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## Research progress of biomass fuel upgrading and distributed utilization technology

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# Research progress of biomass fuel upgrading and distributed utilization technology

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**Abstract.** The study, development and application of biomass energy and alternative petroleum products are effective ways to ensure energy provision, reduce the dependence on fossil energy and resolve the future energy problems. The characteristics of biomass fuel were analyzed, and the upgrading methods of biomass fuels were discussed. Furthermore, the recent technologies of biomass conversion and utilization inland and abroad are reviewed from aspects of direct combustion, biochemical conversion (fermentation and anaerobic digestion), thermal chemical conversion technology (gasification, pyrolysis), liquefaction, compact molding, and supercritical fluid conversion. The application of biomass conversion technologies is presented including biomass gasification to generate electricity, gasification to produce hydrogen, thermal cracking to produce hydrogen, fermentation to produce fuel ethanol, thermal cracking to produce bio-oil, compact molding to produce solid fuel, fermentation of compost to produce fertilizer, anaerobic digestion to produce biogas, catalytic cracking to produce biofuel, and so on. Finally, the development of biomass energy distributed utilization technology is prospected.

## 1. Introduction

With the continuous development of the world economy, non-renewable energy dominated by traditional fossil energy is in shortage day by day, and the problem of environmental pollution is becoming more and more serious. In recent years, the price of oil continues to rise in the international market, and the energy competition is increasingly fierce. The energy problem has become one of the problems affecting the national strategy [1]. With the steady growth of China's economy and rapid industrial development, the demand for energy has increased greatly. Due to the attention paid to the depletion of traditional fossil energy resources and environmental problems, the 13th five-year plan of china has clearly indicated that it will further increase its support for clean energy to accelerate its replacement of fossil energy. The 13th five-year plan for the development of biomass energy released by the national energy administration clearly proposes that biomass energy will basically be commercialized and used on a large scale by 2020, the annual biomass energy consumption reaches 58 million tons in the standard coal, the annual sales revenue is about 120 billion yuan, and the new industrial investment is about 196 billion yuan[2]. In addition, compared with coal, biomass has lower sulfur and nitrogen contents, and less nitrogen oxides and sulfur oxides produced by combustion, which can effectively alleviate air pollution [3]. Therefore, biomass energy has great resource potential and development space, and it is most likely to be the new clean energy that China takes the lead in large-scale utilization.



## 2. Characteristics of biomass fuels

Biomass energy refers to the energy of solar energy stored in biomass in the form of chemical energy. Its raw material comes from six aspects: 1) the trash of timber industry and forest industry; 2) crops and their wastes; 3) aquatic plants; 4) oil plants; 5) animal excrement; 6) municipal and industrial organic waste. Table 1 lists the components and elements of industrial analysis of typical biomass fuels, bituminous coal and anthracite, from which can be seen that biomass fuels have the following advantages compared with coal:

1) The carbon content of biomass is slightly less than that of coal, and the CO<sub>2</sub> produced after full combustion is basically the same as that of coal. But the biomass combustion is roughly equivalent to the release of CO<sub>2</sub> absorbed by its growth through photosynthesis of CO<sub>2</sub>, biomass, growth and utilization of the whole cycle of almost zero emissions of CO<sub>2</sub>, so the development and utilization of biomass energy will help ease the greenhouse effect of the earth;

2) The S, N content of biomass, especially wood fuel is extremely low, after combustion emissions of harmful gases such as SO<sub>x</sub> and NO<sub>x</sub> is rare and need not set gas desulfurization device when burning, so that it reduces the cost, and do good to the protection of the environment;

3) The ash content of biomass is very low, and the amount of ash after burning is very small. There is no need to set up a special ash field, and ash can be used as fertilizer for crops and flowers.

4) The volatile content of biomass fuel is very high, about 3 to 4 times of bituminous coal and 30 to 40 times of anthracite. Therefore, biomass is easy to ignite fire.

5) The fixed carbon content of biomass is only 1/3~1/2 of bituminous coal and 1/5~1/4 of anthracite, so the burnout rate of biomass after burning is very high.

Therefore, compared with coal, biomass is a clean fuel that can be easily used efficiently. Using biomass combustion equipment can be the fastest speed to realize all kinds of biomass resources on a large scale reduction, harmless and recycling use, and the cost is low, so that the use of biomass energy distribution has good economy and development potential.

**Table 1.** Elemental composition and industrial analysis composition of typical biomass fuels and coal.

Fuel type	Industrial analysis(%)				Element composition(%)					Low calorific value (MJ·Kg)
	W	A	V	FC	C	H	N	S	O	
Straw	9.02	1.85	72.48	16.65	44.65	5.24	0.28	0.08	40.72	15.83
Cotton stalk	6.93	3.18	73.00	16.89	44.90	7.50	1.20	0.00	35.47	18.40
Corn stalk	8.52	7.09	68.09	16.30	42.47	3.27	1.18	0.26	52.82	15.50
Rice husk	6.00	16.92	51.98	25.10	35.34	5.43	1.77	0.09	35.36	13.38
Peanut shell	8.84	4.69	68.48	17.99	43.53	6.54	2.24	0.12	34.04	16.28
Pine sawdust	6.11	3.47	74.6	15.82	45.76	6.74	0.07	0.00	37.85	15.41
Straw	4.13	13.56	67.77	14.54	38.09	6.15	0.70	0.06	37.31	13.67
Bituminous coal	8.85	21.37	38.48	31.30	57.42	3.81	0.93	0.46	7.16	24.30
Anthracite	8.00	19.02	7.85	65.13	65.65	2.64	0.99	0.51	3.19	24.42

Description: Data on biomass fuels are cited from literature [4], and data on coal are cited from literature [5].

But biomass fuels also have some characteristics that are not conducive to combustion and utilization:

1) After a large amount of volatilization in biomass fuel is analyzed, if the air is insufficient or the temperature is low, the volatilization content is easy to crack and precipitate carbon black, causing the furnace to emit black smoke;

2) The latter stage of solid fuel combustion is mainly the combustion of fixed carbon, while the biomass has less fixed carbon content. Therefore, the combustion process lasts for a short time and is not resistant to burning.

3) Biomass moisture content is more, and the moisture significantly changed along with the biomass processing and storage conditions [6], so after charging it needs higher drying temperature and the longer drying time, and biomass's low calorific value have a sharp fall with the increases of moisture [7], so when the wet biomass fuel combustion, the temperature field inside the furnace is low,

and organizing a stable combustion is difficult; In addition, more water also increases the volume of flue gas, which increases the heat loss.

4) Biomass (especially the crops straw) contains more chlorine and alkali, which easily forms deposition on the heating surface corrosion when it burning, that is to say, the biomass in the process of combustion, the fly ash particles containing a higher proportion of alkali metal minerals such as binder in combustion equipment parts deposition is formed on the surface, causing heating surface contamination, which in turn leads to heating surface corrosion problem;

5) Biomass fuel has a low accumulation density. For fuel particles form, the packing density of coal is about  $800 \sim 1000 \text{ kg/m}^3$ [8], biomass fuel such as wood, charcoal, cotton stalks in the so-called "hard wood" packing density between  $200 \sim 350 \text{ kg/m}^3$ , the accumulation of the crop straw and other "soft wood" density is far less than wood, such as bulk density of corn stalk is equivalent to only about a quarter of the lumber, wheat straw packing density is less than 1/10 of that of wood[9]. Due to the low density of biomass accumulation, it is much more difficult to collect, store and the stabilization of facility operation than coal, requiring special design and measures:

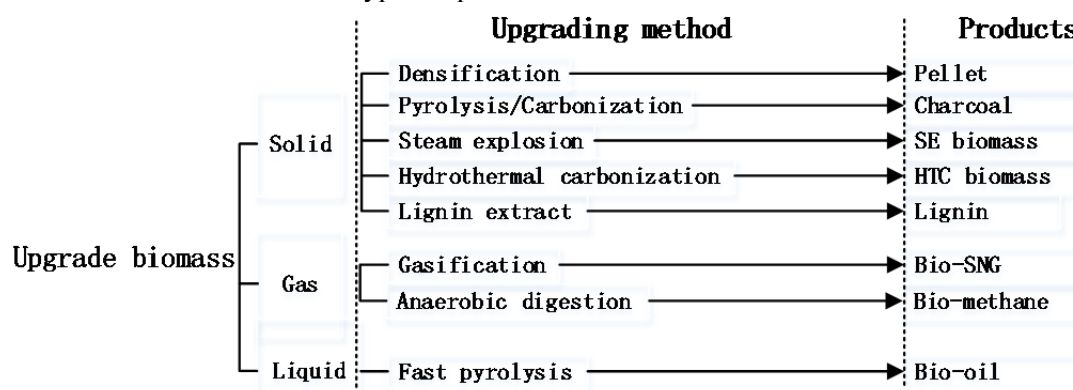
6) The raw material sources of biomass (especially crop straw) are highly seasonal and the source areas are scattered, which causes great difficulties for large-scale and industrialized utilization of biomass.

Biomass utilization method, therefore, must give full consideration to the choice of biomass fuel properties, to guarantee the economy and reliability, and to improve the efficiency of the development and utilization of biomass

### 3. Biomass fuel extraction method

The main purpose of the biomass energy utilization is the biomass energy into the heat energy electric energy and the fuel that can store which are for using, its application ways are more diverse than traditional fossil fuels, according to its properties and characteristics of the broad sense consists of biochemical catalysis and thermo-chemical conversion [10]. Biochemical transformation by microbial or enzyme metabolism is slow. As the composition of biomass elements is roughly the same as that of fossil fuels, biomass energy can be applied to conventional energy utilization technology, so thermochemical transformation method is widely used [11]. The combustion is the main way of biomass thermo-chemical conversion utilization, especially in economic less developed areas, people still use biomass direct combustion heat to obtain necessary in daily life [12].

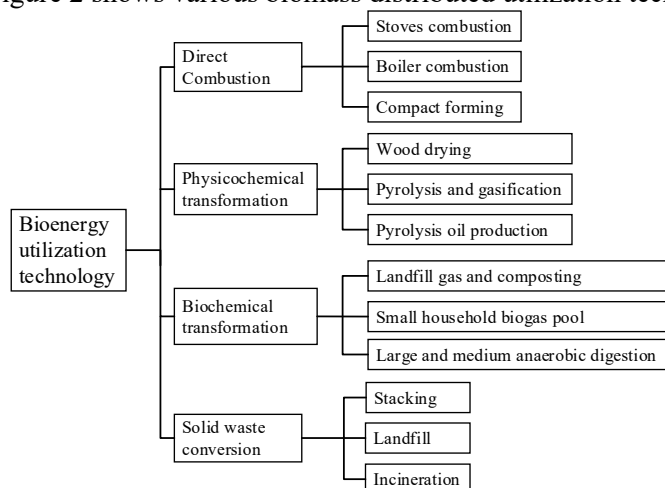
Biomass energy belongs to a kind of low grade energy, however, its combustion heat value is lower than traditional fossil fuels, the combustion efficiency is low, with environment problem increasingly prominent and urgent need of efficient combustion, advanced biomass utilization technology is particularly important. Currently, commonly used methods to improve biomass fuel quality by physical and thermal transformation are shown in Figure 1[11,13,14]. These quality improvement methods are not clearly classified in the practical application process and can be combined with various methods to obtain different types of products.



**Figure 1.** Methods for improving biomass fuel quality by product classification.

#### 4. Biomass fuel distributed utilization technology

Biomass, the biggest advantage is that it is the only renewable carbon resource that can be by thermo-chemical conversion, biochemical process and preparing liquid and gas fuels such as photochemical catalysis [15], involving pyrolysis, gasification, liquefaction, molding and direct combustion technology, which is a kind of cleaner fuel that can easily get in stocking transportation, and is convenient to use. Figure 2 shows various biomass distributed utilization technologies.



**Figure 2.** Biomass energy distribution and utilization technology.

##### 4.1. Biomass direct combustion technology

**4.1.1. Layer combustion technology.** Traditional layer combustion technology is spread on the grate cambium-like biomass fuels, blended with an air distribution, gradually to drying, pyrolysis, combustion and reduction process, combustible gas and secondary air distribution in the space of the above mix combustion. The boiler mainly adopts chain furnace and reciprocating feeding furnace. Biomass layer combustion technology is widely used in the development and utilization of agroforestry wastes and municipal solid waste incineration, etc., which can be suitable for burning high moisture content, particle size, larger changes of biomass fuel, with lower investment and operation cost, generally rated power less than 20 MW.

In Denmark, a special burning furnace has been developed for burning baled straw. A large bundle of straw is continuously transported to the water-cooled mobile furnace stack through the conveying channel by hydraulic piston. Because of straw ash melting point is lower, water-cooled furnace wall or flue gas circulation ways to control the temperature of the combustion chamber is necessary, make it less than 900°C. Denmark ELSAM company contributive transform Benson type boiler heating by two stages, by four parallel feeder supply material, straw, wood chips can be fully burning in the grate, and also set in the furnace and the pipe with fiber filter to reduce harmful substances in the smoke to the wear and corrosion of the equipment. The practical operation proves that the transformed biomass boiler operates stably and has achieved good social and economic benefits [16].

In China, many research units have developed various types of biomass layer burners according to the characteristics of the biomass fuel used, and the actual operation effect is good. They based on the combustion characteristics of raw materials used, the structure of layer combustion furnace is to optimize the productive and furnace structure including double chamber structure[17], closed chamber of a stove or furnace structure[18,19] and other structures, these are provides a valuable experience for our layer biomass combustion furnace design.

**4.1.2. Fluidized bed technology.** Fluidized combustion has a series of advantages such as good heat and mass transfer performance, high combustion efficiency, low emission of harmful gases and large

heat capacity, etc. It is very suitable for burning biomass fuel with large water content and low heat value. Fluidized bed combustion (CFB) is a mature technology that has been commercialized in the clean combustion of fossil fuels. The application of the existing mature technology to the development and utilization of biomass has been extensively and deeply studied at home and abroad, and has entered into commercial operation.

At present, the development and utilization of biomass energy by fluidized bed combustion technology in foreign countries has a considerable scale. American Idaho energy company has developed and produced a fluidized bed boiler with biomass burning. The steam boiler's output is 4.5 ~ 50t/h, and the heating boiler's output is 36.67MW. The power output of the large circulating fluidized bed coal-fired power boiler developed by American CE company using RUQI technology is 100t/h, and the steam pressure is 8.7mpa. The wood-burning fluidized bed boiler manufactured by American B&W company was also put into operation in the late 1980s and early 1990s. In addition, Sweden USES forest waste such as branches and leaves as fuel for large fluidized bed boilers, which have a thermal efficiency that can up to 80%. Denmark adopts high-efficiency circulating fluidized bed boiler, which sends hay and coal into the furnace for combustion at a ratio of 6:4. The boiler's output force is 100t/h and its thermal power reaches 80MW[20].

In China since the late 1980s, biomass fluidized bed combustion technology has also carried on the thorough research, domestic research units and boiler factory cooperation, joint development of various types of burning biomass fluidized bed boiler[20, 21], which put into production after the running effect is good, and being promoted, there are many exported to foreign countries, the use of biomass energy in China played a great role in promoting. For example, according to the physical and chemical properties and combustion characteristics of rice husk, Huazhong University of Science and Technology has designed a combined combustion fluidized bed boiler [22], which is mainly composed of fluidized bed combustion, supplemented by suspension combustion and fixed bed combustion. The boiler has the advantages of good fluidization performance, stable combustion and non-coking.

*4.1.3. Tight forming technology.* The agriculture and forestry waste with a range of size, such as sawdust, rice husk, twigs, straw, etc., after drying under certain pressure effect, can squeeze into a bar, granular continuously, block and other solid fuel molding processing technology called biomass density molding technology[23]. Using lignin special glue adhesion, or add some additives or other adhesives to bond together become the molding fuel[24], biomass after extrusion effect, shrinkage, significantly larger density, moisture content, convenient storage and transportation[25]. This technology has been widely used in high efficiency combustion furnace, biomass gasifier and small boiler[26].

According to the technological characteristic of the biomass density difference molding process is divided into three types: cold dense compact molding, extrusion forming and dense carbide, each process has its characteristics and application scope. In recent years, domestic and foreign scientific research units in biomass forming theory, biomass combustion technology using equipment, etc are studied, which has made breakthrough progress, development and production of a variety of different function and application in the range of biomass density forming machine. In addition, there are single head and multiple screw extruding rod compact forming machines, and has been put into production in small quantities.

#### *4.2. Biochemical transformation technology*

Biomass biochemical conversion generally has four types: landfill gas and compost technology; parliamentary chamber biogas digester technology for small household; large and medium-sized anaerobic digestion technology; and ethanol production technology. Among them, anaerobic digestion technology is divided into two types: anaerobic digestion technology of livestock excrement and anaerobic digestion technology of industrial organic wastewater. The technology of producing ethanol is to make ethanol or methanol liquid fuel by enzyme technology.

#### 4.3. Physicochemical transformation technology

The physicochemical conversion of biomass energy generally consists of three aspects: First, dry distillation and liquefaction technology; Second, pyrolysis and vaporization technology; Third, the pyrolysis of biomass oil technology.

The main purpose of biomass dry distillation technology is to produce biomass carbon and gas at the same time. It is to convert small substances with low energy density into fixed carbon or gas with high heat value, which can be used for different purposes. Biomass liquefaction technology, is an technology which take the biomass raw materials through the use of chemically converted into liquid fuel technology, its essence is to solid organic macromolecule polymer into liquid of small molecule organic material, general process is as follows: decomposition of biomass materials for macromolecular compounds; Parliamentary resolves large molecular chain organic matter until it can be dissolved by reaction media. Residues is hydrolyzed or dissolved in solvents under high temperature and pressure to obtain small liquid organic molecules.

Biomass pyrolysis is to convert biomass into fuel vaporization technology, namely by biomass raw materials in the macromolecular structure under high temperature decomposition, fracture or reforming produce light combustible gas fuel, such as CO, H<sub>2</sub>, CH<sub>4</sub> and so on.

Biomass pyrolysis system oil is a kind of technology convert biomass into liquid fuel technology by thermal chemical methods, compared with liquefaction technology, liquid fuel produced by pyrolysis oil technology generally consists of bio-oil, non condensable gas and coal, such as ether, ester, ketone, phenol, alcohol, organic acids, etc.

#### 4.4. Solid waste treatment technology

For the treatment of solid waste, there are three traditional methods: landfill, incineration and biochemical treatment. Landfill and incineration waste resources and energy. At present, the recycling of waste biomass energy at home and abroad made a more in-depth research, mainly adopts way feed, fertilizer, gas, fuel and other raw material for the use of scientific and effective. If it is processed into feed, make full use of its nutrients; Composting technology was used to treat courtyard waste, organic biological waste, organic residual sludge and agricultural waste. Biogas technology is used to treat all kinds of organic waste in agriculture, industry and human life. In order to avoid secondary pollution, biogas slags and biogas slurry should be reused. Biogas slags and biogas slurry can be directly used as fertilizers or separated into commercial fertilizers by solid solution. The former loose, fine and amorphous biomass raw materials can be compressed into rod, granule, block and other forming fuels under certain conditions by using the compression and molding technology of biomass [27].

#### 4.5. Supercritical transformation technology of biomass

Supercritical fluid (SCF) is a kind of above at the critical temperature and critical pressure, physical property between gas and liquid have good liquidity, transitivity, diffusivity and solubility of the fluid. It doubles as a dual nature and the advantages of the gas and liquid, near the critical point, small changes in the pressure and temperature, can cause fluid density, solubility and dielectric constant of the larger changes in the physical. Supercritical water can dissolve most organic compounds and gas, high density, low viscosity characteristics of biomass in supercritical water gasification and pyrolysis heat utilization efficiency is higher than normal, the biomass of supercritical water gasification technology has been widely focused, which has great development potential [28]. Because the reaction temperature and pressure required for supercritical water gasification have higher requirements on equipment and materials, the related research on biomass supercritical water gasification is limited, and the research in this field in China started relatively late[29]. With the continuous understanding and research of the unique physical and chemical properties of supercritical water, it is found that supercritical fluid can be used in biomass pretreatment, pyrolysis, liquefaction and biodiesel production to transform and efficiently utilize biomass resources. [30] Such as biomass supercritical pyrolysis hydrogen production, biodiesel supercritical preparation, biomass supercritical liquefaction and biomass supercritical pretreatment. The technology of supercritical conversion of biomass has great application potential, especially in the field of supercritical water gasification hydrogen

production and supercritical methanol esterification biodiesel production. However, due to the stringent reaction conditions of supercritical fluids, high requirements on energy consumption and equipment, and large losses, resulting in higher production costs, most of the current applications of supercritical fluids in biomass energy conversion are in the research stage, and there is still huge room for improvement of technology and systems. [31]

## 5. Conclusions and prospects

Biomass energy, as the only renewable carbon resource that can replace fossil energy, plays an increasingly important role in the development of new energy [32]. Due to fossil fuels such as coal, oil, gas, are irrefragable and damage to the environment in use process, biomass energy will become one of the main energy of modern, biomass conversion using the technology will also be the key to this transformation. At present, related to the conversion of biomass utilization applications including biomass gasification power generation thermal cracking, gasification, hydrogen production, fermentation to produce fuel ethanol, thermal pyrolysis bio-oil, curing system of solid fuel, composting fermentation fertilizer, anaerobic digestion biogas, biomass production[33], catalytic cracking to produce biofuels are widely used in many fields.

The annual biomass production in the world is about 146 billion t[34], and the annual resource volume of agricultural and forest waste and livestock waste alone can reach 1 billion t[35]. According to the UN Conference on Environment and Eevelopment (UNCED), by 2050, the conversion and utilization of biomass energy will account for about half of global energy consumption[36]. Biomass energy is expected to contribute half of the EU's renewable energy target, and it is expected to remain a major contributor to renewable energy at the EU level by 2020. Therefore, the sustainable development of biomass is a key issue. Using biomass conversion technology of biomass resources can be recycled, this in saving resources, protecting and improving ecological environment, promoting the harmonious development of regional economy, alleviating human energy crisis plays a decisive role. Due to the different types of biomass, the suitable transformation using the technology are different, because the practicability and economy cannot completely unified, cause most of these techniques are difficult to popularize, but with the deepening of the research at home and abroad, more biomass conversion using new technology and integration technology will emerge.

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