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The Sustainable Processes for Production of Biomass Derived Fuels in China

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Abstract *– As an energy source that is highly productive, renewable, carbon neutral, and easy to store and transport, biomass has drawn worldwide attention. The governments of some developed countries are promoting the utilization of bioenergy through action plans and favorable policies. There are abundant biomass resources in China. It is urgently needed to develop and utilize modern bioenergy technologies in China. The status quo and trends of bioenergy technologies at home and abroad are reviewed in this paper. According to the characteristics of the situation, resources and geography of China, the author puts forward some suggestions for the strategy and policies of bioenergy development in China. In their opinion, the government should draft action plans and favorable policies to promote the development of the technology for liquid fuels and chemicals production technologies from biomass in the future.*

***Keywords* –** Biofuel, biomass, conversion, China.

1. INTRODUCTION

Today fuels and chemicals are predominately derived from unsustainable mineral resources, petroleum and coal, leading to environment pollution, greenhouse gas emissions, and issues on energy security. Biomass is a sustainable feedstock for chemicals and energy products that could potentially enhance the energy independence of China and other countries, which are lack of energy resources. As an energy source that is highly productive, renewable, carbon neutral, and easy to store and transport, biomass has drawn worldwide attention recently. The governments of many countries around the world are promoting the utilization of biomass energy through action plans and favorable policies. However, the commercial utilized biomass energy only accounts for one percent of the primary energy consumed in China, which is remarkably less than that in developed country. Therefore, it is urgently needed to develop and utilize modern biomass process technologies in China so as to get rid of the dependence on imported oil. Fortunately, China possesses abundant and diverse agricultural and forest resources, unused lands suitable for energy crops plantation, and favorable climates. With the developing and commercializing of novel biomass conversion technologies, we have a great opportunity to employ domestic and sustainable biomass resources to enhance the supply of clean fuels and chemicals [1]. The *status quo* and trends of biomass conversion processes for the production of clean fuels and chemicals at home and abroad are reviewed in this paper. Finally, according to the characteristics of the situation, resources and geography of China, the author puts forward some suggestions for the technologies, strategy and policies on development of biomass derived fuels and chemicals in China.

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2. BIOMASS RESOURCES

During the growth of plants, water and CO_2 are absorbed and transformed into organic matter (carbohydrates) through photosynthesis in the present of sunlight. The organic matter that makes up these plants is known as biomass. Biomass contains lots of energy that can be used to produce heat, electricity, transportation fuels, or chemicals. Biomass can be produced as by-products of agriculture, forestry, manufacture of high-value goods (e.g. pulp and paper, sugar and animal feed) and dedicated energy plants (e.g. sugarcane, cassava, sorghum, algae, and rapeseed) [2], [3].

We have used biomass energy for thousands of years, ever since human being started burning wood to cook food or to keep warm. Today, wood is still our largest biomass energy resource. However, many other sources of biomass have been used nowadays including plants, residues from agriculture or forestry, and the organic component of municipal and industrial wastes. Even the fumes from landfills can be used as a biomass energy source. The use of biomass energy has the potential to greatly reduce our greenhouse gas emissions. Biomass generates about the same amount of carbon dioxide as fossil fuels, but every time a new plant grows, carbon dioxide is removed from the atmosphere. The net emission of carbon dioxide will be zero as long as plants continue to be replenished for biomass energy purposes [4]. The use of biomass feedstock can also help increasing profits for the agricultural industry.

There are abundant biomass resources in China. From a theory estimation, its amount of biomass resources existing in cultivated lands, afforestated lands and prairies in the country may be over 5 billion tones in dry weight that is equal to 1700 MTOE (million tons of oil equivalent). In fact, biomass resources available for energy mainly come from crop residues, firewood, forest wood residues and organic refuses, and the amount may be about 540 MTOE, which is more than half of the country’s annually primary energy consumption [5]. Therefore, China has an abundant sustainable resources to develop and utilize biomass derived fuels and chemicals.

3. MODERN BIOMASS CONVERSION TECHNOLOGIES AND THEIR TRENDS

The dominant processes by which energy may be obtained from biomass could be attributed to two main kinds according to their conversion principles: thermo-chemical processes and biological processes (see Figure 1). These processes mainly include combustion, gasification, fast pyrolysis, transesterification, anaerobic digestion, and alcoholic fermentation. Each technology has its own advantages, depending on the biomass source and the type of energy needed.

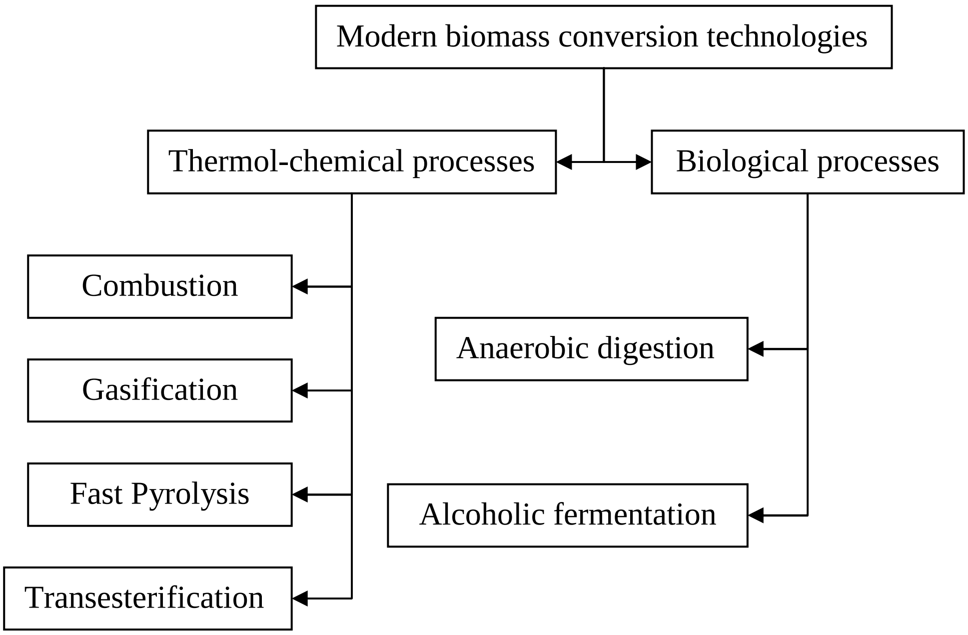

Fig. 1. Specification of modern biomass conversion technologies

Combustion

The burning of biomass in air, combustion, is used over a wide range of outputs to convert chemical energy stored in biomass into heat, mechanical power, or electricity using various equipments, such as stoves, furnaces, boilers, steam turbine, etc. Combustion of biomass produces hot gas at temperatures around 800-1000^{o}C. Net biomass energy conversion efficiencies for biomass combustion plants range from 20% to 40%. The higher efficiencies are obtained with systems over 100MWe or when the biomass is co-combusted in coal-fired power plants [6].

In the United States, the conversion system focus shifted in 1989 from gasification to direct combustion and cofiring with coal for electricity production. The process of cofiring with coal had been demonstrated 10% cofiring with sawmill waste in a pulverized-coal unit at Greenridge [7]. Biomass-fired combined heat and power plants (CHP) are extensively installed in Finland and Sweden to supply district heating and electricity. In Finland, bioenergy (mainly from CHP) supply about one-third of its primary energy consumption [1], [8]. Sweden has good access to biomass, and the total use of biofuel in 2001 was 98TWh, or about 16% of the country's energy supply. The Swedish National Energy Administration estimates that up to 160TWh of biofuel could be used in Sweden by the year 2010 [9]. Many boilers in Western Europe co-fire biomass already, because biomass co-firing in existing pulverized-coal-fired utility boilers is considered to be a relatively straightforward, cost-effective and efficient option for the utilization of biomass as a renewable energy source [10]. However, biomass combustion process can not produce fuels besides power and heat. It will limit the utilization of this process in the future.

Biomass combustion technologies are not developed well in China comparison with developed countries. Recently, China has installed serial biomass combustion power plants imported from European countries using agricultural residues as feedstock.

Gasification

Biomass gasification is the process which conversion biomass into combustible mixture gas by partial oxidation (or cracking at absent of oxygen) at temperatures around 800-900^{o}C. With suitable treatment the mixture gas can be used for the production of heat, power (by gas engines, gas turbines, fuel cells, etc.), transportation fuels or chemicals (hydrogen, methanol, dimethyl ether, or diesel through chemical conversion). Air-blown gasification processes low calorific value gases with a typical heating value (HHV) of 4-7MJ/Nm^3, while oxygen and steam-blown processes produce gases with a HHV of 10-18MJ/Nm^3. Gasification is a robust proven technology that can be operated either as simple, low technology system based on a fixed bed gasifier, or as a more sophisticated system using fluidized bed technology [11]. According to a recent survey, there are nearly 100 biomass gasification and/or pyrolysis installations in Europe and North America [12].

Recently, biomass integrated gasification and gas turbine combined cycle (BIGCC) technology is showing promising perspective for its high overall conversion efficiency. The net biomass energy conversion efficiencies range from 40% to 50% for a plant of 30-60MWe, which are obviously higher than that of biomass combustion technology. However, BIGCC is still in demonstration stage because little commercial experience has been obtained [13]. In China the BIGCC facility with capacity of 4 MWe is underdeveloped, which is supported by Hi-Tec Research and Development project. Suitable technologies should be developed to hurdle the main obstacles met during operation.

Gasification technology is expected to play a key role in expanding the use of biomass as a major renewable energy source. Biomass gasification offers the earliest and most economical route for the production of renewable hydrogen and synthetic fuels, such as methanol, dimethyl ether, or Fischer-Tropsch liquids. Catalytic biomass steam gasification/pyrolysis may yield a mixture of syngas ($CO+H_2$), followed by clean-up to removal impurities (S and N compounds etc.), and water gas shift conversion to produce H_2+CO_2, then after separation, pure hydrogen could be obtained. This will be a promising hydrogen production process in the future [14], [15].

Fast Pyrolysis

Fast pyrolysis is the process that biomass is treated at elevated temperatures without any supply of oxygen to the process. The products are condensable vapors (liquids), non condensable gases, and char (solid). High heating rate of biomass particles and rapid cooling of produced vapors are demanded to get maximizing the yield of liquid products (bio-oil). The produced bio-oil with the heating value range of 18-22 MJ/kg, can be used as a fuel for heating or electricity production by motors or turbines, or as a feedstock for chemicals. Fast pyrolysis technologies are based on fluidized bed, entrained flow, ablative vortex, rotating cone, ablative rotating blade, or vacuum pyrolysis technology [16]. Fast pyrolysis is now accepted as a technology for producing high yields of liquid fuels that can be used in many applications as direct substitutes for conventional fuels or a source of chemicals. There are some interesting challenges to be faced in developing and modifying fast pyrolysis technology, in upgrading the liquids and adapting applications to accept the unusual behavior and characteristics of the liquid products [17]. Although the commercial status for fast pyrolysis processes have been achieved in Europe and North America, It is still at research and development status in China [18].

Transesterification

Transesterification is a technology that produce biodiesel (fatty acid methyl esters for an alternative fuel to petroleum derived ones) by the esterification of triglycerides (from vegetable and animal oils/fats) with alcohols (methanol or ethanol). Biodiesel is biodegradable and nontoxic. There are different processes for production of biodiesel, such as alkali-catalysis, acid-catalysis, lipase-catalysis, and supercritical transesterification. It is well established that biodiesel affords a substantial reduction SOx emissions and considerable reductions in CO, hydrocarbons, soot, and particulate mater (PM) [19], [20]. One milestone step in the development of biodiesel was the first fuel standard ONC1190 for biodiesel in 1991 by the Austrian Standardization Institute assuming a high quality of the fuel. Detailed tests on product properties such as engine performance, emission reductions, biodegradablility, and toxicity were followed, while process improved as well continuously [21]. In China the biodiesel standard (GB/T 20828) was issued 16 years later than the first standard on May, 2007. The European Commission proposed a 12% market share for biofuels by the year 2020. In Europe, rapeseed oil is the main feedstock for biodiesel production, while soybean oil is used in the USA. The output of biodiesel in year 2005 was about 0.3 million tons in China, which is similar to that in USA.

Anaerobic Digestion

Anaerobic digestion is a technology that converts organic material into biogas (mixture of mainly methane and carbon dioxide) by bacteria in an anaerobic environment. Biogas has been produced commercially using animal manure, sewage sludge and the municipal solid waste (MSW), in conventional anaerobic digesters or two-phase anaerobic fermentation [22], [23]. The produced biogas has an energy content of about 20%-40% of the lower heating value of feedstock. The overall conversion efficiency from biomass to electricity is about 10%-16%. As a century long history process, anaerobic digestion is very popular in developing countries such as China and India. This technology had been extensively utilized in rural area of China to supply gas fuel for household. Besides small scale household biogas digesters, about 2355 biogas plants were installed and 18.4 million m^3 of biogas were produced to supply 6.34 million KWh of electricity and fuel gas for 13 million farm homes at year 2003 [1].

Alcoholic Fermentation

Alcoholic fermentation is a technology to convert sugar crops or starch crops to ethanol by enzymes and/or yeast. It is commercially used on a large scale in many countries with long history for production of alcoholic drink or chemical, ethanol. Recently with the shortage of liquid fuel, this technology is being promoted to produce fuel ethanol. Brazil is one of the few industrialized countries in the world in which renewable energy sources represent a meaningful share of energy matrix. Worldwide Brazil is the largest producer of sugar cane and fuel ethanol. The importance of this economic activity grew after the creation of the Brazilian Alcohol Program (PROALCOOL) in 1975, with the purpose of producing anhydrous ethanol to be blend with gasoline. Ethanol price was 85% of gasoline at Brazil in 2004 [24], [25]. China is the third-largest ethanol producer in the world, which has selected serial provinces to use trial blend of 10% ethanol. Where corn is the primary feedstock, but distilleries are also experimenting with cassava, sweet potato, sugar cane and sweet sorghum stem.

As a summary, biomass is one of humanity's earliest sources of energy, which can be used to meet variety of energy needs, including generating electricity, heating homes, fueling vehicles, and providing process heat for industrial facilities. World production biomass is estimated at 146 billion tones a year, mostly wild plant growth. One analysis provided by United Nations Conference on Environment and Development estimated that biomass could potentially supply about half of present world primary energy consumption by the year 2050 [26]. There is a promising perspective for the research, development, demonstration, and utilization of biomass conversion processes.

4. SUSTAINABLE FUELS AND CHEMICALS PRODUCTION FROM BIOMASS

In contrast to other renewable sources of energy (e.g. solar energy, wind energy, geothermal energy) that supply heat and power, biomass represents the sole source of liquid, solid and gaseous fuels and chemicals. Therefore, the production of clean fuels and chemicals from biomass is more important than that of power and heat, which could be produced from other renewable sources. Biofuels, including ethanol, biodiesel, and other liquids, which are made from biomass have the potential to displace a substantial amount of petroleum in the future. Many technologies are being developed around the world to cost-effectively produce clean fuels from various biomass materials. The Research and Development Technical Advisory Committee of the United States set forth a goal that biomass will supply 5% of the nation's power, 20% of transportation fuels, and 25% chemicals by 2030. In order to meet this goal, the Department of Energy (DOE) published a Roadmap for Agricultural Biomass Feedstock Supply [27]. This will be very useful for us to set forth the vision of biomass derived fuels and chemicals in China.

Brazil and the United States have the largest programs promoting biofuels in the world. EU is the third rank of biofuels production world wide. For example, Brazil's ethanol production from sugar cane in 2003 is 9.9 million tons over 200 times the European production; the United States produced ethanol mainly from corn 7.8 million tons in 2003 and is projected to 12.6 million tons in 2025 [28].

The concept of "biorefinery" was put forward by researchers in UK and USA recently [27], [29]-[31]. This may indicated the new trend of the sustainable utilization of biomass. A biorefinery processes biomass into value added product streams. These can range from biomaterials to fuels, such as ethanol and fuel gases or key intermediates for the production of chemicals and other materials. The biorefinery processes can extract carbohydrate, lignin, oils and other materials from biomass, and convert them to multiple products including clean fuels and value-added chemicals via three platforms, syngas platform, sugar platform, and fatty acid methyl ester (FAME) platform. These biomass-derived products include fuels and chemicals, such as hydrogen, methanol, Fischer-Tropsch liquids, ethanol, biodiesel, phenolics, furfural, acetic acid, glycerol, and other chemical intermediates, etc.

In the IEA (International Energy Agency) report (2004), the potential well-to-wheels impacts of various biofuel production processes were studied. This study estimated well-to-wheels energy efficiency and CO_2 emissions that might be typical in the 2010-2015 time frame for the process in Table 1 [32]. It was found that nearly all of the pathways provide very high reductions in well-to-wheels GHG (greenhouse gas) emissions compared to diesel or gasoline vehicles, over 100% in several cases. The greatest reductions were found with cellulose-to-ethanol through hydrolysis, biomass gasification and through F-T synthesis to final fuels such as diesel and DME provide similar reductions. Between biorefinery processes, transesterification of rapeseed oil to biodiesel has the highest energy efficiency of 62%, but has the highest CO_2 emission; DME production via gasification has the second higher energy efficiency of 56%, and lower CO_2 emission.

Table 1. Estimates of energy use and greenhouse emissions from advanced biofuel processes [32]

Fuel	Feedstock/ Location	Process	Energy Efficiency (%)	CO_2 Emission (g/km)
gasoline	petroleum	refining	83	231
diesel	petroleum	refining	91	198
biodiesel	Rapeseed/local	transesterification	62	123
diesel	eucalyptus/Baltic	gasification/F-T	43	-16
bio-oil	eucalyptus/Baltic	pyrolysis	30	72
DME	eucalyptus/Baltic	gasification/F-T	56	22
gasoline	eucalyptus/Baltic	gasification/F-T	37	-10
ethanol	poplar/local	enzymatic hydrolysis	51	-3
ethanol	corn/local	fermentation	45	65
hydrogen	eucalyptus/Baltic	gasification	42	11

The use cellulose based biomass residue via gasification to produce methanol/dimethyl ether or via enzymatic hydrolysis to produce ethanol is becoming more important in China since it does not have not enough land for dedicated energy crops. With the scale-up of biomass conversion processes, the collection, transportation, and storage of biomass feedstock are becoming bottlenecks of bio-energy utilization. There are major institutional and infrastructural barriers to large scale energy crop production. Different from the traditional energy, the economic and cost-effective utilization style of biomass will be distributed and decentralized.

5. CONLUSIONS AND SUGGESTIONS

As the second largest energy consuming country and a developing Asian country, China needs to urgently develop and utilize modern biomass conversion technologies to produce renewable fuels and chemicals from abundant and sustainable biomass resources. Biorefinery is a promising substitute fuels (methanol, ethanol, DME, biodiesel, etc.) and chemicals production plant which can convert biomass into fuels and chemicals via three platforms: syngas platform, sugar platform, and FAME platform.

According to the characteristics of the situation, resources, and geography of China, the author put forward the following suggestions for bioenergy development in China: (1) Promotion of research, development, and demonstration of methanol/DME production via syngas platform. It is forecasted that this technology will be commercialized in China by 2020. (2) Promoting the integration of technology for enzymatic hydrolysis of cellulose base biomass by planting energy crops such as sorghum, sugar cane, and fast growing forests, in unused lands to produce ethanol with high efficiency. It will be commercialized by 2015. (3) Promoting development and demonstration of BIGCC technology in enhancing the gasification efficiency and the quality of producer gas, and energy integration of the whole process. A 10-15 MW capacity of BIGCC plant will be operated by 2015.

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