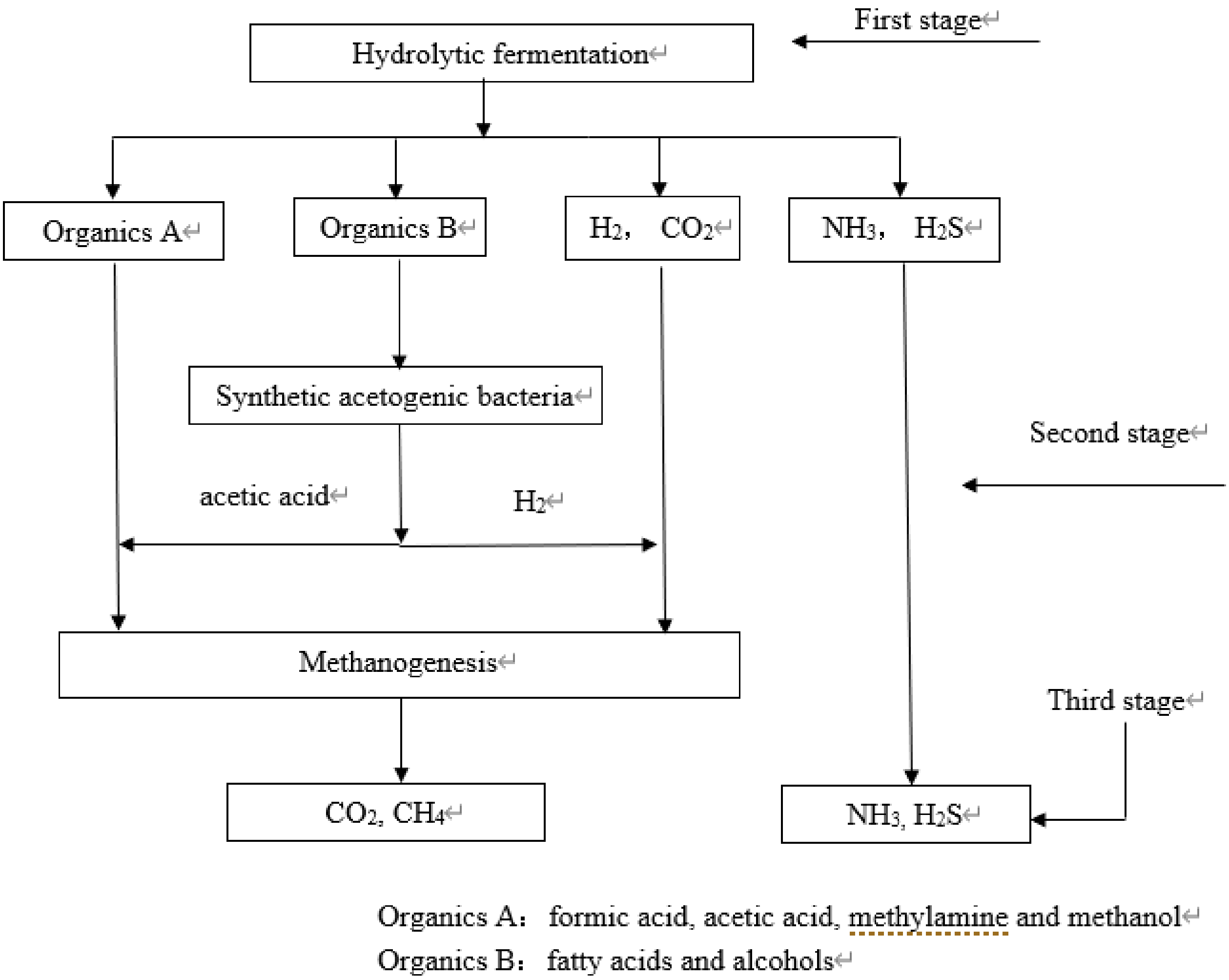

FIGURE 2. Theoretical diagram of three-stage anaerobic fermentation (Adapted from Chen, Yang & Yang 2018.)

The main method of industrial ethanol production is microbial fermentation. Microbial fermentation is the process of using microorganisms (mainly yeast) to transform sugars, starch or cellulose into ethanol under anaerobic conditions. The biochemical reaction of ethanol production from starch and cellulose can be summarized as three stages: macromolecular substances (including starch, cellulose and hemicellulose. The chemical formula is regarded as $(C_6H_{10}O_5)n$) are hydrolyzed into monosaccharide molecules such as glucose, xylose. Monosaccharide molecules form 2-molecular pyruvate by glycolysis. Under anaerobic conditions, pyruvic acid is reduced to 2- molecule ethanol and carbon dioxide is released. The essence of ethanol fermentation is that under anaerobic conditions, glucose is converted into pyruvate by microorganisms through glycolysis. Then pyruvate forms acetaldehyde through decarboxylation, and acetaldehyde is finally reduced to ethanol. The reaction equations for the whole process are as follows. (Chen, Yang & Yang 2018, 109-112.)

$$(C_6H_{10}O_5)n + nH_2O \xrightarrow{\text{Acid or } \alpha\text{-amylase}} nC_6H_{12}O_6 \text{ (glucose)} \qquad \text{First stage}$$

$$C_6H_{12}O_6 \longrightarrow 2CH_3COCOOH + 4H \qquad \text{Second stage}$$

$$2CH_3COCOOH \xrightarrow{\text{Decarboxylatio}} 2CH_3CHO + 2CO_2 \qquad \text{Third stage}$$

$$2CH_3CHO + 4H \longrightarrow 2CH_3CH_2OH$$

3.1.2 Biochemical conversion technologies of biomass

Biogas fermentation technology is a very common technology used to produce biogas in industry. Biogas is a kind of mixed gas produced by anaerobic fermentation of human and animal manure, industrial organic waste liquid and crop straw. Biogas generally contains CH_4 50 % ~ 70 %, the rest is carbon dioxide (CO_2) and a small amount of nitrogen (N_2), H_2 and hydrogen sulfide (H_2S). Biogas fermentation, also known as anaerobic digestion and anaerobic fermentation, refers to the process in which organic substances (such as human and livestock manure, straw, weeds) are decomposed and metabolized by various microorganisms under certain water, temperature and anaerobic conditions, and finally form combustible gas mixtures such as methane and carbon dioxide. Based on the principle of biogas fermentation, biogas fermentation technology aims at energy production, and achieves the comprehensive utilization of biogas, biogas liquid and biogas residue. The biogas fermentation process is essentially the material metabolism and energy conversion process of microorganisms. These microorganisms obtain energy and substance in the metabolism process to meet their own growth and reproduction, and most of the substances are converted into CH_4 and CO_2. (Lin, Wang & Zhou 2007.)

Biogas engineering is the most representative application of biogas fermentation technology in industry. It is a system engineering with large scale anaerobic fermentation as the main technology, integrating sewage treatment, biogas production and resource utilization. Biogas engineering mainly bases on anaerobic fermentation theory and related treatment to reduce the content of organic matter in fecal water, to reach the discharge standard. It takes the anaerobic fermentation technology as the main body and relevant engineering technology to obtain biogas and then directly use it for domestic energy, or power generation, or boiler burning, or directly use it for heating, or as chemical raw materials. Biogas engineering, which uses crop straw, garbage and excrement as raw materials, not only achieves the purpose of waste utilization, but also produces clean energy. It is a biomass energy utilization technology with obvious economic and social benefits. (Zhao & Dong 2008.).

Another typical biochemical conversion technology of biomass is bioethanol technology. Ethanol, also known as alcohol, is an organic compound composed of C, H and O elements. It is also a high-quality liquid fuel, free of sulfur and other impurities. It can directly replace gasoline, diesel and other petroleum fuels. Therefore, it is also the most potential alternative oil fuel. It can be used alone or mixed with gasoline to make ethanol gasoline as automobile fuel. Gasoline blended with ethanol has two functions: one is that the octane number of ethanol is up to 115, which can replace the lead-containing additives that pollute the environment to improve the explosion-proof performance of gasoline; the other is that the oxygen content of ethanol is high, which can improve combustion, reduce the carbon deposition in the engine and the emission of incomplete combustion pollutants such as carbon oxide. Compared with the same volume of bioethanol gasoline and gasoline, the calorific value of combustion is about 30 % lower. But because only 10 % is added, the reduction of calorific value is not significant, and the engine can be used without modification. Biomass can be used to produce ethanol by biotransformation, and the technology of producing fuel ethanol by fermentation of starch or carbohydrate biomass is quite mature. (Chen, Yang & Yang 2018, 8-10.)

3.2 Chemical conversion of biomass

The chemical conversion of biomass includes esterification, transesterification and hydrothermal conversion. Esterification and transesterification are the main production methods of biodiesel. Hydrothermal conversion of biomass includes hydrothermal gasification, hydrothermal liquefaction and hydrothermal carbonation. Based on the chemical conversion of biomass, biomass can be directionally converted into the required products and directly applied to industry. (Chen, Yang & Yang 2018.)

3.2.1 Chemical conversion principles of biomass

Transesterification is the main method to produce biodiesel. The core of transesterification are esterification and transesterification. Esterification is the reaction of carboxylic acid (R—COOH) and alcohol (R'OH) to form ester (R—COOR') under the condition of acid as catalyst. The general formula of esterification can be expressed as:

$$R\text{—}COOH + R'OH \underset{}{\overset{\text{Acid catalysis}}{\rightleftharpoons}} R\text{—}COOR' + H_2O$$

Where: R is the carbon chain of carboxylic acid.

R' is the alkyl of alcohol.

For example, 1 mol carboxylic acid can react with 1mol alcohol to produce 1mol ester and 1mol water. Esterification is a reversible reaction. The by-product water from esterification will dilute the alcohol concentration of the reactant, resulting in the reduction of alcohol concentration, thus reducing the reaction rate and prolonging the reaction time, which is not conducive to the forward process of the reaction, and ultimately the production of the product ester will be greatly reduced. Therefore, in the process of producing biodiesel by esterification, in order to speed up the reaction rate, in addition to the use of catalyst, the by-product water should be constantly removed to maintain the high concentration of alcohol, so that the esterification reaction will proceed in the positive direction. Esterification can be carried out according to three mechanisms. (Xing 2005.)

The first mechanism is addition - elimination mechanism. When carboxylic acid is esterified, carboxylic acid provides hydroxyl group and alcohol provides hydrogen. The result of the reaction is that the hydroxy group on carbonyl carbon is replaced by a nucleophilic reagent. When carboxylic acid is esterified with primary alcohol and secondary alcohol, it mainly belongs to this mechanism. The second mechanism is carbon positive ion mechanism. In the esterification of carboxylic acid and tertiary alcohol, because of the large volume of tertiary alcohol, addition reaction is not easy, but to dehydrate first to form positive ions, and then to combine with carbonyl oxygen to complete the esterification process. The third mechanism is acyl cation mechanism. Only a few esterification reactions belong to this mechanism, such as the esterification of 2,4,6 – trimethyl benzoic acid. (Xing 2005.)

Transesterification is the alcoholysis reaction of ester and alcohol to produce a new ester and a new alcohol under the action of acid, alkali, enzyme and other catalysts or supercritical conditions. All kinds of natural animal and vegetable oils and waste oils from food industry can be used as raw materials for biodiesel production by transesterification. The alcohol used in the transesterification reaction is mainly short chain alcohol such as methanol and ethanol. Because of the short carbon chain and strong polarity of methanol, it can react with the fatty acid glyceride quickly, and the price is low, so methanol is the most commonly used. Triglyceride is a mixture of three fatty acids and one glycerin. It is the main component of animal and vegetable oils and a derivative of carboxylic acid functional group. The total reaction equation of the transesterification reaction between triglyceride and methanol can be expressed as:

$$\begin{array}{c} CH_2OOCR_1 \\ | \\ CHOOCR_1 \\ | \\ CH_2OOCR_1 \\ \text{(Triglyceride)} \end{array} + \begin{array}{c} 3CH_3OH \\ \text{(Methanol)} \end{array} \overset{\text{Catalyzer}}{\rightleftharpoons} \begin{array}{c} R_1COOCH_3 \\ R_2COOCH_3 \\ R_3COOCH_3 \\ \text{(Fatty acid methyl ester)} \end{array} + \begin{array}{c} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \\ \text{(Glycerol)} \end{array}$$

Where: R1, R2 and R3 are saturated or unsaturated straight chain hydrocarbon.

In the transesterification reaction, glycerides of triglycerides are replaced by methanol to form long-chain fatty acid methyl esters. After transesterification reaction, a macromolecule of vegetable oil or animal oil is divided into three separate fatty acid methyl esters, which shortens the length of carbon chain, reduces the viscosity of the product, improves the volatility and also improves the low-temperature fluidity of the product. (Chen, Feng & Zhao 2015.)

The chemical reaction mechanism of hydrothermal gasification is very complex. The chemical reactions in the gasification process may include pyrolysis, hydrolysis, steam reforming, water-gas conversion and methanation. The supercritical hydrothermal gasification of biomass consists of the following three reactions:

$$CH_{2x}O_y + (1-y)H_2O === CO + (x+1-y)H_2$$

$$CO + H_2O === CO_2 + H_2$$

$$CO + 3H_2 === CH_4 + H_2O$$

The first reaction is thermal cracking reaction, and the volatile component produced by thermal cracking is a very complex mixed gas, including at least hundreds of hydrocarbons, in which there are more CO and H_2 contents. The second reaction is called CO transformation reaction, which is an important reaction to produce gas fuel with H_2 as the main component, and also the basic reaction to provide H_2 source for methanation. The third reaction is methanation. Part of the methane in biomass gas comes from the product of pyrolysis of raw materials, and the other part is the result of this reaction. (Chen, Yang & Yang 2018, 161-165.)

As the definition of biomass is very extensive and the composition of various biomass is extremely complex, there is no unified and clear understanding about the reaction mechanism of various biomass components in hydrothermal liquefaction currently. Generally speaking, the hydrothermal liquefaction process of biomass can be roughly divided into two steps. The first step is that the main chemical components of biomass (cellulose, hemicellulose and lignin) are depolymerized into monomers or oligomers. The second step is that the monomers or oligomers form small molecular compounds through the processes of dehydrogenation, decarboxylation, dehydration, and the small molecular compounds form new compounds through condensation and cyclization. (Chen, Yang & Yang 2018, 161-165.)

Hydrothermal carbonation is a typical exothermic process, which mainly reduces the content of O and H elements in raw materials by dehydration and decarboxylation. However, the specific reaction process is very complex, during which a series of side reactions will occur. In addition, hydrothermal reaction is carried out in a closed system, so it is difficult to achieve accurate detection and control of the chemical process at present and its mechanism also needs to be further explored. At present, there is a mechanism of hydrothermal carbonation proposed has been accepted by most researchers. It is believed that the process of hydrothermal carbonation is mainly divided into three stages. The first stage is that the precursor hydrolyzes to monomer, and the pH value of the system decreases. The second stage is dehydration and polymerization of monomers. The third stage is that the aromatization leads to the formation of final products. Taking cellulose as an example, when the temperature is higher than 220 ℃, the hydrous ions produced by water autoionization will catalyze the hydrolysis of cellulose to produce oligosaccharides (such as cellobiose, cellotriose, cellopentose) and glucose. Glucose is converted into fructose by isomerization, and fructose decomposes to produce organic acids, and the free hydrogen ions produced by these acids will play a catalytic role in the subsequent reactions. The oligomers produced in the initial stage are hydrolyzed into different monomers. Then the monomers are dehydrated and cracked to produce soluble products, such as 1,6-dehydrated glucose, erythritol, furfural compounds. The decomposition of furfural compounds also produces acid aldehyde and phenolic substances. Then, through the intermolecular dehydration or aldehyde alcohol condensation reaction, the polymerization or condensation reaction is further induced to form soluble polymer. At the same time, the aromatization of the polymer results in the formation of carbon materials with rich active oxygen groups on the surface. (Chen, Yang & Yang 2018, 161-165.)

3.2.2 Chemical conversion technologies of biomass

Biodiesel technology and biomass hydrothermal technology are the main chemical conversion technologies of biomass. Among them, biomass hydrothermal technology includes hydrothermal gasification technology, hydrothermal liquefaction technology and hydrothermal carbonation technology. Biodiesel is clean alternative fuel that can be used in compression ignition engine, which is produced by renewable biological resources such as plant and animal fat. In terms of chemical composition, biodiesel is a series of long-chain fatty acid methyl esters. Although vegetable oil can be used as fuel of internal combustion engine directly, it needs to be esterified to produce biodiesel in order to avoid troubles and problems of combustion equipment due to its high viscosity and poor volatility. Therefore, esterification can make it closer to diesel in nature and become an ideal alternative fuel for diesel. Biodiesel has high oxygen content, no sulfur, lead, halogen and other harmful substances, no aromatic compounds, and no carcinogenicity. Compared with ordinary diesel, biodiesel has less smoke exhaust, less carbon monoxide emission, high biodegradability and excellent environmental protection characteristics. The cetane number of biodiesel is high, the combustion performance is better than that of ordinary diesel, and the combustion residue is slightly acidic, which prolongs the service life of catalyst and engine oil. Biodiesel blended with petrochemical diesel in a certain proportion can reduce fuel consumption, improve power performance and reduce exhaust pollution. The flash point of biodiesel is nearly twice higher than that of petrochemical diesel, which is not dangerous goods and is safer in transportation, use, treatment and storage. Biodiesel has good compatibility with diesel engine, so it can be added directly without changing the diesel engine. (Shu, Yu & Xiong 2012.)

Hydrothermal gasification refers to the reaction of biomass and supercritical water at 400-700 ℃, 16.5-35 Mpa and long residence time to generate gas which dominated by H_2, CH_4, carbon monoxide (CO), CO_2 and a few liquid products. The gaseous products are further catalytically converted into the gas mainly composed of H_2, CH_4 and CO_2. After drying, CO_2 removal and compression, the synthetic gas is used to prepare natural gas or fuel cell to realize the conversion of high-grade clean energy such as biological hydrogen production. The liquid products contain phenols, hydroxymethylfurfural, furfural, organic acids and a small amount of alcohols. These organics are separated into light bio oil and inorganic minerals by desalination and purification. Light bio oil can be reused after upgrading its quality, while inorganic minerals can be used as nitrogen, phosphorus and potassium fertilizers. (Chen, Yang & Yang 2018, 161-165.)

The hydrothermal liquefaction of biomass is a process in which biomass samples are decomposed into liquid products in subcritical water (temperature 280-380 ℃, pressure 7-30 Mpa, residence time 10-60 min). The liquid product is mainly composed of light component and heavy component. The light component is soluble in water, mainly composed of organic acids, alcohols, aldehydes and other substances. It is yellowish brown, with a low heating capacity of 19-25 MJ / kg. The heavy component is mainly composed of butylated hydroxytoluene and dibutyl phthalate. After hydrothermal liquefaction, it is obtained by solvent extraction, with a high heating capacity of about 30-35 MJ / kg. The whole process is shown in FIGURE 3. (Chen, Yang & Yang 2018, 161-165.)

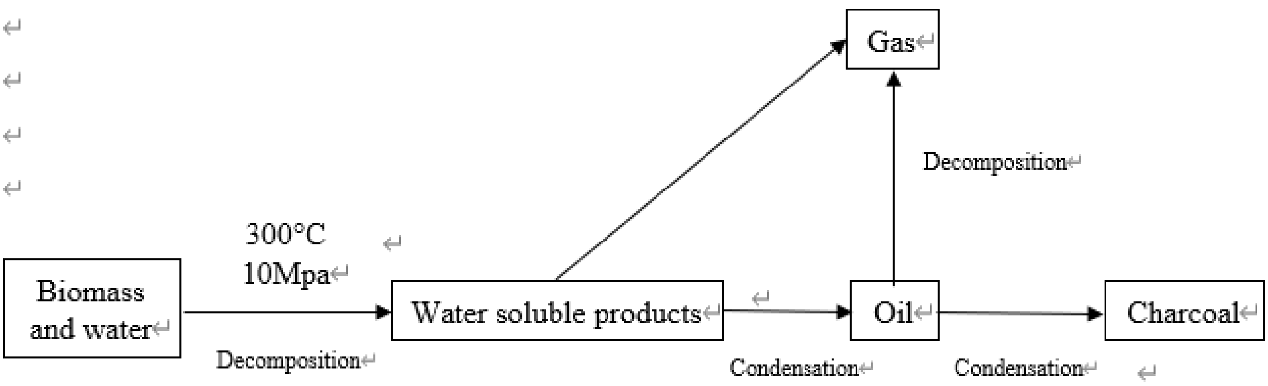

FIGURE 3. Schematic diagram of hydrothermal liquefaction process (Adapted from Chen, Yang & Yang 2018.）

Hydrothermal carbonization is a kind of hydrothermal reaction, which takes the solid product coke as the target product, blends the biomass and water completely in a certain proportion and adds them into the reactor, under a certain temperature (180 ~ 250 ℃), reaction time (4 ~ 24 h) and pressure (1.40 ~ 27.6 Mpa). Compared with hydrothermal gasification and liquefaction, the temperature and pressure required for hydrothermal carbonation are lower, and the conditions are relatively mild. In terms of energy density, the quality of hydrothermal coke is close to peat and lignite, and it can be used as composite solid fuel directly. In addition, carbon with uniform size and good morphology can be obtained after the raw materials are treated by hydrothermal carbonization. Through synthesis, it can be used as carbon functional materials with high efficiency, stability and nano scale, and widely used in electrode materials, fuel cells and other fields. (Chen, Yang & Yang 2018, 161-165.)

3.2.3 Chemical conversion applications of biomass

Hydrothermal carbonation technology has developed rapidly in recent years. The applications of this method in main industrial fields are introduced below. Electrode coating materials for lithium-ion batteries is a typical application. The traditional positive and negative electrode materials of lithium-ion battery have the characteristics of easy expansion, short cycle life and many surface side reactions, which limit the wide application of lithium-ion battery. Due to its strong structural stability and chemical stability, the carbon materials obtained by hydrothermal carbonation technology are expected to improve the performance of lithium-ion batteries when used as the coating materials for positive and negative electrodes of lithium-ion batteries. (Wu & Ma 2003.)

Electrode material of super capacitor is a typical application. Carbon materials are commonly used as electrode materials in supercapacitors. At present, improving the specific surface area of carbon materials and doping elements of carbon materials are two important ways to improve the performance of supercapacitors. The method of hydrothermal carbonization can be used to prepare porous carbon materials, and it is easy to dope carbon materials, so it is an ideal method to prepare electrode materials for supercapacitors. (Wu & Ma 2003.)

Water purification materials is a typical application. The existence of heavy metal ions or radioactive elements in water will cause serious harm to the safety and health of aquatic organisms and human beings, so how to effectively control this kind of pollution has become the focus of many researchers. The surface of carbon material obtained by hydrothermal treatment contains a large number of oxygen-containing groups, which makes the carbon surface negatively charged and is conducive to adsorption of positively charged metal ions. In addition, the surface of carbon materials can be modified by hydrothermal carbonation process and subsequent chemical treatment, and the adsorption of heavy metal ions or radioactive elements can be more effective by regulating surface functional groups. (Wu & Ma 2003.)

Drug carrier is a typical application. The carbon material produced by hydrothermal carbonization technology has good biocompatibility and fluorescence, and its surface is rich in oxygen-containing groups, which is also conducive to the uniform fixation of targeted substances. Therefore, when it is used as drug carrier, it can be tracked in cells without additional fluorescent labeling and can successfully transport the impermeable molecules into cells. Catalyst carrier is a typical application. The excellent chemical stability of carbon material is the necessary prerequisite for it to be used as catalyst carrier. There are abundant oxygen groups on the surface of carbon material produced by hydrothermal carbonization technology, which can realize more uniform and stable fixation of catalyst. (Wu & Ma 2003.)

3.3 Thermochemical conversion of biomass

Thermochemical conversion of biomass refers to converse biomass into fuel or chemicals by chemical means under heating conditions, including combustion, gasification. Thermochemical conversion of biomass is also the most direct form of biomass in industrial utilization. Its related technologies have also been used in industry. As people realize that biomass is a clean and renewable resource, large-scale utilization can effectively reduce greenhouse gas emissions. Using advanced combustion technology and gasification technology to utilize biomass efficiently has attracted attention in the past decade. Moreover, it has formed a new industry with rapid development in the world. (Chen, Yang & Yang 2018.)

3.3.1 Thermochemical conversion principles of biomass

Biomass combustion is one of the simplest thermochemical conversion methods, and it is also an important way of large-scale and efficient clean utilization of biomass energy. From the chemical point of view, biomass combustion is a process in which the organic matter that makes up biomass reacts violently with oxygen in the air to release heat; from the perspective of energy conversion, it is a process in which the chemical energy contained in biomass organic matter is converted into heat energy through oxidation reaction. In essence, biomass combustion belongs to gas-solid heterogeneous reaction, but due to the complexity of its properties, combustion includes drying (water evaporation), pyrolysis, gas-phase combustion and coke combustion stages, which are the coupling of chemical reaction, heat transfer, mass transfer and many other processes. In the combustion process of biomass, the combustible part reacts with O_2 at a certain temperature, which transforms the chemical energy into heat energy to raise the temperature of combustion products. Biomass is characterized by high water content, less carbon content than fossil fuels, and more organic hydrogen content. In the combustion process, carbon and hydrogen are easy to combine into hydrocarbons and volatilize, and the ignition point is low. In the early stage of combustion, enough air is needed to meet the requirement of volatile combustion, otherwise the volatile is easy to crack, resulting in incomplete combustion and carbon black. Biomass combustion can be roughly divided into four stages: fuel drying stage, volatile component separated out and coke formation stage, volatile component combustion stage, coke combustion and burnout stage. (Chen, Yang & Yang 2018, 38-41.)

The first stage is fuel drying stage. The temperature of biomass increases continuously after being heated. When the temperature reaches 100 ℃, the surface water and the inner water in the gap begin to evaporate, and the biomass enters the drying stage. When water evaporates, it needs to absorb the heat released in the combustion process, which will reduce the temperature of combustion chamber and slow down the combustion process. The second stage is volatile component separated out and coke formation stage. When the temperature continues to rise and reaches a certain temperature, the volatiles in biomass begin to separate out. When the volatiles are completely separated, the rest is coke. In the above two stages, biomass is in endothermic state, which is called pre combustion preparation stage. (Li & Yang, 2009, 1-7.)

The third stage is volatile component combustion stage. With the increase of temperature, the volatiles begin to burn. This temperature is called the ignition temperature of volatiles. Because of the complexity of volatile composition, combustion reaction is also more complex. The combustible gas in the volatile will burn, release a lot of heat, and the temperature will rise further, which will promote the volatile analysis and combustion, playing a positive feedback process. The last stage is coke combustion and burnout stage. The combustion of volatile matter consumes a lot of oxygen, reduces the amount of oxygen diffused to the surface of coke, and inhibits the combustion of coke. In addition, volatile combustion increases the temperature of the gas flow on the coke surface. The gas flow heats the coke by convection, conduction and radiation. When the ignition temperature of the coke is reached, the coke starts to burn. The later stage of coke combustion is called burnout stage, in which the ash content increases continuously. (Li & Yang, 2009, 1-7.)

Gasification refers to the thermochemical process of transforming solid or liquid fuel into gas fuel. In this process, free oxygen or combined oxygen reacts with carbon in fuel to produce combustible gas. Biomass gasification is a process of transforming solid biomass into gas fuel by pyrolysis, oxidation, reduction, transformation and other thermochemical reactions under high temperature environment with biomass as raw material in air, oxygen, water vapor or their mixture. The process of biomass gasification is complex, including the separation of biomass volatiles, the oxidation and reduction of coke and the transformation of water gas. The biomass fuel is heated, dried, volatilized, pyrolyzed, cracked, reformed and also reacts with tar and coke. Then, the pyrolysis products and coke are burned, and the combustion products CO_2, H_2O may have reduction reaction with coke. Finally, the biogas with CO_2, H_2 and CH_4 as the main components is generated. The medium needed for gasification reaction includes air, oxygen, subcritical water vapor or their mixture. (Sikarwar, Zhao & Clough 2016, 2939-2977.) Biomass gasification is a collection of complex reactions, such as pyrolysis of raw materials, combustion of pyrolysis products and reduction of combustion products. For different gasification devices, processes, reaction conditions and types of gasifiers, the reaction processes are different. However, they can be divided into four reaction stages: drying, pyrolysis, reduction and oxidation. (Zhu 2006.)

3.3.2 Thermochemical conversion technologies of biomass

Since human beings learned to use fire, they began to use biomass as fuel. Direct combustion is the most primitive and practical way to use biomass energy. However, the traditional combustion technology is relatively backward, and the efficiency of heat energy conversion is low. With the development of society and the progress of science and technology, the facilities and methods of burning biomass are also improving. Biomass combustion technology can be divided into biomass direct combustion technology, biomass briquette fuel combustion technology and biomass coal combustion technology. (Chen, Yang & Yang 2018, 38-39.)

Biomass direct combustion refers to the pure combustion of biomass, mainly divided into stove combustion and boiler combustion. The combustion efficiency of traditional stoves is very low. Biomass boiler combustion is to use biomass as the fuel of the boiler, using advanced combustion technology to improve the efficiency of biomass utilization, which is suitable for the areas where biomass resources are relatively concentrated and can be used on a large scale. According to the different combustion modes of the boiler, it can be divided into layer combustion furnace and fluidized bed boiler. Layer burning technology is widely used in the development and utilization of agricultural and forestry wastes and the incineration of urban domestic waste. Layer burning technology refers to lay biomass fuel on the grate to form a layer, mix with the first air distribution, and gradually carry out the drying, pyrolysis, combustion and reduction process. The combustible gas and the secondary air distribution are fully mixed and burned in the space above the grate. This technology is widely used in the development and utilization of agricultural and forestry wastes and municipal waste incineration, with low investment and operation cost. Fluidized bed combustion technology has the advantages of high combustion efficiency, less harmful gas emission and large heat capacity, which is suitable for burning biomass fuel with high moisture content and low heat value. Its advantages lie in high combustion efficiency, less harmful gas emission and large heat capacity. (Ma, Chen & Yan 2007, 43-48.)

Biomass briquette fuel is characterized by small volume, large density, convenient storage and transportation, no flying debris, convenient use and high cleanliness. It is a kind of clean energy with stable combustion, long cycle, high combustion efficiency and low pollutant content in the ash and flue gas after combustion. Its combustion technology is also a good way of utilization. However, due to the high cost and the immature pressing equipment of briquette fuel, the utilization scale of biomass briquette fuel in various countries is still not massive. At present, it is only used for heating, cooking and other specific purposes, and its application scope needs to be expanded. (Jenkins & Baxter 2003, 17-46.)

Biomass coal combustion technology is a common blended combustion technology in industry. In coal-fired industrial boilers, using biomass to replace part of the coal, only a small transformation of the equipment, is a low-cost, low-risk way of combustion utilization at this stage. In many countries, hybrid combustion is also the most economical technology choice for CO_2 emission reduction. According to the different mixing modes, it can be divided into direct mixed combustion, indirect mixed combustion and parallel mixed combustion. All of these require local transformation of the original fuel transportation system and burner to adapt to the combustion characteristics of biomass. (Heinzel, Siegle & Spliethoff 1998, 109-125.)

Biomass gasification takes biomass as raw material, using oxygen (O_2), water vapor, or H_2 as gasification agent. The combustible part of biomass is converted into combustible gas by thermochemical reaction under high temperature. The main effective components of the gas from biomass gasification are CO, H_2 and CH_4. Gasification can convert biomass into high-quality gaseous fuel, which can be directly used as boiler fuel or power generation to generate required heat or electricity, or as syngas to indirectly produce liquid fuel or chemical products such as methanol and dimethyl ether. There are many forms of biomass gasification. It can be divided into two types, using the gasification medium and not using the gasification medium. If the gasification medium is not used, there is only retort gasification. If the gasification medium is used, it can be divided into air gasification, oxygen gasification, steam gasification, steam-oxygen mixed gasification and hydrogen gasification. In fact, retort gasification is a special case of pyrolysis gas. It is a kind of biomass pyrolysis without oxygen or only providing limited oxygen so that gasification will not occur in large quantities, it can also be described as partial gasification of biomass. Retort gasification is the volatilization of biomass under certain temperature, the main products are solid coke, wood tar, wood vinegar and gasification gas. (Chen, Yang & Yang 2018, 59-61.)

Air gasification refers to the gasification process with air as the gasification medium and the oxygen in the air reacts with the combustible components in the biomass to produce combustible gas. The heat released in the reaction process provides the required energy for other processes of gasification reaction, i.e. thermal decomposition and reduction. However, as 79 % of N_2 in the air does not participate in gasification reaction, it dilutes the content of combustible components in the gas, thus reducing the calorific value of the gas. Since air can be obtained at will and no external heat source is needed in the air gasification process, air gasification is the simplest and easiest form in all gasification processes. Therefore, this gasification technology is widely used. (Chen, Yang & Yang 2018, 59-61.)

Oxygen gasification is to provide a certain amount of oxygen to biomass fuel for oxidation-reduction reaction to generate combustible gas. Because there is no inert gas N_2, under the same equivalence ratio as air gasification, the reaction temperature increases, the reaction rate increases, the reactor volume decreases, and the thermal efficiency increases. However, at the same reaction temperature as air gasification, the oxygen consumption and equivalence ratio decrease, and then the gas quality is improved. (Chen, Yang & Yang 2018, 59-61.)

Steam gasification refers to the reaction between water vapor and biomass at high temperature. It includes not only the reduction reaction of water vapor carbon, but also the conversion reaction of CO and water vapor, and the thermal decomposition reaction of biomass in the gasifier. The main gasification reaction is the endothermic reaction process. Therefore, the heat source of steam gasification comes from the external heat source and the heat source of steam itself. The content of H_2 and CH_4 in the gasified gas is high. (Chen, Yang & Yang 2018, 59-61.)

Steam-oxygen mixed gasification refers to the gasification process in which O_2 and steam are used as gasification agents at the same time. Theoretically speaking, steam-oxygen mixed gasification is a superior gasification method than air or water vapor alone. On the one hand, it does not need complex external heat source. On the other hand, a part of O_2 required for gasification can be provided by water vapor, which reduces the consumption of O_2, and generates more H_2 and hydrocarbons. Especially in the presence of catalyst, CO is further converted into CO_2, reducing the content of CO in the gas, making the gas fuel more suitable for use as urban gas. (Heidenreich & Pier 2015, 72-95.)

Hydrogen gasification refers to the process in which H_2 reacts with carbon and H_2O to generate a large amount of CH_4. The reaction conditions are harsh and need to be carried out under the conditions of high temperature, high pressure and hydrogen source. However, the gasification needs high temperature and high pressure, and H_2 is dangerous as gasification agent, so this kind of gasification reaction is not often used. (Heidenreich & Pier 2015, 72-95.)

3.3.3 Thermochemical conversion applications of biomass

Biomass gasification technology is widely used in industry. Here are two applications of biomass gasification technology in main industrial fields. Biomass gasification power generation technology is a very effective method for large-scale utilization of biomass energy. The process flow diagram is shown in FIGURE 4. Biological raw materials are converted into biological gas in the gasification plant. After the ash, tar and other impurities in the gas are removed by the dedusting, purification and cooling system, they are transported to the gas power generation plant for power generation. The generated power can be incorporated into the power grid or directly supplied to the nearby power facilities. (Zhang, Yang & Dong 2007.)

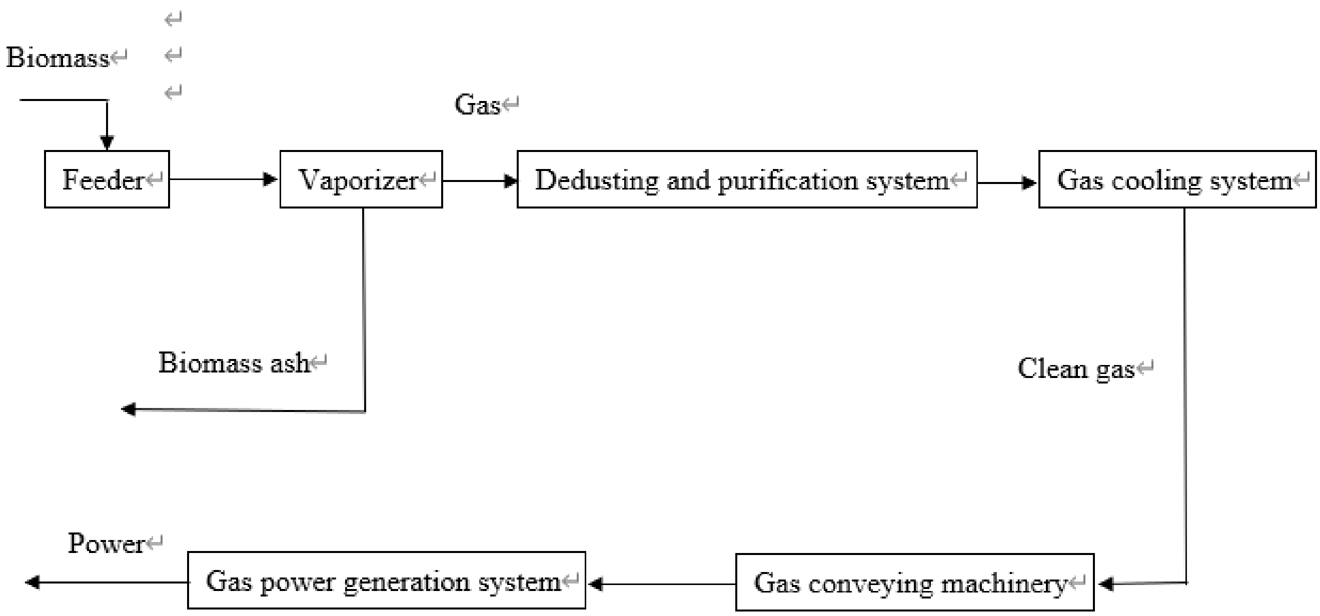

FIGURE 4. Process flow diagram of biomass gasification power generation (Adapted from Chen, Yang & Yang 2018.）

There are three characteristics of biomass gasification power generation technology. It is a flexible technology. Power generation equipment can be internal combustion engine or gas turbine, or steam power generation system, and appropriate power generation equipment can be selected according to the power generation scale to ensure reasonable power generation efficiency. It is good for environmental protection. The biomass belongs to renewable energy, which can effectively reduce emissions of greenhouse gases such as CO_2, SO_2 and pollution gases. It is an economical technology. Compared with other renewable energy power generation technology, this technology has the advantages of simple equipment, no high voltage process and less investment. (Zhang, Yang & Dong 2007.)

Another application is biomass gasification for chemical synthesis. Gasification synthesis technology is a set of integrated technology that takes biomass as raw material, obtains high-quality synthetic feed gas through gasification and component adjustment, and then uses catalytic synthesis technology to produce liquid fuel and chemicals, which can produce hydrocarbon fuel, alcohol chemicals and synthetic ammonia. The technology of biomass directional gasification can be divided into two stages: directional gasification and gasification reforming transformation. Different from conventional gasification, the purpose of directional gasification is to prepare chemical synthesis gas, so the output of synthesis gas needs to be increased to reduce the difficulty of subsequent reforming transformation. (Gallezot 2012.)

Gasification reforming transformation mainly consists of purification, reforming and conversion. The purpose of gas purification is to prevent the fine dust particles and micro droplet tar from entering the subsequent process. Gas reforming is to reformate the hydrocarbon components and tar in the gas by adding appropriate amount of water vapor and then to generate H_2 and CO. Gas conversion is to increase the content of H_2 in the gas through water gas transformation reaction, adjust the hydrogen carbon ratio in the gas, and make it meet the final requirements of chemical synthesis process. (Gallezot 2012.)

3.4 Microbiological Fuel Cells

Different from the above-mentioned traditional agricultural and forestry biomass, Microbiological Fuel Cells (MFC) is a new utilization form of microbial biomass in industry in recent years. With the decrease of global petroleum fuel and the aggravation of greenhouse effect, a kind of clean and efficient energy has emerged, which is MFC. This is also a major innovation in developing biomass into energy. MFC technology has brought great impetus to the development of world economy, society and environment, and made contribution to the recycling of resources and the realization of sustainable development. (Chen, Yang & Yang 2018.）

3.4.1 Microbiological Fuel Cells principle and classification

MFC is a kind of device that uses microorganism as the main body of reaction to directly convert the chemical energy of fuel (organic matter) into electrical energy. There are many similarities between the working principle of the fuel cell and that of the traditional fuel cell. Take the fuel cell with glucose as the substrate as an example, the chemical reaction equations are as follows:

Anode reaction: $C_6H_{12}O_6 + 6H_2O \xrightarrow{\text{Catalyzer}} 6CO_2 + 24e^- + 24H^+$

Cathode reaction: $6O_2 + 24e^- + 24H^+ \xrightarrow{\text{Catalyzer}} 12H_2O$

Generally speaking, MFC is realized by transferring electron oxidation electron donor to anode under the condition of anoxia. The electron donor can be microbial metabolic substrate or artificial auxiliary electron transfer intermediate. This intermediate can obtain electrons from microorganisms and then transfer the obtained electrons to the anode. In some cases, microorganisms can produce soluble electron transfer intermediates, or directly transfer the generated electrons to the anode surface, and the electrons reach the cathode through the external circuit. The protons released in the oxidation process of organic compounds reach the cathode through the proton exchange membrane, which can restrict dissolved oxygen to enter the anode chamber. Finally, electrons, protons and oxygen combine on the cathode surface to form water. (Yuan, Wu & Ma 2005.)

According to different catalysts, MFC can be divided into microbial fuel cell and enzyme biofuel cell. The former uses the whole microorganism as the catalyst, while the latter directly uses the enzyme as the catalyst. According to the different electronic transfer mode, MFC can be divided into direct MFC and indirect MFC. Direct MFC means that the fuel is oxidized directly on the electrode, and the electrons are transferred directly from the fuel to the electrode. The fuel of indirect MFC is not oxidized on the electrode, and the electrons are transferred to the electrode by some way after being oxidized elsewhere. (Yuan, Wu & Ma 2005.)

3.4.2 Microbiological Fuels Cells technology

MFC is a new energy production and utilization technology. The mechanism of MFC is to transfer the electrons generated in the redox reaction to the electrodes of fuel cells by using the microbial redox organics, which is a process of converting biochemical energy into electrical energy. Energy and environmental problems are the two focuses of social concern. MFC can produce electric energy while dealing with pollutants. In the process of conversion, MFC has the advantages of high energy conversion rate, fuel diversification, mild operating conditions, safety and pollution-free. This technology is widely valued by researchers. (Chen, Yang & Yang 2018, 202-204.)

The applications of MFC in practice are various, such as the degradation of brewery wastewater and sugarcane wastewater in industry, the degradation of domestic sewage and the generation of electricity from landfill leachate in life. With the development of MFC technology, the electrochemical activity of benthic MFC can be used to determine the relationship between bacteria, and the cathodic enzyme can be used to catalyze the biological current of MFC to enhance dye decolorization. New technology of MFC is constantly breaking through, such as ultrasonic treatment of MFC to change the degradation characteristics of organic matter in sludge. (Chen, Yang & Yang 2018, 202-204.)

3.4.3 New prospect of Microbiological Fuel Cells

The microorganisms used in MFC include Escherichia coli, Proteus vulgaris. Due to the complexity of microbial catalytic reaction and plenty of by-products, MFC is rarely used for direct power supply, mainly used for biosensor, sewage treatment or microbial culture and performance measurement. Mediator-less MFC is a new type of MFC. Microbial cell membranes contain non-conductive substances such as lipids or peptidoglycans, which make it difficult for electrons to pass through, so most MFC need mediators. Because of the high cost of common mediators, the emergence of the non - mediators Microbiological Fuel Cells has greatly promoted the commercialization of fuel cells. There is cytochrome on the extracellular membrane of shewanella putrefaciens, which has good redox ability and can play a role of mediator in the process of electron transfer, and it is a part of the cell membrane itself, without the problem of permeability. Therefore, high-performance Microbiological Fuel Cells without mediator can be designed. (Chen, Yang & Yang 2018, 202-204.)

MFC has been widely valued because of its simple operation, clean and efficient characteristics. Great progress has been made in the research of MFC battery in recent years. The researchers found that MFC can not only be used for sewage treatment, as a biosensor, but also for other applications. However, the output power of MFC designed at present is far from the actual application requirements. The output power can be improved by screening high-efficiency microorganisms, optimizing electrode materials and designing a reasonable reactor. With the development of research, MFC as a kind of clean energy, will become the core power of energy technology in the future. (Chen, Yang & Yang 2018, 206.)

4 DEVELOPMENT STATUS AND PROSPECT OF BIOMASS ENERGY

With the international community paying more attention to energy security, ecological environment protection, climate change and other issues. Accelerating the development and utilization of renewable energy, such as biomass energy, has become a common consensus and concerted action of all countries in the world. Moreover, this is also a major strategic measure for global energy transformation and the realization of the goal of coping with climate change. (Zhang 2015.)

4.1 Development status

Biobased materials, bio fuels and biobased chemicals are important strategic products related to people's livelihood quality and national energy and food security. In 2017, the global scale of biobased materials and biomass energy industry exceeded US $1 trillion, and the US reached US $400 billion. According to the report issued by the Organization for global Economic Cooperation and Development (OECD), about 35 % of the chemicals and other industrial products in the world will come from bio manufacturing in 2030. Biomass energy has become the first renewable energy in the world, and the United States plans to take up 30 % of the transportation fuel by 2030. Sweden, Finland and other countries plan to completely replace petroleum based vehicle fuel with biomass fuel by 2040. At present, all countries in the world have put forward clear development goals of biomass energy, formulated relevant development plans, regulations and policies to promote the development of renewable biomass energy. For example, some industries such as corn ethanol in the United States, sugarcane ethanol in Brazil, biomass power generation in northern Europe, and biogas in Germany are developing rapidly. (Li, Wang & Xu 2011.)

Biomass energy technology mainly includes biomass power generation, biomass liquid fuel, biomass gas, solid forming fuel, biobased materials and chemicals. The following analysis will be made for the development status of each specific technology in the world and China. Biomass power generation technology is the most mature and developing modern biomass energy utilization technology. At present, there are 3800 biomass power plants in the world with an installed capacity of about 60 million kilowatts. Biomass power generation technology is the most developed in Europe and the United States. Denmark's direct combustion of agricultural and forestry waste power generation technology, Norway, Sweden, Finland and the United States of America's biomass combustion power generation technology are in the world's leading level. The waste incineration power generation in Japan is developing rapidly, and the treatment capacity accounts for more than 70 % of the harmless disposal capacity of domestic waste. In

China, biomass power generation is mainly direct fired power generation, which starts late but develops rapidly. By the end of 2017, the total installed capacity of biomass power generation in China was 14.762 million kilowatts, including 7.09 million kilowatts of agricultural and forestry biomass power generation, 7.253 million kilowatts of domestic waste incineration power generation, and 500000 kilowatts of biogas power generation; the total installed capacity of biomass power generation in China is second only to the United States, ranking second in the world. (Ma, Tang, Wang, Sun, Lyu & Chen 2019, 434-442.)

Biomass liquid fuel has become the most potential alternative fuel, among which biodiesel and fuel ethanol technology have achieved large-scale development. In 2017, the global biodiesel production reached 32.232 million tons. The United States, Brazil, Indonesia, Argentina and the European Union are the main countries and regions for biodiesel production, among which the biodiesel production of the European Union accounts for 37 % of the global production, the United States for 8 % and Brazil for 2 %. In 2017, the global production of biofuel ethanol reached 79.81 million tons. The United States and Brazil are the countries with the largest production of fuel ethanol, with production of 44.1 million tons and 21.28 million tons respectively. At present, the output of biofuel ethanol in China is about 2.6 million tons / year, accounting for only 3 % of the global total output, and there is still a large space for development. China has made a breakthrough in the production of bio aviation oil by cellulose, and has realized the cotransformation of hemicellulose and cellulose in biomass to bio aviation oil. At present, it has taken the lead in the international demonstration application stage. Using animal and vegetable oils as raw materials, the bio aviation fuel produced by the self-developed hydrogenation technology, catalyst system and process technology has been successfully applied in commercial passenger carrying flight demonstration, which makes China become one of the few countries in the world with the self-developed production technology of bio aviation fuel and successful commercialization. (Ma, Tang, Wang, Sun, Lyu & Chen 2019, 434-442.)

Biomass gasification technology is mature and industrialized. Europe is the most mature region of biogas technology. The biogas engineering equipment in Germany, Sweden, Denmark, Netherlands and other developed countries has reached the standardization of design, seriation of products, modularization of assembly, industrialization of production and standardization of operation. At present, Germany has the largest number of rural biogas projects in the world. Sweden is the country with the best biogas purification for vehicle gas. Denmark is the country with the most characteristics in the development of centralized biogas engineering, in which the centralized combined fermentation biogas engineering has been very mature and is used for the collection and treatment of livestock manure, crop straw and industrial waste, most of which adopt the mode of cogeneration. China's biomass gasification industry mainly consists of gasification power generation and rural gasification gas supply. In recent years, the large-scale biogas engineering has developed rapidly, forming the mode of combined heat and power supply. (Ma, Tang, Wang, Sun, Lyu & Chen 2019, 434-442.)

Solid fuel molding technology in Europe and the United States is the leading level, and its relevant standard system is relatively perfect, forming the entire industrial chain from raw material collection, storage, pretreatment to the production, distribution and application of forming fuel. At present, the solid forming fuel production of Germany, Sweden, Finland, Denmark, Canada, the United States and other countries can reach more than 20 million tons / year. China's solid fuel molding technology has made remarkable progress, and its production and application have initially formed a certain scale. However, in recent years, the development of China's molding fuel industry shows a trend of increasing first and then decreasing. The annual utilization scale of China has increased from 3 million tons in 2010 to 8.5 million tons in 2014, and began to fall back after 2015, mainly because the environmental benefits of biomass direct combustion power generation are controversial, and some provinces even limit the bio-mass direct combustion and mixed combustion power generation projects. (Ma, Tang, Wang, Sun, Lyu & Chen 2019, 434-442.)

Biobased products are a major focus of future development. At present, the world is actively promoting the development of synthetic biobased products through various means. With the continuous progress of bio refining technology and bio catalysis technology, the organic synthesis with high energy consumption and high pollution is gradually replaced by green and sustainable biosynthesis. Moreover, the production capacity of biobased products produced by sugar, starch and cellulose is growing rapidly. (Ma, Tang, Wang, Sun, Lyu & Chen 2019, 434-442.)

4.2 Development prospect

In recent years, biomass as a clean and efficient new energy has emerged. Its development prospect is very broad, specifically in the following aspects. More varieties of high value biobased products have appeared. In today's fierce industrial competition, the development of high value biomass products is one of the development trends of biomass energy, such as military special fuel energy additives, military ultra-low freezing point diesel, adipic acid, high molecular monomer glycol, low-cost bioplastics and biomass dyes. The bio liquid fuel extends to the bio based chemical industry, and its technology focuses on diversified bio refining. It forms a wealth of energy derived alternative products such as fuel ethanol, mixed alcohol and biodiesel, and constantly expands the application fields such as aviation fuel and basic chemical raw materials. (Zhang 2015.)

Interdisciplinary and deep integration development of multi-technology has formed. With major scientific breakthroughs in modern information technology, biotechnology, computer technology, advanced manufacturing technology, polymer materials and other fields. Internet, big data and artificial intelligence will bring new opportunities for the development of biomass energy, and multi-disciplinary deep integration will become an inevitable trend of future development. The development and utilization of biomass energy will present a trend of diversification, intelligence and networking. (Wu, Yin, Liu & Chen 2016, 191-198.)

New biomass has developed on a large scale. With the rapid development of biomass industry, traditional biomass resources are not enough to support the huge demand of biomass resources. On the basis of efficient recycling of traditional agricultural and forestry biomass, new biomass (such as algae, microorganisms and energy plants) must be developed to meet the demand of industrial development. (Li & Yang 2009, 1-7.)

5 PROBLEMS IN DEVELOPMENT OF BIOMASS

Biomass energy is the only new energy that can be converted into a variety of energy products. It is an important part of the development of circular economy to improve the local environment directly through the treatment of waste, with obvious comprehensive benefits. However, from the perspective of resources and development potential, biomass energy is still in the early stage of development. In terms of China, there are still the following major problems. There is no consensus. There is not enough understanding of biomass energy from all walks of life. Some places even limit the application of biomass energy such as solid fuel molding technology, which results in the restriction of biomass energy development. (National Energy Administration 2016.)

Agriculture lacks experience in distributed commercial development and utilization. Due to the current agricultural production mode in China, it is difficult to collect agricultural and forestry biomass raw materials on a large scale. For some projects with annual utilization over 100000 tons, it is difficult to collect raw materials. The collection of animal excrement is lack of special equipment. Therefore, it is urgent to explore the distributed commercial development and utilization mode of biomass energy that is collected, transformed and consumed nearby. (National Energy Administration 2016.)

The low technical level of specialization and marketization needs to be improved. Biogas and biomass forming fuel are still in the early stage of development, limited by the rural market, the degree of specialization is not high, the market system is not perfect, and the high-value commercial market has not been successfully developed. The key technology and engineering of cellulosic ethanol have not yet been broken through, so it is urgent to develop modern special equipment such as high-efficiency mixed raw material fermentation device, large-scale low emission biomass boiler, and also improve the engineering level of bio natural gas and formed fuel. (National Energy Administration 2016.)

The standard system is not perfect. There is no industrial standard system for biogas and biomass forming fuel and there is no standard and specification for equipment, products and engineering technology. There is no specific pollutant emission standard for biomass boilers and biogas projects. The construction of biomass energy testing and certification system lags behind, which restricts the development of industrial specialization and standardization. (National Energy Administration 2016.)

The policy is not perfect. The development and utilization of biomass energy involves raw material collection, processing and transformation, energy product consumption, by-product treatment and many other links need to be optimized. The priority utilization mechanism of biomass energy products has not been established, and there is no terminal subsidy policy support for biogas and biomass forming fuel. (National Energy Administration 2016.)

6 CONCLUSION

Through biomass conversion technologies, biomass can be efficiently converted into industrial energy. In this paper, we studied these technologies and their principles as well as the main applications in industry. At the same time, the development status of biomass energy in the world and China, and the development prospect of biomass energy in the future are explored. In addition, combined with the current development of biomass energy in China, the problems encountered in the development process of biomass energy are also summarized.

Biomass energy is a kind of industry convergence, which is not only renewable energy, but also belongs to the category of biotechnology and bio industry. Compared with wind energy, nuclear energy, solar energy and other new energy sources, biomass energy has unique advantages of wide source of resources, diversified utilization, diversified energy products and significant comprehensive benefits. At present, the utilization of biomass energy in industry is not enough, and the relevant technological processes are not perfect. Therefore, biomass energy has great development potential, and it is bound to become the main energy in the future.

REFERENCES

Chen, H., Yang, S. & Yang, H. 2018. Principles and Technology for Biomass Energy Conversion. Beijing: China Water & Power Press.

Chen, G., Feng, X. & Zhao, M. 2015. Preparation of biodiesel from waste oil. Beijing: Chemical Industry Press.

Gallezot, P. 2012. Conversion of Biomass to Selected Chemical Products. ChemInform, 19, 2216-2224.

Heinzel, T., Siegle, V. & Spliethoff, H. 1998. Investigation of Slagging in Pulverized Fuel Co-combustion of Biomass and Coal at a Pilot-scale Test Facility. Fuel Processing Technology, 54, 109-125.

Jenkins, B. & Baxter, L. 2003. Combustion Properties of Biomass. Fuel Processing Technology, 54 (8), 17-46.

Li, B. & Yang, H. 2009. Current situation and Prospect of biomass combustion technology. Industrial boiler, 5, 1-7.

Li, H., Yuan, Z. & Ma, X. 2011. Modern biomass energy utilization technology. Beijing: Chemical Industry Press .

Lin, C., Wang, J. & Zhou, C. 2007. Theory and engineering of biogas technology. Beijing: Chemical Industry Press.

Li, W., Wang, L. & Xu, J. 2011. Modern energy chemical technology. Beijing: Chemical Industry Press .

Ma, L., Tang, Z., Wang, C., Sun, Y., Lyu, X. & Chen, Y. 2019. Research Status and Future Development Strategy of Biomass Energy. Bulletin of the Chinese Academy of Sciences, 34 (4), 434-442.

Ma, W., Chen, G. & Yan, P. 2007. Summary of biomass combustion technology. Biomass chemical engineering, 41, 43-48.

National Energy Administration. 2016. ‘13th five year’ plan for biomass energy development.

Shi, Z. & Hua, Z. 2007. Handbook of biomass and Bioenergy. Beijing: Chemical Industry Press.

Shu, Q., Yu, C. & Xiong, D. 2012. Biodiesel science and technology. Beijing: Metallurgical Industry Press.

Sikarwar, S., Zhao, M. & Clough, P. 2016. An Overview of Advances in Biomass Gasificiation. Energy and Environmental Science, 9, 2939-2977.

Steffen, H. & Ugo, F. 2015. New cpncepts in Biomass Gasification. Progress in Energy and Combustion Science, 46, 72-95.

Wu, C., Yin, X., Liu, H. & Chen, Y. 2016. Perspective on Development of Distributed Bioenergy Utilization. Bulletin of the Chinese Academy of Sciences, 31 (2), 191-198.

Wu, C. & Ma, L. 2003. Modern utilization technology of biomass energy. Beijing: Chemical Industry Press.

Xing, Q. 2005. Basic organic chemistry. Beijing: Higher Education Press.

Yuan, Z., Wu, C. & Ma, L. 2005. Principle and technology of biomass energy utilization. Beijing: Chemical Industry Press.

Zhang, J. & Liu, D. 2009. Biomass energy utilization technology. Beijing: Chemical Industry Press.

Zhang, D. 2015. Research progress and application prospect of biomass energy. Beijing: Beijing Institute of Technology Press.

Zhang, J., Yang, Y. & Dong, C. 2007. Biomass power generation technology. Beijing: China Water & Power Press.

Zhao, L. & Dong, B. 2008. Large and medium scale biogas engineering technology. Beijing: Chemical Industry Press .

Zhu, X. 2006. Principle and technology of biomass pyrolysis. Hefei: University of Science and Technology of China Press.