Study on China Biomass Energy Technology Development Roadmap

Energy Research Institute, National Development and Reform Commission

2010

Project Sponsor:

China Sustainable Energy Program

Project Implemented by:

The Renewable Energy Development Center of Energy Research Institute (ERI), China National Development and Reform Commission (NDRC)

Project Director: *Runqing Hu*

Project Team Members: *Runqing Hu, Shiping Qin, Jingchun Fan, Qingfen Zhang, Yongqiang Zhao, and Zhengmin Zhang*

Contents

List of Figures

List of Tables

1. Preface

1.1 The impending need for a biomass energy development roadmap

There exist varieties of biomass energy technologies with imbalanced application status in China. Currently, some biomass technologies have been developed maturely in the market such as biogas, that can be economically competitive, commercially developed, and applied in large scale, while other technologies are in the early stage of commercial applications, that need subsidies and other financial incentives to encourage them in the market. These include biomass power, biomass pallet fuel, biofuels from non-grain feedstock, etc. There are also many emerging biomass technologies which are at R&D and demonstration stage and are expected to develop into industrial and commercial applications, such as biological ethanol fuel from cellulose and biodiesel from oil plants.

Due to the differences in terms of technology maturity, development stage, market competitiveness, and future perspectives of the various biomass technologies, so the obstacles can be different, the needed incentives also vary. It is an important task for any country to study and design a biomass energy development roadmap to ensure implementation of a nation's biomass energy development objectives.

The biomass energy development roadmap shall include assessment of various biomass technology status and objectives, development of approaches in biomass technology research and development, pilot projects, demonstration, and application promotions, and identify supporting incentives in techniques and regulations.

Biomass development roadmaps have been developed by many nations in order to ensure development targets. For example, the US Biomass Energy Research and Development Technical Advisory Committee launched the US Biomass Energy Technology Development Roadmap in December 2001 to advise the Secretary of Energy for the US biomass energy and biomass products long-term objectives. By this roadmap, the advisory committee identifies future biomass technology development for the US department of energy, agriculture, interior, environment, and National Science Foundation, and the US Technology policy office.

The European Union 2003 Biofuel Promotion Ordinance proposed biofuel 2020 target. The 2005 issued Biomass Energy Action Plan covered a comprehensive biomass energy development application plans for biomass power, biomass thermal applications, and transport biofuel technologies. In 2006, the EU announced the Biofuel Development Strategies. These legislations played significant part in promoting biomass applications in EU member nations.

In the long-term plan for renewable energy development issued by the government of China in 2007, targets have been defined for the development of wind, solar, and biomass energy by 2020. However arguments exist on whether the defined targets are achievable and how to accomplish these objectives. At the same time, because there are many varieties of biomass resources and technologies with different development status, technological maturity, and existing obstacles, and without thorough study on biomass technology roadmap, it can be difficult for central administration to make a detailed plan for technology R&D program, for industrial development strategy, and for focal project plan of critical technologies.

1.2 Tasks of the study

Purpose of this study will be (a) proposing a system of indicators for assessing biomass technologies, (b) using quantitative method to compare different biomass technologies and their development status, (c) identify the priority technologies, development approaches, and economic performance for biomass energy from various resources such as agricultural residues, livestock waste, life garbage, and biofuels, and (d) proposing future biomass technology development roadmap for 2015 and 2020.

The study will focus on developing a biomass energy development roadmap through scientific and quantitative method. The study team has designed a system of biomass technology assessment indicators and applied the system to evaluate each potential technology in a quantitative way. Based on the evaluation, a biomass technology development roadmap has been proposed.

Since the national biomass development objectives and targets have been defined. No further research and scenario analysis are needed. However, the study will focus on some critical questions on in what critical measures to ensure the national targets to be fulfilled? What should a development roadmap be appropriate for China?

1.3 Innovation points of the study

1.3.1 New research methodology

The project team developed an innovative study methodology for the biomass technology development roadmap.

Biomass energy industry in China is still at its very early stage. Assessment of a biomass technology is based only on its technical and economic level, lack of systematic comparative analysis on multiple technical processes. Meanwhile, due to the proliferation of many biomass technologies with different maturity and applications, it is difficult to compare among them. Therefore, comparison of biomass technology benefits in resources, social and environmental aspects is usually qualitative without a quantitative assessment indicator system. So far, most of the studies on biomass technology development roadmap are qualitative in nature.

The methodology used in this study includes the following three important components: (1) development of an indicator system for evaluating biomass technologies; (2) quantification of the evaluation indicators; (3) using the evaluation system on the biomass technologies. The study designed a system of biomass technology evaluation indicators. By quantifying and applying the evaluation indicators, the biomass roadmap is studies and proposed in a systematic and quantitative method.

The biomass energy comprehensive evaluation indicator system developed in this study is a multiple criteria system covering technology, economy, resource, environment, and social factors into nine categories. Quantification of the indicators allows not only computation of external economic benefit of each technology, but also quantitative evaluation of future development perspectives. This makes possible the systematic comparative analyses of different biomass application technologies.

1.3.2 Quantitative assessment criteria

In the study, quantification of evaluation indicators is based on support of large datasets, while the quantification is the most challenging and also spot-light task.

The task of quantification of the evaluation indicators will include following aspects:

Firstly, design of a quantitative system of evaluation system. Generally, evaluation indicators of biomass energy shall include two groups: technological strength and overall benefits. The overall benefits are evaluated by capital investment cost and external benefits (including energy benefit, environmental benefit, and social benefit), that can be ranked by computational points, while technology strength can be assessed by three major indicators: technology maturity, technical obstacles, and intellectual property right ownership so that future biomass technology development strength can be evaluated by ranking method in order to identify stage-wise ranks of the biomass energy technologies.

Secondly, the indicators are quantifies by weights, scores, and quantitative standards, so that final scores can reflect future development strength of a particular biomass technology.

Quantitative scores of each biomass technology are evaluated at three temporal points: current, 2015, and 2020. These quantitative assessments need large number of basic data sets. These include fundamental data on typical biomass application cases, understanding on current and future biomass technologies, which become bases of evaluation indicators and their quantification.

In this study, 14 biomass technologies are analyzed and quantitative evaluated, including five agricultural and forestry residues for energy (direct firing, co-firing, gasification, pellet fuel, and pellet charcoal), two livestock waste for energy (in-grid biogas power and off-grid biogas power generation), tow garbage for energy technologies (incineration and fill gas power generation), and five liquid biofuel technologies (biofuel ethanol from non-grain, ethanol from sugar plants, ethanol from cellulose feedstock, biodiesel from waste oil, and biodiesel from oil plants). The current status, development by 2015 and 2020 are analyzed quantitatively for the 14 biomass technologies on their investment, cost, energy benefit, social benefit, and environment benefit. At the same time, development potentials of each biomass technology are evaluated by scores. This allows systematic comparison within each type of biomass resources.

1.3.3 Assessment method used

To complete the quantitative analysis and design of the roadmap, applying a solid evaluation system is critical. This means that by utilizing the proposed comprehensive evaluation indicator system for the 14 biomass technologies, it is critical to design a roadmap based on the evaluation results.

First of all, biomass resource availability will be the most important indicator for the evaluation, as biomass technologies shall not compete in the market unless they utilize the same type of biomass resources. Therefore, the evaluation of biomass technologies is resource based. Future development potential of biomass technologies using a kind of resource are scored and ranked to achieve more reasonable and practical comparison result. In the study, biomass resources are classified into four categories: agricultural and forestry residues, livestock waste, life garbage, and resources for biofuels.

Biomass technologies for the same resource category are evaluated and compared for the development potential and comprehensive benefits. Based on the technology development trends, technical obstacles and corresponding measures at different stage are identified. It is shown from the study result that under appropriate measures, the biomass technologies under different resource categories can be technologically mature by 2020 and can meet the demand of biomass energy targets. To determine the scale and priority of biomass technology development, it depends not only on technologically maturity, but also on many aspects of economy, energy, and social contributions of each biomass technology. The comprehensive benefit evaluation can produce clarified quantitative conclusion and development suggestions.

2. Biomass energy required for China social development

2.1 Necessity for development renewable energy technologies

2.1.1 Requirement for reforming China's energy structure

Over the recent past years, China's economy develops fast by consuming increasingly more energy products. In 2008, China consumed 2.85 billion tce of the primary energy products. It is estimated that by 2010, the annual energy consumption will be 3 billion tce. This means that within the next 6 years, 1 billion more tce will be consumed. To fulfill the objective that GDP by 2020 will be doubled based on the value in the year 2000; China is expecting a new economy boom period. By transference of international manufacturing capacity into China and the urbanization process, China's economy will depend more on energy supply. The energy issue will become a critical "bottle neck" constraint for economic and social development and life quality improvement in the country. Based on a preliminary projection, by 2020, China's national energy consumption will be up to 4-4.8 billion tce.

The sharp increase in energy demand makes China face tougher challenges in the energy supply. To ensure a stable, cost-effective, clean, and secure energy supply will be an important task for a sustainable development in China. Conventional energy resources are scarce in China, especially lack of oil and natural gas resources. This has become a critical factor affecting the social and economic growth. Since 1993, China has become an oil importer. By 2008, China's 50% oil consumption depends on import. While strengthening both conventional energy exploitation and energy saving campaigns, it will be urgent to reform the current energy consumption structure into a multiple energy sources and clean energy approach.

2.1.2 Need for environmental protection and GHG emission reduction

Relying significantly on coal, China is the largest coal producer and consumer country in the world. This implies that China faces more challenges in pollution control and green house gas emission than other countries. According to the statistics, 90% of the SO2 emission is due to coal combustion, which has become major air pollutant such that one third of China's land is polluted by acid rains. The serious environmental pollution and air quality problems have severely affected China's social and economic development and threatened people's health. A better energy production system with reduced pollutant discharge has become a must if China wants to be a sustainable economy.

The global climate change has been a threat for all peoples. It has been a common interest for the international community to take measures to curb the green house gas emission and face the challenges of climate change and slow down its impact on earth. Many nations have committed to reduce their GHG emissions at different levels.

As a fast growing developing country, China is the second largest CO2 emitter country only after the US, while its economic growth rate becomes the fastest in the world. Although without committing the specific obligations in the GHG emission control, China as a responsible member of the international community is liable to reduce its CO2 emission. Furthermore, along with the world political and economic development trend, China is willing to take its responsibilities according to the global contribution liabilities. Therefore, China will face more and more international challenges in the global climate change. In the mean time, China itself must look at domestic requirement of pollution control, environment protection, and sustainable development. Without taking an active role, the climate change issues will even become one of the large uncertain factors for China's future economic development.

The government of China attaches great importance in coping with the global climate change. The China National Action Plan for Climate Change was issued in 2007. By the beginning of 2009, China's per unit GDP energy consumption has reduced by 13% compared with that in 2005. It is expected the energy use per GDP will reduce by 20% by 2010. On November 26, 2009, Chinese government announced its objectives in controlling green house gases by determining that by 2020 China's per GDP emission shall reduce by 40%-45% based on the level in 2005. This demonstrated the government's determination and actions in fighting with the climate change and created a positive international image in emission control.

According to the international best practice, improving energy efficiency and developing renewable energy will be two of the most effective measures. China has committed development of renewable energy technologies as important means to deal with global warming and emission reduction. According to its long-term renewable energy development plan, China expects to reduce 15-20% of green house gas emission by using RE sources by 2020.

2.2 Importance of developing biomass energy technologies

2.2.1 Biomass contribution in the renewable energy production

China is a biomass resource rich country with variety of biomass applications for electricity, biogas, liquid biofuel, and solid fuels.

In 2009, China applied a total of 259 million tce of renewable energy. Without hydropower, a total of 48.08 million tce renewable energy products have been produced, including 18.47 million tce from biomass energy, or 38.4% of non-hydro renewable sources. The applications of biomass energy were only after solar thermal and far more than wind power production (9.29 million tce). Biomass energy has become an important part of renewable energy applications.

Table 2-1 Installed capacity of renewable energy in 2009

Technologies	Potential	Annual production	Coal equivalent (10^4tce)
I. Power generation	227.18GW	661.674 bkWh	
Hydropower	196.79GW	615.64 bkWh	21054.8
In-grid wind power	25.80GW	26.9 billion kWh	919.9
Off network small wind power	150MW (25 systems)	274 million kWh	9.4
Solar PV	300MW	360 million kWh	12.3
Biomass power	4.12GW	18.4 billion kWh	588.8
Geothermal power	250MW	100 million kWh	3.2
II. Biogas		13 billion m2	928.2
III. Thermal applications			
Solar water heaters	145 million m2		1740

Solar stove	330 stoves		75.9
Geothermal applications	40 million m2	80 mGJ	200
IV. Biofuels			
Pellet biomass fuel	1.75 million tons		82.5
Vehicle ethanol fuel	1.72 million tons		176.3
Biodiesel	500 thousand tons		71.5
Total			25862.8
RE contributes to the primary energy consumption			8.34%
Biomass applied in non-hydro RE			38.40%

Looking ahead, biomass energy development is constrained by resource. The biomass market shall be smaller than that of wind power and solar energy. However, due to the characteristics of biomass resources, biomass technologies will become uniquely important that draws great attention in the world

2.2.2 Practical need for waste reuse

Reuse of garbage and waste for biogas will effectively reduce methane emission while provide energy. In fact, methane contributes 10 times more than CO_2 to the green house effect.

Energy plantation can provide energy supply while effectively increase carbon sinks.

2.2.3 Requirement for alternative liquid fuels

Among many renewable and alternative energy technologies, biomass energy is currently only energy product that can substitute liquid petroleum fuel.

2.2.4 Requirement for peak adjustment

Biomass is the only renewable energy that human efforts can be involved in the entire process of collection, storage, transport, and energy transformation. Biomass power stations (CHP) can provide electricity for power network peak adjustment while wind power and solar PV must be provided with peak adjustment systems.

a)

b)

2.2.5 Direct benefits to rural residents

Firstly, biomass energy applications can provide employment opportunities for local farmers and increase farmers' income. Development biomass energy will facilitate longer agriculture production chain and develop new industries in rural areas. The industry will help more income for local farmers and support more advanced agriculture sector in the same time. According to estimation, a 25MW biomass fuel generation turbine system can produce electricity of 130 million kilowatts each year if running 6000 hours. It can be millions Yuan value added. Over 1000 jobs can be provided for local farmers in straw collection, transportation, and processing. This will be very important for local economy in terms of solving rural labors, increasing local government income, driving local industry and service sector, improving rural economy, and upgrade China's agriculture sector competitiveness in the end.

Secondly, biomass development can effectively avoid in-field fire of crop straws, livestock waste discharge, and environment pollution by waste water and waste gas emission to the atmosphere, soil, and water bodies. While biomass resources can be non-harm processed for energy, it can help better rural environment and higher life quality for rural residents.

Thirdly, breath system disorder is a kind of frequent disease for rural women, which is considered correlative with habit of using straw as cooking fuel in China's rural areas. Biomass technologies can help provide clean energy and largely reduce the use of crop straw firing. Cleaner in-house environment will reduce the disease cases

2.2.6 Demand by the new rural development program

Currently rural area is the weakest in China's social and economic development, with backward infrastructures and slow farmer income growth. Biomass resources are mainly from agriculture and forestry. Therefore, development of biomass energy will contribute to the rural development.

In terms of energy supply, due to the lagged infrastructure development, about 7 million rural residents still has no electricity access in China that make them far from modern life style. In addition, about 70% of rural energy sources will come from crop straws and fire woods, with very low energy efficiency. On the other hand, biomass resources are very abundant in the country areas. Application of the biomass resources can help electric power supply at the remote rural areas. Fully use of the local biomass energy resources will provide rural residents with clean energy and improve their life quality.

For environmental benefits, biomass development and applications will improve rural productivity and life quality, and contribute to an energy saving and environmentally friendly social development. Through making use of the previously abandoned agricultural and forestry residues for energy by collecting and processing the resources, straw and livestock waste pollution can be effectively resolved and rural environment can be significantly improved. Meanwhile, application of the agricultural biomass will produce large amount of organic fertilizers. The more organic fertilizers can in turn improve soil organism and reduce usage of chemical fertilizers and pesticide.

While looking at social benefits, biomass development will promote rural industry and small township development, which will help smaller gap between urban and rural life standard.

By conclusion, development of biomass energy will facilitate increased farmer's job opportunities and income, improved environment, reduced disease, and improved rural life quality. It will also help improved rural energy supply. With the significant environmental and social benefits, biomass energy sector development in rural area will become an effective and practical approach for promoting the modern agriculture and rural development program through biomass industry driving force.

2.3 Defined targets of biomass energy development

According to current research results by the ERI, the study defined biomass energy target by 2015 and 2020. By 2015, produced biomass for energy shall be totaled 51.79 million tons and 119 million tons by 2020, which include installed biomass power capacity of 34.50GW, biogas of 112.7 billion m3, biomass pellet fuel of 30 million tons, and liquid biofuel of 12 million tons. Development targets for each biomass technology will be as the following table 1-3.

Table 2-2 Biomass product development targets in 10^4t

Technologies	2015		2020	
	Capacity	Energy equivalent (10^4tce)	Capacity	Energy equivalent (10^4tce)
Biomass power (10^4kW)	1449	3192	3450	7494
From crop straws	675	1445	1618	3405
From biogas	407	882	1025	2193
From municipal solid waste	367	865	807	1896
Biofuel gas (10^8m3)	163	1127	288	1635
Straw gasification	37	137	150	549
Biogas	126	990	138	1087
Biomass pellet fuel (10^4tons)	600	300	3000	1500
Liquid biofuel (10^4tons)	500	560	1200	1304
Fuel ethanol	350	365	1000	1043
biodiesel	150	195	200	261
Total		5179		11933

To fulfill the above targets, 78.36 million tons coal equivalent biomass resources will be consumed by 2015 and 17.901 billion tce by 2020, of which crop and forest residues will contribute to 50% of the total biomass resources. For detailed resource data, please see the following table 2-3.

Table 2-3 Development objectives for biomass resources

Resources	**2015**		**2020**	
	Biomass (10^4t)	Coal equivalent (10^4tce)	Biomass (10^4t)	Coal equivalent (10^4tce)
Agro-forestry residues	7299	3337	21313	9743
Livestock waste	63000	1980	115200	3621
Municipal solid waste	13760	1966	22816	3259

Feedstock for fuel ethanol		355		1012
Aged grain	525	156	525	156
Cassava	770	115	980	146
Sweet sorghum	1280	83	10880	709
Biodiesel		198		266
From waste oil and grease	180	154	225	193
From woody oil plant	120	44	200	73
Total		7836		17901

2.3.1 Targets for agricultural and forestry residues for energy

In 2008, a total of 700MW crop residue biomass power generation capacity has been installed, which provided 200 million m3 biogas, 1.2 million tons of pellet fuel, substituted 2.08 million tce fossil fuel and consumed a total of 9.35 million tons of crop residues in rural area.

Table 2-4 Rural crop residues for energy in 2008

Technologies	Capacity	Energy produced (10^4tce)	Resource used (10^4t)
Electricity (10^4kW)	70	148	593
Co-firing	3	6	20
Direct firing	62	130	519
Gasification	5	11	46
Carbonization	1	1	9
Fuel gas (10^8m3)	12	0.4	203
Gasification	6	0.1	35
Carbonization	6	0.3	169
Pellet biomass fuel (10^4t)	120	60	138
Total	202	208	935

It is expected that by 2015, the crop straw for energy technology will consume 72.44 million tons per year and utilize 209 million tons straw biomass by 2020.

Crop and forestry residues for energy technologies include power generation, gasification for fuel gas, and pellet biomass fuel. Of them, power generation from straw biomass will still be a popular technology for consuming straws in China’s rural areas by 2015 and 2020, which will produce energy of 14.55 million tce and 34.05 million tce respectively, or accounting for 76.77% and 62.44% of this biomass technology by 2015 and 2020.

Table 2-5 Targets of straw biomass technologies and resource demand

Technologies	2015			2020		
	Capacity	Energy produced (10^4tce)	Resource used (10^4t)	Capacity	Energy produced (10^4tce)	Resource used (10^4t)
Electricity generation(10^4kW)	675	1445	5674	1618	3405	13995
Co-firing	250	525	1800	667	1360	4800
Direct firing	250	525	2100	250	510	2100
Gasification	154	350	1400	615	1360	5600
Carbonization	21	45	374	86	175	1495
Fuel gas (10^8m3)	37	137	861	150	549	3443
Gasification	9	16	51	37	63	203
Carbonization	28	122	810	113	486	3240
Pellet biomass fuel (10^4t)	600	300	690	3000	1500	3450
Total		1882	7224		5454	20888

2.3.2 Development objectives of livestock waste for energy

By the end of 2008, 12 billion m3 or 8.65 million tce biogas have been applied including home biogas digesters. Installed livestock farm biogas power generation capacity has been 31MW producing energy of 70,000 tons coal equivalent.

By 2015, total applications of livestock waste for energy will be expected to exceed 630 million tons per year. The annual capacity will be 1.152 billion tons by 2020.

Looking at livestock waste biomass technologies, power generation and biogas fuel are two of major applications, including in-grid and off-grid biogas power generation. By 2015, biogas for fuel will be applied more than for power generation. 66.85% of biogas will be applied for electricity and become main applications of livestock waste biomass technology by 2020.

Table 2-6 Livestock waste biomass technologies, development objectives and resource demand

Technologies	2015			2020		
	Capacity (10^4kW)	Energy produced (10^4tce)	Resource used (10^4t)	Capacity (10^4kW)	Energy produced (10^4tce)	Resource used (10^4t)
Power from biogas (10^4kW)	252	882	31500	645	2193	80625
In-grid biogas power	101	353	12600	387	1316	48375
Off-grid biogas power	151	529	18900	258	877	32250
Biogas for fuel (10^8m3)	126	990	31500	138	1087	34575
In-grid	50	396	12600	83	652	20745

Off-grid	76	594	18900	55	435	13830
Total		1872	63000		3280	115200

2.3.3 Development objectives of municipal solid waste

In 2008, 1.09 million kilowatts of municipal solid waste power generation capacity has been installed which included capacity of incineration 1.06 million kilowatts and landfill gas generation 30MW2, substituting a total of 2.63 million tce fossil fuels.

It is expected that by 2015, total applications of municipal solid waste biomass for energy will exceed 138 million tons per year. The annual capacity will be 228 million tons by 2020.

Municipal solid waste biomass technologies are mainly incineration and landfill gas power generation and garbage incineration power generation will become the dominated technology in future municipal solid waste application. By 2015, incineration power generation will contribute to 97.17% of total municipal solid waste capacity. The percentage will become 98.92% by 2020, which will produce 18.96 million tce each year.

Table 2-7 Municipal solid waste targets and resource demand

Technologies	2015			2020		
	Capacity (10^4kW)	Energy produced (10^4tce)	Resource used (10^4t)	Capacity (10^4kW)	Energy produced (10^4tce)	Resource used (10^4t)
Landfill gas power	7	25	5760	6	19	4416
Incineration power	240	840	8000	552	1877	18400
Total	247	865	13760	558	1896	22816

2.3.4 Biofuel development objectives

In the year of 2008, China produced a total of 1.71 million tons of biological fuel ethanol and 0.4 million tons of biodiesel, substituted 2.3 million tce of fossil fuel.

Table 2-8 Biofuel applications in 2008

Technologies	Capacity (10^4kW)	Energy produced (10^4tce)	Resource used (10^4t)
Fuel ethanol	171	178	/
From aged grain	150	156	525
From Cassava	20	21	140
From sweet sorghum	1	1	16
From cellulose	0	0	0
Biodiesel	40	51	/
From wasted oil	40	51	60
From oil plants	0	0	0

Total	/	230	/

It is expected that by 2015, 5 million tons of biofuels will be produced annually. The production will be 12 million tons by 2020 with more than 80% of fuel ethanol in China.

The fuel ethanol produced will be mainly from aged grain, cassava, sweet sorghum, and small amount from crop straws. By 2020, sweet sorghum will become main feedstock for fuel ethanol with 108.8 million resources will be consumed, while biodiesel will mainly be from waste oil and oil plant. By 2020 waste oil and grease will be the major feedstock for biodiesel production with 2.25 million tons of waste oil consumed each year.

Table 2-9 Biofuel targets and resource demand

Technologies	2015			2020		
	Capacity (10^4kW)	Energy produced (10^4tce)	Resource used (10^4t)	Capacity (10^4kW)	Energy produced (10^4tce)	Resource used (10^4t)
Fuel ethanol	350	365	2650	1000	1043	12610
From aged grain	150	156	525	150	156	525
From Cassava	110	115	770	140	146	980
From sweet sorghum	80	83	1280	680	709	10880
From cellulose	10	10	75	30	31	225
Biodiesel	150	195	300	200	261	425
From wasted oil	120	154	180	150	193	225
From oil plants	30	41	120	50	68	200
Total	500	560		1200	1304	

3. Methodology for comprehensive assessment

Currently, biomass utilization industry in China is still at early stage. Assessment of a biomass technology is based only on its technical and economic level, lack of systematic comparative analysis on multiple technical processes. Meanwhile, due to the proliferation of many biomass technologies with different maturity and applications, it is difficult to compare among them. Therefore, comparison of biomass technology benefits in resources, social and environmental aspects is usually qualitative without a quantitative assessment indicator system. So far, most of the studies on biomass technology development roadmap are qualitative in nature. For the purpose of biomass roadmap study, a rational assessment based on large amount of basic data can be very important for the overall biomass technology evaluation in order to develop a scientific biomass technology development roadmap.

3.1 The assessment methodology

In this study, an overall and comprehensive assessment system is developed with designed criteria in terms of resource potential, technology trend and overall benefit. Based on thorough theoretical analysis supported be solid basic data, future biomass technology development and their overall benefits will be quantitatively analyzed.

3.1.1 Special feature of the methodology

The biomass development roadmap is analyzed by using a comprehensive assessment criteria system. The assessment methodology has the following characteristics:

(1) Resource priority

From the following figure 3-1 of summary biomass technologies, biomass can be utilized by multiple technologies and using diversified resources, as well as producing different biomass energy products. It is difficult to compare the technologies under a single indicator due to their diversity in technologies. Furthermore, technologies using different biomass resources may not be competing each other in the market. Therefore, the comprehensive assessment of biomass technologies must be resource specific so that future development potential of biomass technologies using the same type of resource can be compared and ranked practically. For different biomass technologies, future development objectives will be determined based on their resource potentials.

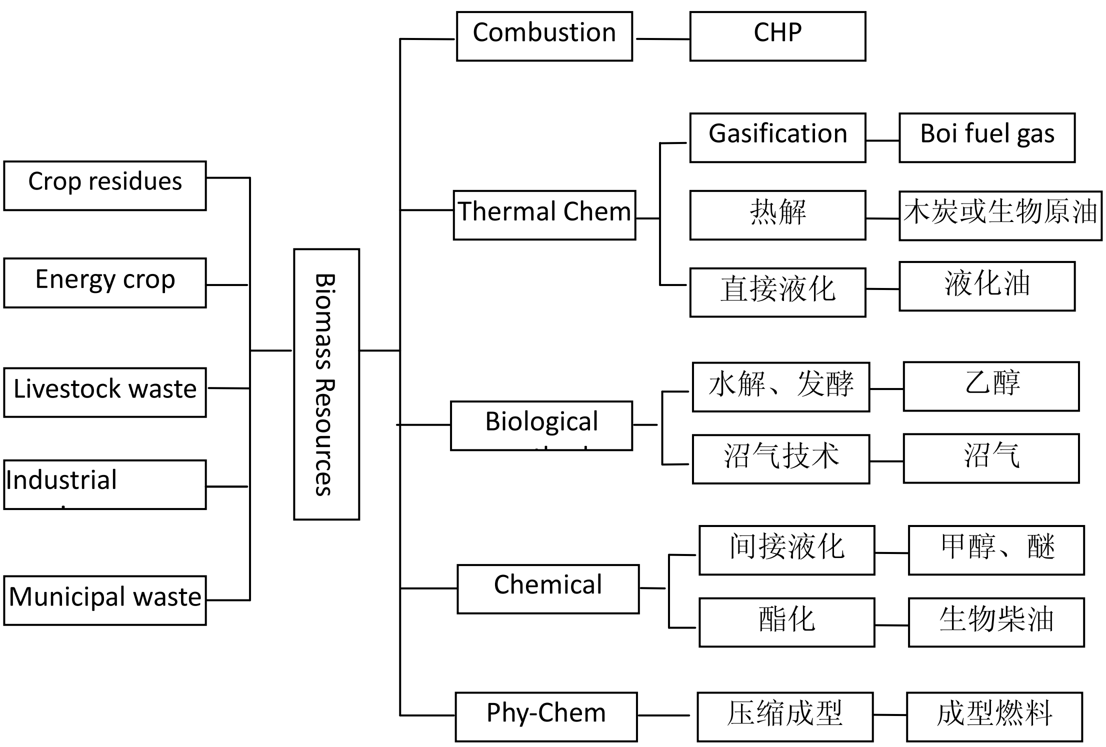

Figure 3-1 Biomass utilization technologies

(2) Multi-criteria quantitative assessment

The biomass technology comprehensive assessment in this study will be a multiple criteria systematic assessment. The assessment criteria will cover technical, economic, resource, environmental, and social factors into nine categories. The criteria are quantified based on large amount practical data and analytical methods. The quantification of the assessment criteria will not only include economic and external returns, but also technological development in the future. The assessment results are resource specific. Therefore, the technical assessment result scores will describe biomass future development in a quantitative way.

3.1.2 Study scope

Since there are diversified biomass technologies, some representative biomass utilization technologies are selected to reflect future biomass development in China. The selected biomass technologies are further classified based on their resources, including technologies of agricultural and forestry residues, livestock waste for energy, municipal solid waste for energy, and biofuels[1]. The selected biomass technologies to be analyzed are summarized in the following table 2-1.

Table 3-1 Summarized biomass technologies

Resources	**Crop residues**	**Livestock waste**	**Municipal solid waste**	**Liquid Biofuel**
Technologies	Direct combustion Gasification generation Co-firing generation Biomass pellet fuel Charcoal pellet	Biogas power in-grid Biogas power off-grid	Power generation by incineration Landfill gas power	Non-grain ethanol Ethanol from sugar feedstock Ethanol from cellulose Biodiesel from waste oil Biodiesel from oil plant seeds

3.2 Criteria system for the comprehensive assessment

The proposed criteria system for comprehensive assessment of biomass technologies can be classified into two categories, i.e. technology development potential and overall benefit. Criteria in each category are further broken down into detailed indicators. The two categories of assessment criteria have relatively independent ranking method and score computation, with total scores of 100 points. Through rankings of the two categories of technology assessment, final scores of both technology potential and benefit can be obtained to indicate market trends of a biomass technology application and its overall benefit. According to the scores, technology rankings are given for the temporal horizon at 2008, 2015, and 2020.

Steps of defining the criteria system are summarized as follows:

- Design of classified criteria
- Give weights of the classified criteria in each category
- Break down design of detailed assessment indicators

[1] Liquid biofuel technologies are not classified into resources.

- Determine quantitative standards for each indicator
- Determine score of each detailed indicator

According to the above definition and quantification method, a criteria system for the biomass technology assessment is obtained as the following figure 2-2.

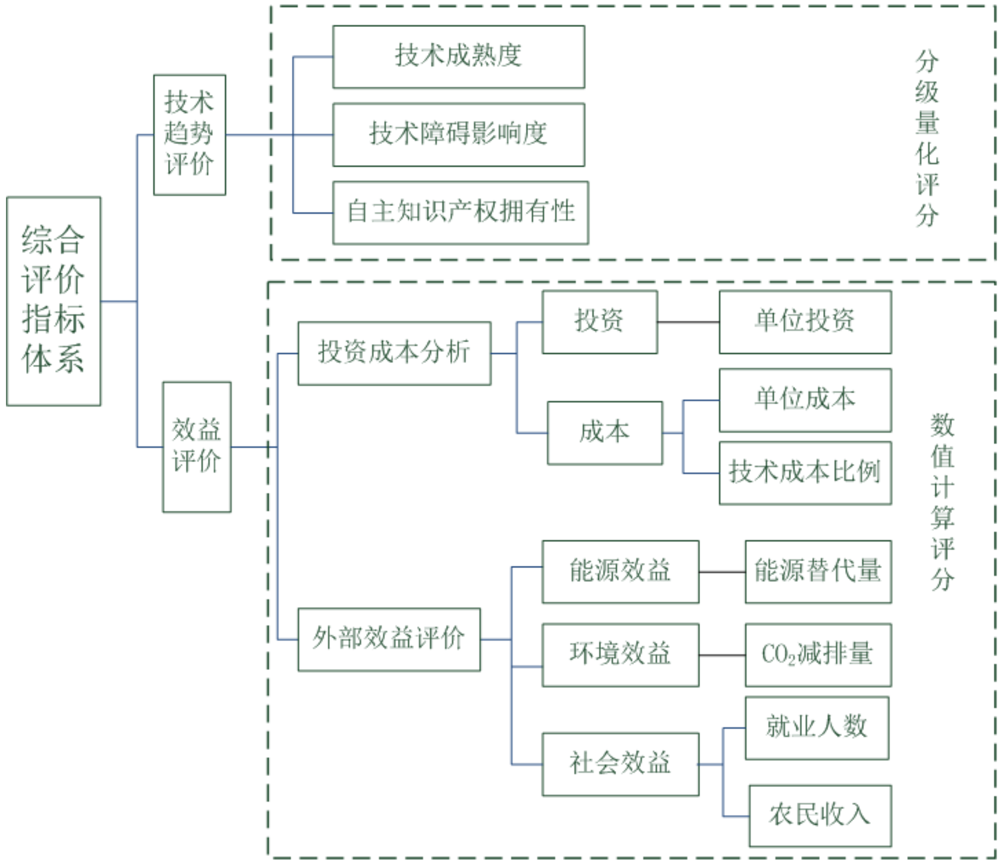

Figure 3-2 A framework of criteria system for assessing biomass technologies

The above criteria system is designed based on data from large number of typical biomass energy cases. The criteria system considers current status and future development of biomass technologies and development. In particular,

- Three sub-criteria have been identified for biomass technology development trend: maturity, impact of technical obstacles, and IPR ownership. Biomass technology development trends are evaluated by the proposed criteria and give scores and final rankings in temporal stages.
- Benefit assessment will be on investment cost and external return, based on typical cases of technological applications. Data from the biomass cases will be computed to obtain projection of economic cost and external return of each biomass utilization technology. Possible and priority biomass technologies are identified according to the trend assessment.

In later sections, detailed quantification of criteria and evaluation methods will be presented.

3.3 Assessment of technology trends

3.3.1 Steps of the assessment

The assessment of technology trends will include quantitative evaluation of the three categories of criteria about technology maturity, impact of obstacles, and IPR ownership:

Step 1：Design of classified criteria

Design of technology trend criteria will consider technological aspects of future biomass technology development with detailed indicators critically affecting future biomass technology development.

Step 2：Determine weights of the classified criteria in each category

As critical factors affecting future biomass technology development, impact of the indicators can be varying. Based on expert evaluation and practical projects, maximum weight values of the criteria are determined to represent the impact on the biomass technology in the future.

Step 3：Determine quantitative level standards for each indicator

Leveled criteria for the technology trends are determined by descriptive information plus scores of each level. The maximum score is the weight value, zero score at the minimum level.

Step 4：Scoring

Each biomass technology to be assessment will be scored according each of the detailed criteria of three categories. Sum of the category scores shall indicate future biomass technology development trend and the final score will be used to compare technologies for the same resource to identify priority at certain temporal stage.

3.3.2 Quantification method of criteria

The three categories of criteria for assessing biomass technology development trends will be used qualitatively and quantitatively. Qualitative method is used to analyze the criteria and quantitative method is used to assign score to each level. Levels of each category of criteria are as follows:

1. Technology maturity

The technology maturity criterion is used to indicate industrial progress of a biomass technology, which is defined according to different maturing stage. The following chart identified six progress stages during a biomass technology developing into industrial application. Technology maturity will be assessed according to the stages and scored for each stage.

2. Impact of technological obstacles

The criterion for technological obstacle impact in the future biomass applications is measured as indifferent, affecting project efficiency and cost, impacting on system integration, and affecting applications. Each level of impact will be given by different score.

3. IPR ownership

The IPR ownership is an indicator for domestic enterprises to master critical technologies. The criterion is measured into three levels: fully own the IPR, imported critical technology or partial ownership, and completely imported without IPR ownership.

3.3.3 Assigning scores

Table 3-2 shows the scores given for different technology development status. The highest score of each category criterion is the weight value. Total score of 100 is composed by maturity 40%, impact of obstacles 40%, and IPR ownership 20%.

Table 3-2 Criteria and weight scores of technology trend assessment

Major criteria	Levels	Scores
Maturity	Mature technology	40
	Technology system formed	32
	Market promotion	24
	Demonstration	16
	Research & Development	8
	Basic theory research	0
Technology obstacle overcome	No sensitive technology obstacle	40
	Affecting system efficiency and cost	25
	Affecting technology integration	15
	Affecting applications	0
IPR ownership	Fully owned	20
	Critical technology import (or partial IPR)	10
	Completely imported	0
Total score		100

3.4 Benefit assessment

3.4.1 Assessment steps

The assessment of benefit of a biomass technology will include quantitative evaluation of its investment cost and external returns. Data source for the assessment come from large number of biomass project cases. The assessment steps will include:

Step 1：Design of classified criteria

Design of benefit criteria will consider most conventional technical and economic indicators as well as external benefit criteria. These criteria must be able to quantified and supported by basic datasets.

Step 2：Determine weights of the classified criteria in each category

Currently investment cost analysis is based on conventional cost-effective evaluation to compute project investment and unit capacity cost. External benefits can be analyzed by several quantitative indicators such as employment opportunities, emission reduction, substituted energy, etc.

Step 3：Determine quantitative level standards for each indicator

Benefit assessment involves multiple benefits in technical economy, social, environmental, and energy contributions. Based on expert input and practical project investigation, criteria weights are determined for leveled indicators in describe impact of biomass technology development.

Step 4：Scoring

Each biomass technology to be assessed will be scored according each of the detailed criteria of comprehensive benefits. Sum of the category scores shall indicate future biomass technology development benefits and the final score will be used to compare technologies for its multiple benefits at certain temporal stage.

3.4.2 Investment cost analysis

1. Basic data

Investment cost analysis of a biomass technology is carried out following national standard financial evaluation method. Basic data come from existing biomass technology cases as indicated in the following table 3-3.

Table 3-3 Data sets required for technology investment coast analysis

Category	Major indicators	Unit	Remarks
Investment	Project scale		Installed capacity for power generation technology and annual production for other biomass technology
	Fixed asset invested	10^4 RMB	In cases of typical biomass projects
	Of which percentage of equipment	%	
	Loan percentage	%	
	Flowing capital	10^4RMB/year	
	Interest rate	%	
	Duration of loan	Year	
Cost	Raw material cost: at-gate price	Yuan/ton	
	Material energy value	kcal/kg	
	Sales price	Yuan/ton	
	Job as before material enter plant	person	
	Other material cost: water price	Yuan/m3	
	Water consumption	10^4m3/year	
	Power price	Yuan/kWh	
	Electricity consumption	10^4kWh/Year	

	Price of other energy products	Yuan/ton	
	Consumption of other energy products	10^4t/year	
	Human resource cost: number of people	person	
	Average salary	10^4Yuan/year	
	Welfare index	%	
	Other cost	10^4Yuan/year	
	Maintenance cost ratio	%	
	Other costs	10^4Yuan/year	
	Cost for depreciation: duration of depreciation	year	
	Remain value	%	

In the investment cost analysis, attention will be paid to biomass technology investment cost variation at certain future years, with major indicators as follows:

- Productivity variation
- Fixed asset investment variation
- Employment salary variation

2. Computation of the indicators

Cost analysis for biomass technology investment involves three major indicators: unit capacity investment, unit cost, and cost compared with conventional energy. Their computational formulas are:

$$\text{Unit investment} = \frac{\text{Fixed assesst invstment+interst during project duration}}{\text{Project size}}$$

$$\text{Unit cost} = \frac{\text{fuel cost+financial cost+human cost+maintenance cost+depreciation cost+other cost}}{\text{Annual production}}$$

$$\text{Technology cost ratio}=\frac{\text{biomass technology unit cost-conventional energy unit cost}}{\text{Biomass technology unit cost}}$$

3.4.3 Assessment of external benefits

Assessment of external benefits of a biomass technology means the quantitative assessment of social benefit, environment benefit, and energy benefit contributed by the technology. Specific computation of the benefits will be based on data from cost analysis, into four indicators: energy substitution, CO2 emission reduction, number of employment, and farmer income, computed by the following formulas:

$$\text{Energy substitution}=\frac{\text{Project total production*unite energy substitution}}{\text{Consumed total energy by the project}}$$

$$\text{CO2 emission reduction}=\frac{\text{Project total production*unit CO2 emission reduction}}{\text{Total energy consumed by the project}}$$

$$\text{number of employment}=\frac{\text{employment of material preparation+in-plant employment}}{\text{Total material consumed by the project}}$$

$$\text{Farmer income}=\frac{\text{Total material consumed*Material sales price}}{\text{Employment for material preparation}}$$

3.4.4 Assessment of comprehensive benefits

The comprehensive assessment of biomass technology benefits is conducted through computation of each major indicator and summation of the sub-scores of the indicators. Final score of a biomass technology comprehensive benefit is obtained, based on the same type of biomass resource used. Specific assessment method is described in the following:

(1) Define the impact of each indicator on biomass development. Table 3-4 gives neither positive nor negative contribution of the impact. Positive contribution of an indicator means the higher indicator value will contribute more on biomass development while the negative contribution refers that the indicator will produce unfavorable impact on the biomass applications.

(2) Compare the indicator values for each biomass resource technologies and rank them according to their contribution. The highest score is 100 and minimum of zero, while other scores mean the gap between the maximum score and the minimum.

(3) Weighted sum of the scores will be the final score of comprehensive benefit evaluation.

Scores are calculated according to the following formulas:

(1) Positive contribution indicator:

$$\text{Indicator score}=\frac{\max_{\text{Resource}}\text{indicator}-\text{technology indicator}}{\max_{\text{resource}}\text{Indicator}-\min_{\text{resource}}\text{Indicator}}\times 100$$

(2) Negative indicator:

$$\text{Indicator score}=\times 100\%$$

According to the above method, each indicator of every biomass technology will be computed. Apart from investment cost analysis and external benefit assessment indicators; resource collection difficulties are also assessed in the benefit assessment to indicate resource obtainability of each technology. Weights and contribution of each indicator is summarized in the following 3-4.

Table 3-4 Criteria of comprehensive benefit assessment

Indicators	Quantification of the indicators	Contribution	Weight
Difficulty in resource collection	Project size (104t material/project)	Negative	10%

Cost-effectiveness	Production cost	Negative	35%
Social benefit	Employment (persons/104t material)	Positive	15%
	Farmer income (Yuan/person)	Positive	20%
Environmental benefit	ton CO2/ton material	Positive	15%
Energy benefit	tce/ton material	Positive	5%

4. Biomass resource potential analysis

4.1 Status of biomass resources

There are varieties of biomass energy resources with multiple application technologies. In terms of sources, biomass energy can be classified into two major categories. The first category of biomass resource comes from agricultural production and household such as crop residues, forest residues, municipal solid waste, and industrial organic waste. The other biomass resource category is from human planted biomass sources such as energy crops, energy forest, and alga microorganism that can be utilized for biomass fuels. Organic waste water in the industrial process must be processed to protect environment. It is not necessarily for purpose of energy. Alga microorganism for energy is still at lab research stage. It has not been utilized in the energy market. Therefore, it can be one of potential energy sources. This study will focus mainly on crop straws, livestock waste, forestry biomass, municipal solid waste, and energy plantation as biomass resources, without special attention to the industrial organic waste and alga microorganism.

Considering biomass resources, obtainability, competing uses, and utilization for energy, the following table summarized biomass resources and availability for energy in the year 2008.

Table 4-1 Biomass resource and obtainability in 2008

Biomass sources	Total available biomass resources (10^8tons)	Obtainability (10^8tons)	Available energy (10^8tce)
Agro-forestry residues	11.86	5.00	2.47
Livestock waste	17.78	10.67	0.38
Municipal solid waste	1.54	1.54	0.22
Liquid biofuels	/	/	0.03
Total			3.09

4.1.1 Crop residues

Agricultural biomass resources in China are mainly crop straws as well as rice husks, corn cores, and bagasse from food processing. According to agriculture production, crop straw uses, and residues form agricultural product processing, it is estimated that in 2008, there were about 816 million tons of crop biomass resources, of which 339 million tons can be used for energy, including 133 million tons for rural household fuel and 210 million tons left unused. Uses of the crop residues are estimated in the following table 4-2.

Table 4-2 Crop residue resources, availability and uses in 2008

Uses of crop residues	Total resources (10^8t)	Percentage (%)
Stubble left in field	1.33	16.3
Fertilizers	1.02	12.5
Feedstuff	2.11	25.9
Fuel	1.29	15.8
Industrial material	0.16	2.0
Other uses	0.15	1.8

Left unused	2.1	25.7
total	8.16	100.0

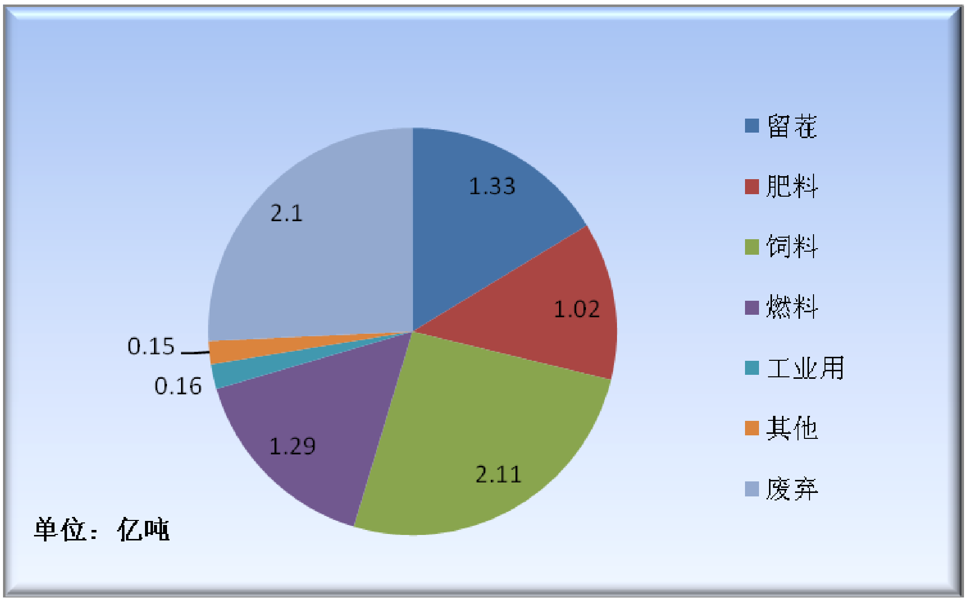

Table 4-1 Crop residue uses

4.1.2 Forestry waste

Forest residues may include harvesting and wood processing residues, forest management cuttings and small branches, shrub cutting, economy forest, bamboo forest, under tree shrubs, municipal green forest cutting, etc. According to a report by China forest biomass study project, the biomass resources and availability in 2008 are summarized as the following table 4-3.

Table 4-3 Forest biomass resources and availability for energy in 2008

Sources	Estimated resources (10^4t)	Availability for energy (10^4t)
Harvesting residues	13100	2600
Processing residues	2900	2900
Shrub management	4200	2500
Other sources	10000	1500
Total	36800	16100

4.1.3 Livestock waste

Livestock wastes refer to all the animal excretions from livestock farming, which are animal conversion from feedstuff (grain, crop residues and grass) to dejecta, urines and underlay mix. The livestock farm waste can be estimated according to number of animals, types, weights and each animal's excrement. According to animal farming at pig, cattle, horse, donkey, camel, sheep, and poultry farms and by considering the livestock waste uses, collection conditions, and environmental protection requirement for the livestock waste processing, it is estimated about 1.778 billion tons of livestock waste resources are available in China. 70% of the resources, or about 1.067 billion tons, are from large livestock farms and can be used for energy.

Table 4-4 Livestock waste resources and availability in 2008

Animals	On hand(10^4)	Total excrement(10^8t)
pig	46291	4.22
cattle	10576	9.65
horse	682	0.5
donkey	673	0.37
mule	296	0.22
camel	24	0.02
sheep	28085	1.54
fowl	1085470	1.27
Total		17.78

4.1.4 Municipal solid waste

In the recent past twenty years, China's urbanization process developed very fast, resulting continuing expansion of cities and towns with increased urban populations, so that more and more daily life garbage are produced by each urban resident per year in China. Based on the statistics (China Statistics Yearbook 2009), in 2008, among the 15.438 billion tons of municipal solid waste processed in China, only 10.307 billion tons, or 66.8%, were non-harmfully managed. The non-harmful processing methods include sanitation landfill, compost, and incineration for electricity generation. For example, even though strongly encouraged by the national environmental protection agency as ideal technology, there are only 74 garbage incineration power projects in China established processing merely 15.7 million tons municipal solid waste, which accounted for 15.2% of non-harmful processing, or about 9% of municipal solid waste managed. Meanwhile, about half of urban waste is sanitarily filled, with another one third without any processing. Therefore, harmless treatment, amount reduction, and utilization for energy become an urgent task for China to reduce municipal solid waste. In this study, the amount of municipal solid waste in China refers to total of waste resources for energy. Manageable amount is equal to the availability of municipal solid waste for energy.

Table 4-5 Transported and harmlessly processed municipal solid waste in China in 2008

Treatment	Number of facilities	Capacity (10^4t/day	Amount processed (104t/year)	% of total garbage
Transported	15438			
Non-harmfully processed	509	31.5	10307	66.8
Of which, sanitation landfill	407	5.3	8424	81.7
compost	14	0.5	174	1.7
Incineration	74	5.2	1570	15.2

Data source: State Statistics Bureau, China Statistics Yearbook 2009.

4.1.5 Materials for liquid biofuels

Resources for liquid producing biofuels can include agricultural and forestry products, crop residues, municipal waste oil, energy plant, and microorganism (microalgae for diesel). Since biodiesel from non-grain materials is encouraged in China, feedstock for biofuel process can include waste sugar materials, animal grease, cassava, sweet sorghum, jatropha curcas, energy plants, and crop residues. The liquid biofuel materials investigated in this study are mainly cassava, sweet sorghum, waste oil, and oil plant seeds, with including cellulose and microorganism materials.

Over the recent past years, about 600,000 ha cassava have been planted with annual production around 11 million tons, mainly used to produce starch and industrial raw materials, only few used for food products. Annually, about 2 million tons of waste oil or animal grease can be utilized for energy in China. 8.042 million hectares of woody oil trees are planted with about 2.2 million tons of oil fruit products produced each year. However most of the resources are wasted without effective utilization.

Table 4-6 Resources for liquid biofuels and availability of the resources in 2008

Sources	Total resources (10^4t)	Availability (10^4t)	Availability in energy (10^4tce)
Cassava	1100	140	21
Sweet sorghum	250	250	16
Waste oil	200	200	171
Woody oil plants	220	170	62
Total			271

4.1.6 Marginal land resource

Because of the huge population and short of arable land resources in China, biomass energy must be developed in the principle of non-competition with food production.

Because there is no complete and systematic survey on marginal land for biomass energy utilization, definition on marginal land uses, land classification, and available marginal land and their potential data obtained by different organizations and research institute are different significantly. So far, existing related studies are based on data obtained by national land resource administration on land resources (mainly from the 2002 issued Land Classification in China (trial regulation)), data on national survey on current land uses and pattern changes, data by the Ministry of Forestry on marginal forest land resources, data by Ministry of Agriculture on arable land uses. A preliminary assessment has been done on marginal land resources and potentials for energy crops and energy woods. According to the different data sources and calculations, it is estimated generally that there are 32-75 million hectares of marginal land, including 7.34-9.37 million hectares for back-up arable land that can be used to plant energy crops, 8.66 million hectares of used land during winter season that can be used to plant rape, 16-57 million hectares of back up forest land that can be used to plant energy forest, and 3.43 million hectares of existing low yield oil forest land that can be improved

Table 4-7 Available marginal land resources

Marginal land	Area (10^4ha)	Crops can be planted

Back-up land for agriculture crops	734	Energy crops (sweet sorghum, cassava, sweat potatoes)
Unused land during winter	866	Winter rape
Back up land for forest	1600～5704	Fire wood and oil forest
Existing low yield oil forest land	343	Improved for biodiesel feedstock
Total area	3543～7647	/

4.2 Biomass resource potentials

4.2.1 Crop and forest residues

Figure 4-2 depicts productions of grain, cotton, and oil products over the past ten years. In the figure, the data of cotton production is 100 times more than actual production and data of oil product is 20 time more higher than practical yield. We can see in the figure that grain production contribute 93-95% of total major agricultural yield. Over the past ten years, grain production in China maintains at 450-500 million tons. It is estimated that this production will maintain stable in the long-term future. Therefore, crop residues by 2015 and by 2020 will be similar with the data in 2008.

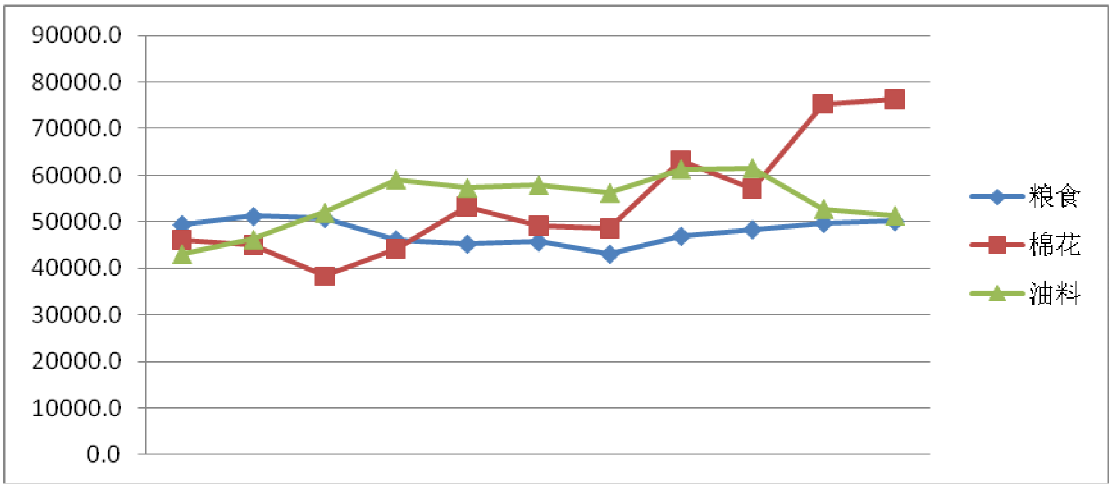

Figure 4-2 Grain, cotton, and oil product yields in China

Although it is expected that area of forest land in China will continue to increase, forestry residue resources will maintain stable by 2015 and by 2020 due to many constraints such as cutting regulations, lack of industrial collection, capacitated processing, environmental protecion, and competing uses with other industrial production activities. Therefore, the 2008 resource data will be used in this study.

4.2.2 Livestock waste

Along with the improved factors in farming cost, techniques and agro-product qualities, rural home animal farming are developing towards scale livestock farm practices. With changing food sources and improved living standard in China, animal farm product consumptions continue to grow while grain consumptions are getting less. This change will drive the sustained animal farming sector in China. Meanwhile, along with the improving environmental awareness and national policies on pollution control, more demand for large livestock farm biogas projects will be expected in the future. It is expected that by 2015, a total of 2.24 billion tons of livestock excretion will be produced in China, with 1.58 billion tons, or 70.3% of the resource will come from large livestock farms. By 2020, the total livestock waste will be 2.54 billion tons, of which 1.92 billion tons, or 75.7%, will be from large scale livestock farms in China.

Table 4-8 Livestock farm waste resources and availability

Year	Total resources (10^8t)	Availability (10^8t)	Available energy (10^8tce)
2008	17.78	10.67	0.38
2015	22.25	15.48	0.55
2020	24.56	18.59	0.66

4.2.3 Municipal solid waste

By 2008, processed municipal solid waste in China totaled 154 million tons compared with actual yield of the life garbage more than 150 million tons. With continuing improved awareness of resource utilization and biomass technology, growth rate of municipal solid waste is expected to mitigated. Anyway it is projected that by 2015, 200 million tons of municipal solid waste will be generated annually and the amount will reach to 230 million tons by 2020. All these waste can be harmless treated for energy. This means all generated municipal solid waste can be available for biomass energy.

Table 4-9 Available municipal solid waste in China

Year	Total resources (10^8t)	Availability (10^8t)	Available energy (10^8tce)
2008	1.54	1.54	0.22
2015	1.93	1.93	0.28
2020	2.32	2.32	0.33

4.2.4 Liquid Biofuel feedstock

Energy crops and forest need long time efforts (more than 10 years) to breed and plant before they can be harvested for energy due to the long time to grow, high cost, and constraints of natural conditions. Resource availability for biofuels is analyzed by considering multiple factors such as China’s policy of non-grain feedstock, current non-grain energy plantation, marginal land uses, and transforming technical process, etc.

For fuel ethanol from aged grain, the capacity will be strictly limited by national policies. Therefore by 2020, the availability of aged grain shall maintain at 1.52 million tons.

Currently there are about 2 million tons of waste oil and grease resource. With increased population and improved life quality, the account is expected to be more. However the increase shall be limited due to the improved awareness of energy saving, low carbon economy, and encouraging frugality. By 2020, the available waste oil and grease will be kept at about 2 million tons in China.

Cassava can be a major starch-type material for biofuel production. Currently 11 million tons of cassava products are produced each year in China, mainly from China’s southern province of Guangxi, accounting for 70% of the country’s total yields. The principal 200,000 ton fuel ethanol production facility developed by China’s food corporation (COFCO) consumes 1.4 million tons of cassava each year. Increased cassava resource can be achieved through two major approaches:

planting more at marginal land for another 5 million tons annually, and increase yield. Current yield of cassava can only be 1 tons per Mu in average. The improved breed of cassava is expected to yield 4-4.5 tons. Suppose 50% of the cassava breeds are improved, 5-6 million tons in total can be produced each year. Therefore we project that by 2020, more than 11 million tons of cassava can be produced annually.

Sweet sorghum is planted mainly in coastal provinces of Jiangsu, Shandong, and Liaoning, as the saline land in these provinces is unsuitable for grain production. Sweet sorghum is a saline-alkali resistant crop suitable for the land in the coastal area with rather high yield. It is expected that 110 million tons of sweet sorghum (including stalks) can be produced annually by 2020.

Currently there are over 100 varieties of oil crops suitable for biodiesel, but most of the crop breeds need to be improved to increase yield. Among the most promising crops are Jatropha curcas, sapium sebiferum, and vernicia fordii etc. Jatropha curcas are mostly planted in China’s southwest provinces while vernicia fordii is popular at central China provinces. Oil crops can be planted at large area of marginal land, totalled in areas of 30 million ha. It is expected that by 2020, about 7 million tons of oil seeds will be available each year.

Table 4-10Available raw materials for liquid biofuels

Year	**2008**		**2015**		**2020**	
Resource	**Availability (10^4t)**	**Available energy (10^4tce)**	**Availability (10^4t)**	**Available energy (10^4tce)**	**Availability (10^4t)**	**Available energy (10^4tce)**
Aged grain	525	156	525	156	525	156
cassava	140	21	800	119	1100	164
Sweet sorghum	250	16	2700	176	11000	717
Waste oil	200	171	200	171	200	171
Oil seeds	170	62	300	110	700	257
Sum		427		733		1466

4.3 Priority technologies

Basic principles for livestock farm waste utilization for energy will be: “strengthening pollutant discharge control at livestock farms to stop uncontrolled discharges of livestock farm wastes. The biogas project development will help provide daily life fuels and quality organic fertilizers in rural areas. Protective planting, professional, industrial and commercial animal waste processing capacity will be built in China”. Livestock waste will be naturally yielded as the livestock farms operate to produce meat, egg, and milk products. However current livestock waste from some farms without treatment has resulted serious pollutions in local areas. Proper treatment of the animal manure must be solved to ensure sustainable supply of meat, egg, and milk products in the market. Therefore, livestock farm waste utilization for energy must be developed as priority biomass technology in China.

According to an investigation by the National Environmental Protection Administration, half of Chinese cities are surrounded by municipal solid waste. It is difficult to find nearby landfill sites. Based on a research by the study team, since 1998, Beijing municipal government planned to select a garbage landfill site at its surrounding counties, but failed to decide after ten years efforts. City garbage has become a new pollution source. Municipal solid waste treatment for energy has been considered the most effective approach. Therefore, it will be a priority project for biomass technology. Garbage treatment capacity will depend on available municipal solid waste resource. Economic benefit should not be considered as its market share with other biomass technologies.

Agricultural and forestry residues can be utilized for energy apart from stubbles leaving in the field for fertilizers and as livestock feedstuff. However in Chinese rural areas, in field combustion of crop residues are still popular. This not only resulted in serious pollution, but a huge waste of the biomass resources. Utilization of crop straws for energy will not only increase farmers' income but also contribute to alternative energy supply and improvement of environment, as well as promote local economy in a sustainable development. Therefore, crop straws in the rural area will be utilized as priority technology. Comparatively, due to many existing obstacles for in environmental protection policies, competing uses with industrial processing, high cost in collection, and natural conditions, large scale utilization of forestry residues for energy is still facing challenges. It is considered by the study team that forestry biomass technology will not be fast developed by 2020.

According to the policy of biofuels from non-grain materials, in near and medium term, biofuel production will mainly from waste sugar materials, animal grease, cassava, sweet sorghum, energy plants like Jatropha curcas, and cellulose crop residues. Recently, the biomass energy resources including large scale plantation of non-food, sugar and starch crops and energy plantation in marginal land will be encouraged. Cellulose feedstock from agricultural and forestry residues is still waiting for improved and optimized processing technologies.

4.4 Summary

Based on the above analysis on current and future resources of crop residues, livestock waste, municipal solid waste and biofuel materials, the following table 4-11 depicts total resources and availability for biomass energy. To fulfill the national biomass energy target in China, the biomass resources in China will be sufficient for the future development.

Table 4-11 Summarized biomass energy resource and availability in China by 2015 and by 2020

Resources	2008		2015		2020	
	Availability (10^4t)	Available energy (10^4tce)	Availability (10^4t)	Available energy (10^4tce)	Availability (10^4t)	Available energy (10^4tce)
Crop residues	50000	24700	50000	24700	50000	24700
Livestock manure	106700	3800	154800	5513	185919	6621
Municipal solid waste	15400	2200	19300	2757	23200	3314
Feedstock for fuel ethanol		194		452		1037
Aged grain	525	156	525	156	525	156
cassava	140	21	800	119	1100	164
Sweet sorghum	250	16	2700	176	11000	717
Materials for biodiesel		234		282		429
Waste oil	200	171	200	171	200	171
Woody oil seeds	170	62	300	110	700	257
Total		31127		33703		36101

By comprehensively considering each type of biomass resources and the demand for energy production, by 2020, livestock waste and municipal solid waste for energy shall be encouraged as prioritized sector in China. Crop residues and forestry waste will also be developed. During the development period, energy plantation is not expected into commercial application since the immature transforming technology. The priority for energy crops will be optimizing breeds, cultivating high yield trees, and developing plantation bases.

5. Assessment of technology development trends

5.1 Agricultural and forestry residues for energy

Agricultural and forestry residues can be applied for energy through power generation by direct combustion, co-firing, gasification, pellet fuel, and biomass carbonization technologies.

5.1.1 Power generation form straw fuel direct combustion

5.1.1.1 Technical process

Direct combustion refers to power generation completely from biomass fuel that are combusted in specially designed biomass boilers to generate steam driving steam turbines generate electricity. The critical difference between biomass direct combustion and conventional fossil fuel lies in raw material preprocessing and dedicated straw boilers. The biomass fuel preprocessing and special biomass furnace must ensure the boiler heat efficiency, life span, and stable operation.

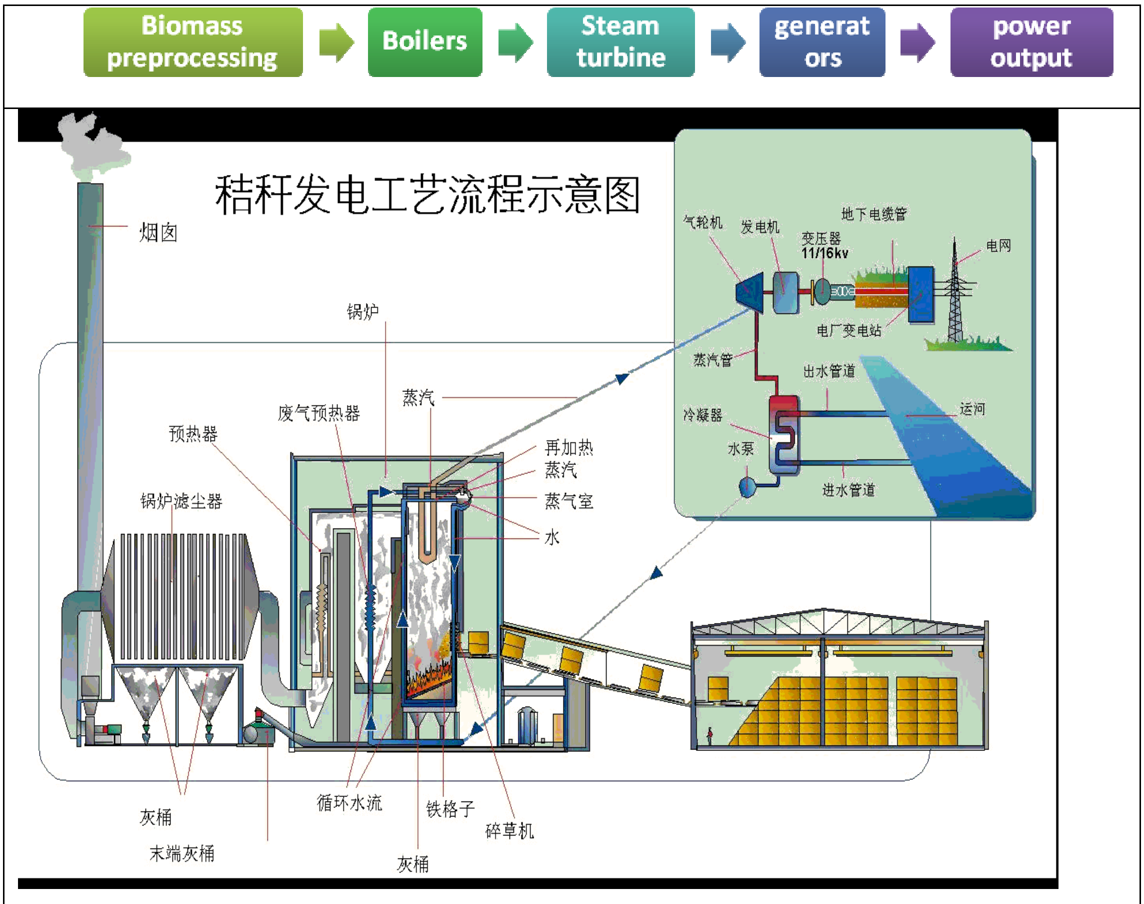

Figure 5-1 Technical process of power generation from direct firing crop straws

5.1.1.2 Scale of the industry

Biomass direct firing power generation technology is a new deployment in China. The first biomass cogeneration project was installed at Guoneng Shanxian biomass cogeneration completed in December 2006. The project is using Danish BWE technology manufactured in China. With total investment of 337 million Yuan, the installed capacity of the cogeneration project is 25MW.

By the end of 2007, a total number of 16 biomass direct firing projects have been completed with total installed capacity up to 367MW. Of the Guoneng biomass power co. ltd invested 10 projects, 250MW power capacity has been installed (8 projects of 25MW and 2 projects of 12MW). Other biomass generation projects include: Suqian biomass power plant invested by China Energy Conservation of 24MW, Jinzhou biomass power plant invested by Hebei Construction Investment of 24MW, the 24MW Jiangsu Huai'an biomass project invested by Jiangsu Guoxin, the Baoying biomass cogeneration project (15MW) and Lianyungang biomass plant (12MW) by HK GCL, and Henan Changge thermal power plant of 15MW.

29 biomass direct firing projects were completed in the year 2008 with total installed capacity of 618MW. These biomass projects were mostly developed in China's Shandong, Jiangsu, Henan, and Hebei. Few projects were also developed in Dongbei, Xinjiang, Anhui, and Hubei provinces.

In developing biomass direct firing power generation projects, Guoneng (NBC) Biomass Co. is the leader company. The developed biomass cogeneration projects contributed 68% of the biomass power market in China before 2007. By the end of 2008, this situation changed. For example, by 2008, the company completed 6 new projects, each with installed capacity of 12MW and total capacity of 72MW, with accumulated capacity of 322MW. However, by the end of 2008, the nationally installed biomass direct firing capacity has reached to 618MW and Guoneng's market share reduced to 54%. Although still the largest investor in the China biomass power market, many new investor companies has entered to the sector.

Table 5-1 Completed biomass direct firing power generation projects in 2008

No.	Province	Projects	Completed by	Installed capacity (MW)
Projects developed by Guoneng Biomass				
1	Shandong	Guoneng Shanxian Biomass Power	2006	30
2	Shandong	Guoneng Gaotang Biomass Power	2007	30
3	Shandong	Guoneng Kenli Biomass Power	2007	30
4	Shandong	Guoneng Juye Biomass Power	2008	12
5	Henan	Guoneng Junxian Biomass Power	2007	30
6	Henan	Guoneng Luyi Biomass Power	2007	30
7	Henan	Guoneng Fugou Biomass Power	2008	12
8	Hebei	Guoneng Weixian Biomass Power	2007	30
9	Hebei	Guoneng Cheng'an Biomass Power	2007	30
10	Xinjiang	Guoneng Awati Biomass Power	2008	12
11	Xinjiang	Guoneng Bachu Biomass Power	2008	12
12	Jiangsu	Guoneng Sheyang Biomass Power	2007	30
13	Jilin	Guoneng Liaoyuan Biomass Power	2007	30
14	Heilongjiang	Guoneng Wangkui Biomass Power	2007	30
15	Liaoneng	Guoneng Heishan Biomass Power	2008	12

16	Inner Mongolia	Guoneng Tongliao Biomass Power	2008	12
Projects using Wuxi Huaguang Industrial Boilers Products				
17	Hebei	Hebei Jinzhou Straw Cogeneration Plant	2007	24
18	Jiangsu	Jiangsu Huai'an Power Company	2008	24
19	Anhui	Huadian/Suzhou Biomass Power	2008	24
20	Anhui	Datang Anqing Biomass Power	2008	24
21	Hubei	Hubei Shenzhou New Energy Stock Co.	2008	12
22	Shanghai	GCL Shanghai/Lianyungang	2007	15
23	Hanghai	GCL Shanghai/Gaoying	2007	15
24	Shandong	Wuxi Guolian Group/Shandong Boxing Zhongdian	2008	12
25	Jiangsu	Jiangsu Guoxin Rudong Biomass Power	2008	12
Other Projects				
26	Jiangsu	Zhongjieneng Suqian Biomass Power	2007	24
27	Henan	Henan Changge Thermal Power	2007	12
28	Heilongjiang	Guodian Tangyuan Biomass Power	2008	24
29	Shandong	Guodian Wuli Biomass Power	2008	24
		Total		**618**

5.1.1.3 Analysis on technology obstacles

There are variety of agricultural straws from different crops and in diversified forms and contents. From content analysis, crop straws share characteristics of high moisture, high volatilization, low ash content, and low heat value. Therefore combustion of the biomass fuel can be different to coal. Especially, crop straws contain more alkali metal than coal so that its ash melting point can be lower and prone to result in ash and dreg accumulation during combustion. The alkali metal in ash and chlorine in smoke could corrupt inner surface of boilers. The content of alkali metal and chlorine is generally related with straw types, soil, and fertilizer used and planting habit, therefore different in areas. Among them yellow straws such as rice straw, wheat straw, corn stalks and rice husks contain higher alkali metal content. Hence it is risky to dreg and corruption, while alkali metal content can be much lower when using cotton stalks and wood chips and it is less likely to create dreg and corruption.

So far, manufacturing of dedicated straw boilers is just started. For example, Wuxi Guanghua Boiler Co. has successfully developed its straw boiler product with complete IPR. 20 systems of 75t mid temperature and mid pressure boilers have been installed so far with satisfactory operation. A sub high temperature and sub high pressure 110t/h capacity boiler has been installed at Jiangsu Rudong biomass power plant. Jinan Boiler Corporation by introducing Danish BWE technology of straw boilers and manufactured 130t/h capacity high temperature and high pressure straw boiler product and installed at over ten biomass power plant in China, though critical components need to import.

For direct combustion biomass power generation technology, current principal technical obstacle lies in boiler manufacturing. Internationally advanced direct firing boilers are mostly high temperature and high pressure, while domestic boiler products are mid temperature and mid pressure, which are 2-3% lower in heat efficiency and 10% or less generation efficiency. Research and development efforts are being made at universities and research institute together with manufacturing enterprises to develop preprocessing equipment for the direct firing boiler technologies. Moderate scale experiments and demonstrations have been conducted. In particular, sub-high temperature and sub-high pressure system developed by Wuxi Guanghua has been applied at demonstration project. It is expected that y 2010 the sub-high systems will be widely manufactured in China and by 2012 into demonstration, and product widely deployed by 2015.

To largely deploy biomass generation technology, biomass fuel collection, storage, transportation and other process techniques must be solved. So far, very limited mechanic operation has been used or at very preliminary degree though applied. This at certain degree restricted scale of biomass power development and industrial applications. Since there are many types of biomass fuel collection and storage equipment, locally suitable systems must be developed into series equipment products. It is hoped that by 2012, the supply chain system for biomass fuels will be basically developed and by 2015, series of biomass fuel processing products will be industrially manufactured.

5.1.2 Co-firing generation

5.1.2.1 Technical processes

Co-firing of coal and biomass fuel is operated in coal generation boilers. Firstly, biomass fuel is crashed and transported through a conveying system to the boiler. Another special furnace will be used to insert biomass fuel into the boilers and co-fire with coal. According to an experiment in other countries, when proportion of biomass fuel is no more than 20%, the high chlorine and high alkali biomass fuel will not result in corruption and accumulated ash that could corrupt the boiler systems.

Figure 5-2 A straw co-firing power generation plant

Upper: straw cabin

Right upper: straw conveyer

Right bottom: straw fuel into boiler (three pipes, for straw fuel in the middle and other two for coal)

Figure 5-3 major system for a straw and coal co-firing generation facility

5.1.2.2 Industry scale

Since there is lack of clear incentive policies towards biomass co-firing generation applications, the technology is merely at pilot and demonstration stage. For example, Shandong Shiliquan power plant tested the co-firing technology at its No.5 boiler. It is a 400 ton/h steam boiler driving a 140MW turbine system. 20% of biomass fuels were used with annual biomass fuel consumption of 250,000 tons. In 2006, a total of 55,000 tons of biomass fuels were co-fired.

Hong Kong GEL Group has installed 21 small thermal power plants in Jiangsu, Shandong, and Anhui provinces, of which 7 plants used biomass fuel, including crop straws, rice husks, tree barks, reed, and mud from municipal waste water processors.

5.1.2.3 Technical obstacles

Because of the biomass consumption metering and regulatory problems in China, suitable subsidies have not been worked out such that the technology is unable to largely implement due to lack of metering instrument and method. This has been limited the technology development. It is widely applied in the developed countries as a main stream technology. However, due to the undeveloped business trust monitoring system and no effective co-combustion metering technique, tariff policies and other incentives are unable to implement successfully.

R&D on biomass co-firing metering equipment has been conducted. It is expected that by 2010 the prototype system will be completed and two more years would be needed to evaluate, certificate, and prepare regulations. Therefore the co-firing biomass technology is expected to develop fast after 2013.

5.1.3 Power generation from biomass gasification

5.1.3.1 Technical processes

Power generation from biomass gasification uses gas fuel from biomass feedstock after purification. The fuel gas combust to drive engine or gas turbines to generate electricity. The gasification utilizes biomass fuel together with air and steam as media to generate fuel gas through thermal chemical process under high temperature condition. The fuel gas generated contains CO and H2, called biomass fuel gas. The critical gasification generation techniques are low coast fuel gas purification process and associated power generation system. Since the biomass fuel gas from gasification furnace contains certain impurities such as tar, ash, and minim alkali metal substances, while the tar will affect normal operation of the downstream process for power generation if not properly purified.

Two of the most popular technical processes of biomass gasification are circulated fluid bed and fixed bed techniques, depicted as in the following Figure 4-4 and Figure 4-5.

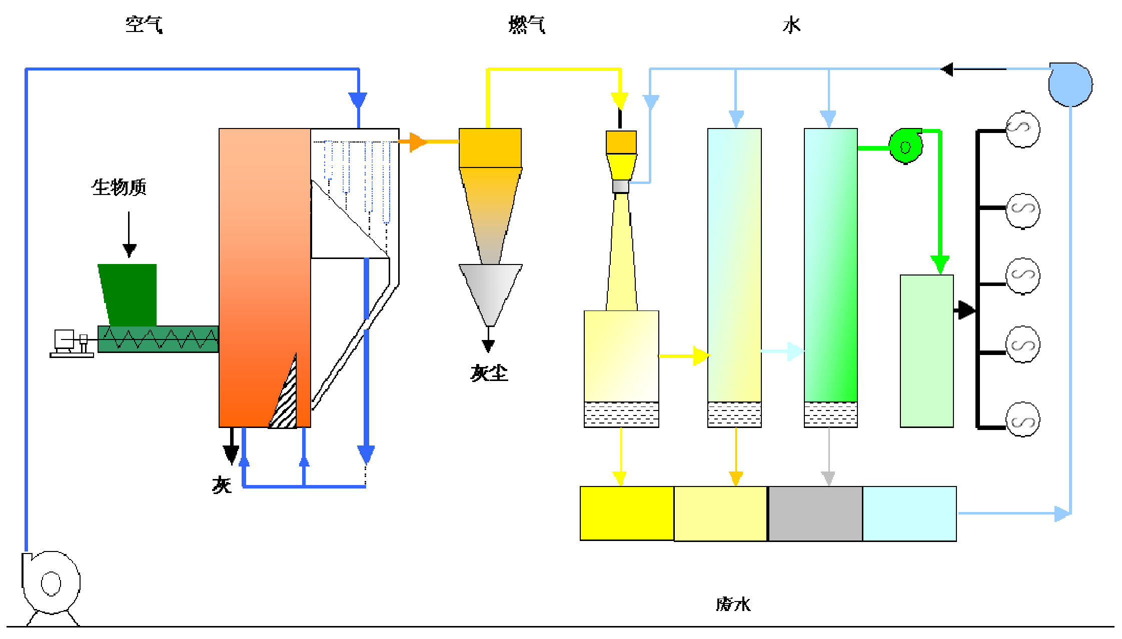

Figure 5-4 Flow chart of circulated fluid bed technical process

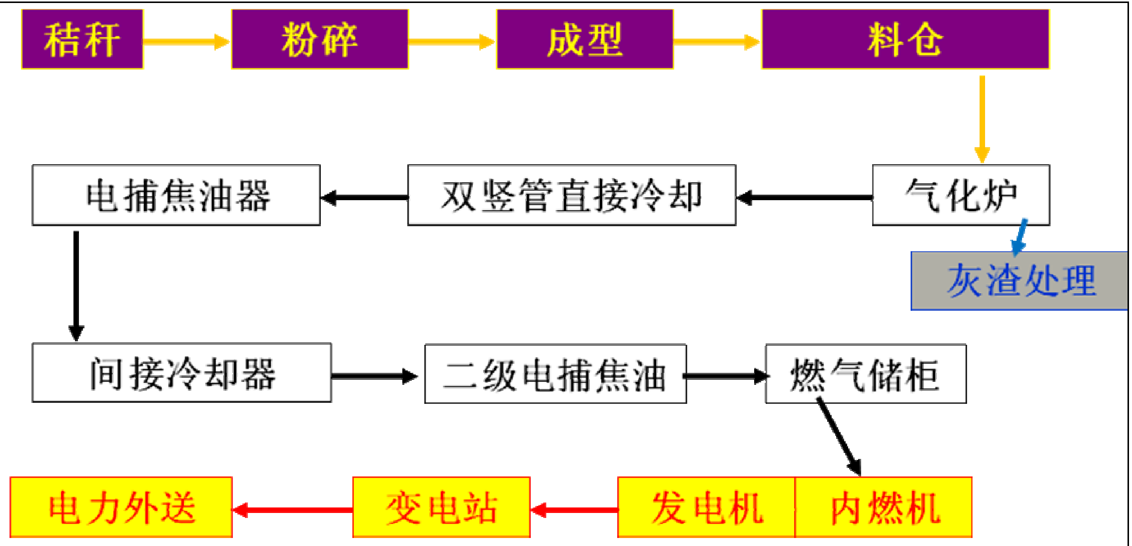

Figure 5-5 Technical process of the fixed bed gasification generation

5.1.3.2 The gasification generation industry

The currently applied biomass gasification generation technique is developed by Guangzhou Energy Institute of the Chinese Academy of Sciences. The circulated fluid bed gasification process generates gasified fuel gas to produce electricity after by water-washing purification technique to generate purified fuel gas. The purification process uses water shower method to eliminate tar and ash in the fuel gas. However this is still insufficient to solve the entire tar pollution problem. The generated waste water is further processed by using bacteria processing to crack down the tar into mud and the water is recycled to reuse. The current technical process is under process test and further improvement. Meanwhile, high temperature catalyzing cracking technique to eliminate tar is being under research development.

Since the first 1MW rice husks biomass gasification generation project established in Fujian province's Putian before 2000, several other demonstration projects are also installed, such as China's first wood chips gasification power generation project in a wood mill in Hainan, the demonstration of straw gasification power plant in Hebei's Handan, and recently completed 20 gasification generation systems by using crop residue biomass such as rice husks, rice straws, tec. More than 40 million Yuan have been invested for the projects with annual generation of 75 million kilowatts.

The 4MW rice husk biomass power plant has been developed at Jiangsu's Xinghua. It is a high-tech demonstration project supported by the China Ministry of Science and Technology. The project installed a circulating fluid bed furnace driving 1×400KW and 1×600KW fuel gas engine to generate electricity with CHP boilers and steam turbine systems. It was completed in October 2005 and has been operating for 1500 hours so far with the longest continuing operation for a month. Biomass fuels of the project mainly include rice husks and cotton stalks. As the high silicon content from rice husk ash and dregs, which can be reused with high value added applications, the CHP plant uses water-washing technique to eliminated tars and recycles the waste water. The project consumes 320,000 tons of (dry) biomass fuel each year to produce 28 million kWh electricity annually.

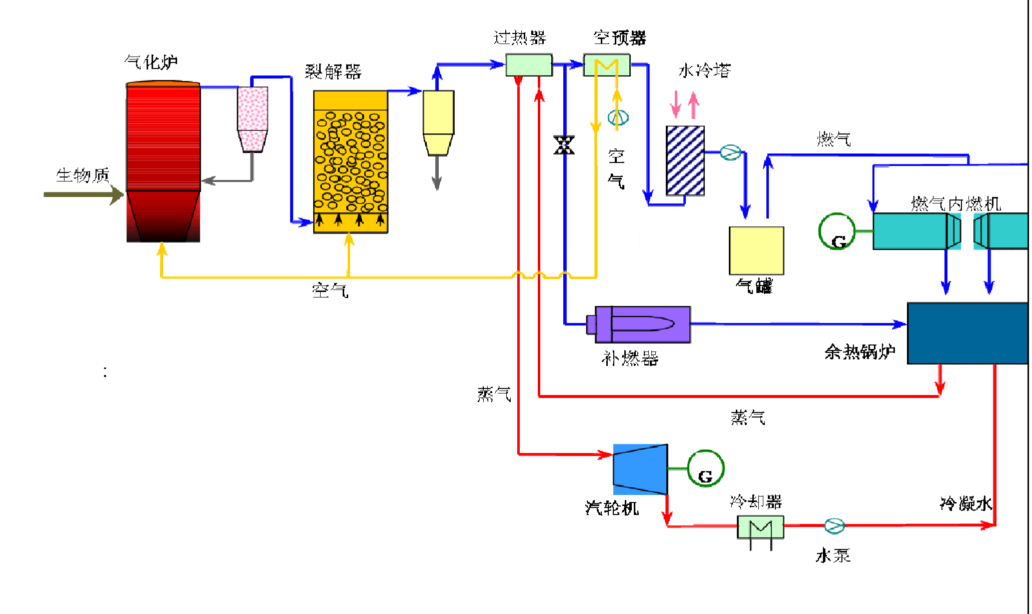

Figure 5-6 Flow chart of biomass circulating fluid bed technical process

Figure 5-7The Jiangsu Xinghua biomass circulating fluid bed power plant

Jiangsu's another biomass fixed bed gasification project is under construction, where China's first gasification furnace purification and power generation system has passed contiguous 60 hours operational test with satisfactory result. It is planned to operate online by March 2009.

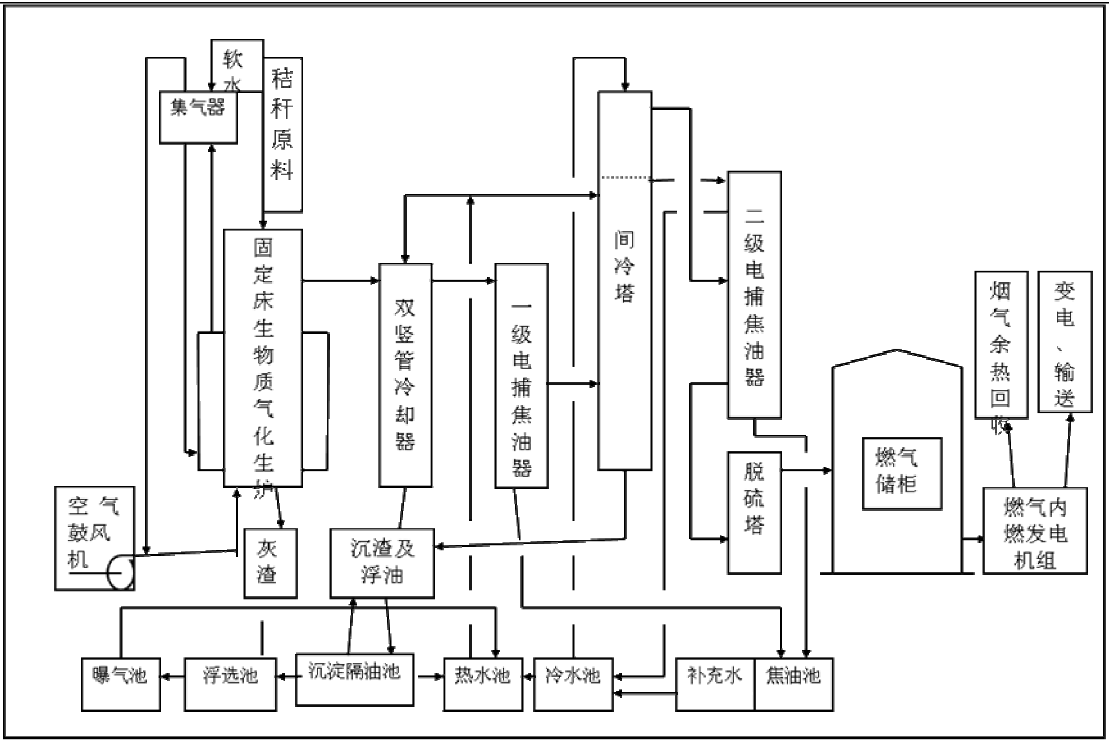

Figure 5-8 Technical process of fixed bed gasification generation

Figure 5-9 Jiangsu's Gaoyou biomass fixed bed gasification power plant

5.1.3.3 Technical obstacles

One of the major technical obstacles of biomass circulating fluid bed gasification is to eliminate tar in the fuel gas. Because of the high oxygen content in the fuel gas from circulating fluid bed gasification, electrical tar capture technique cannot be used to eliminate tar, which results in high tar in the fuel gas such that the tar remains inside engine cylinder and causes abnormal engine operation. According to current R&D activities, it is expected that by 2011, the fuel gas purification for biomass circulating fluid bed gasification process can be resolved and be widely applied by 2013.

Main problem for biomass fixed bed gasification technique lies in lack of systematic demonstration projects and short of operational data from industrial scale applications. Therefore, problems of whole equipment systems may not be fully revealed. Based on current demonstration project on biomass fixed bed gasification for electricity in Jiangsu, the demonstration system can be completed by 2010. And by 2013, industrial processes of biomass gasification, fuel gas purification, fuel gas for power generation, and fuel gas supply systems can be widely deployed.

Both of the two biomass gasification technologies must use engine to generate electricity. However, there exist certain technical obstacles in terms of engine driven turbine systems using low heat value fuel gas. First of all, capacity of single system is too small. Currently largest capacity of low heat value engine turbine system can only be 500kW. Secondly, generator system efficiency is very low, only 32-34%, or 2-3 percent lower than the same kind of foreign products. It is assumed according to progress in engine power system R&D conducted in domestic manufacturers that by 2011, the efficiency of current 500kW made-in-China system can catch up to international advancement and by 2012, 1MW or above capacity system can be developed and deployed before 2014.

5.1.4 Biomass pellet fuels

5.1.4.1 Technical processes

Biomass pellet fuel process utilizes mechanical force to compress biomass materials (mainly agricultural and forestry residues, such as crop straws and wood chips) to increase the biomass bulk density and obtain the same combustion characteristics of various biomass raw materials. The pellet fuel technique helps to make loose biomass straws to be easy to transport and storage, as well as improve their fuel efficiency.

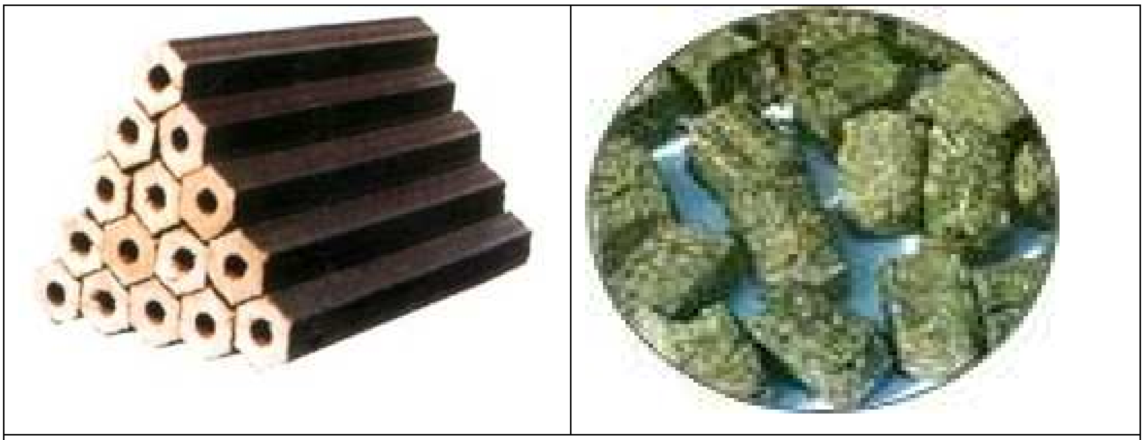

Figure 5-10 Biomass pellet fuels

5.1.4.2 The biomass pellet fuel industry

R&D and applications of biomass pellet fuels develop fast over the past three years since 2008 when only a total of 1.2 million tons were produced. The pellet fuels can be sold to the following major users:

- Rural households under the government subsidized fuel programs. Some local government (such as Beijing Municipal Government) promotes biomass pellet fuel in rural areas. Under these programs, government subsidizes farmer families to buy biomass pellet fuel stoves and rural households are encouraged to buy the pellets. Annual demand for this kind of uses will be about 500,000 tons.
- Pellet fuels for small biomass boilers. Some companies have develop special biomass fuel boilers while producing the biomass pellet fuel equipment, mainly steam boilers and hot water boilers of capacity no more than 4t/h, which can be used by hotels, restaurants, and public baths. Due to increasingly strict environment protection regulations, fossil fuel boilers are restricted, including those polluting coal fueled boilers, high cost oil fueled boilers, and gas boilers requiring natural gas pipelines. Biomass pellet fuel boilers therefore become a cost efficient solution because of its low emission and support by national renewable energy policies. It is estimated that annual pellet fuel demand for the boilers is 20-25 tons, accounting for nearly 25% of the total biomass pellet fuel sales.
- As materials for biomass charcoal. Machine production of biomass charcoal is through carbonization of pellet fuel, per ton of machine-made charcoal from about 3 tons of biomass pellets. Along with improved life standard, there is an increasingly more consumption the biomass charcoal for barbecue and hot pot restaurants. Meanwhile, there is also market in Korea and Japan. More than 100,000 tons of machine-made charcoal products are exported. About 600-700 thousand tons can be demanded in the market, which account for nearly 70% of the biomass pellet fuel sales each year.

5.1.4.3 Technical obstacles

There is no impassable technical obstacle for biomass pellet fuel techniques. But production projects need to be regulated. Although many biomass pellet producers exist in China, only few successful projects can be selected for demonstration of the technology.

It is expected that between 2010 and 2011, several national level demonstration projects will be developed at different areas to provide models of biomass pellet fuel production and industrial development.

Figure 5-11 Production equipment for biomass pellet fuels

5.1.5 Biomass carbonization

5.1.5.1 Technical process

生物质干馏技术是将生物质原料在隔绝空气的环境中加热，使原料中富含的挥发份析出，成为生物质碳粉、木焦油、木醋液和燃气。干馏分为内热式和外热式两种，外热式是原料置于炭化室中加热，炭化室中没有氧化剂 (空气) 通入，挥发份热分解的热量完全来自原料之外。内热式则是将氧化剂 (空气) 通入炭化室，将生物质原料燃烧一部分，燃烧产生的热量供给挥发份分解。两种方式同样可以得到以上四种产品，但是内热式干馏的燃气热值将会下降。下图为内热式干馏的工艺流程示意图。

The biomass carbonization technology is to heat up biomass feedstock in the air isolated environment so that volatilization content in the biomass materials can be separated to produce biomass carbon powders, wood tar, wood vinegar, and fuel gas. The carbonization process can be of inner heating and external heating. The external heating process is to heat up materials inside the carbonization chamber without air. The heat required for volatilization degradation is completely from other than biomass materials, while the inner heating process will inject oxygen (air) into the carbonization chamber to combust part of biomass materials. The heat from the combustion will utilized for the degrading process. Both the two processes can result the above mentioned four products, except that carbonization fuel gas from inner process can have lower heat value. The following figure depicts the technical process of inner heating carbonization.

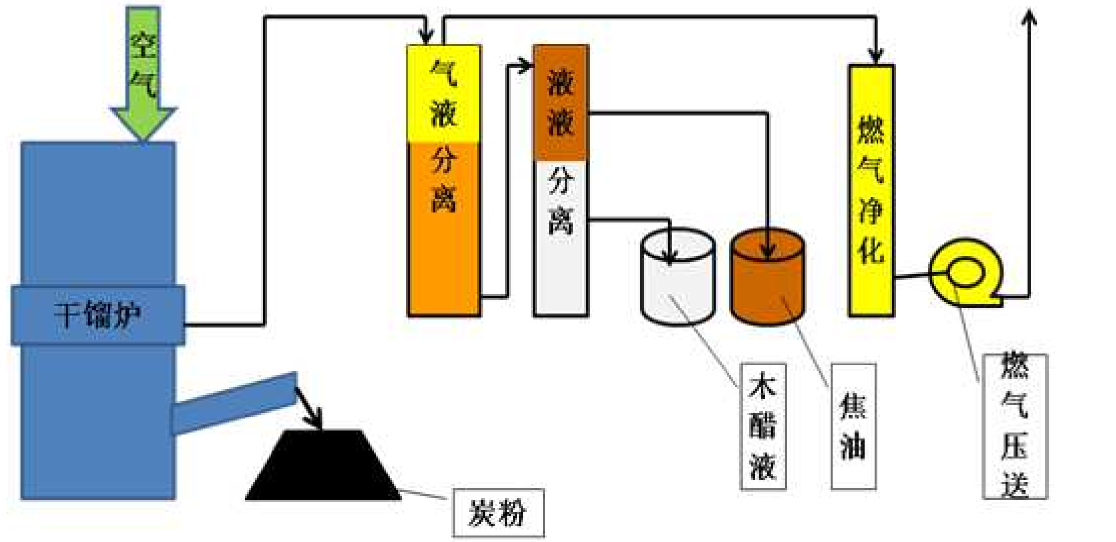

Figure 5-12 Flow chart of the inner heating biomass carbonization process

5.1.5.2 Industrial development

The industry of biomass carbonization technology is just started in China. For instance, Liaoning energy institute developed a small external heating carbonization furnace system only for small scale production. Henan Sanli Company has developed a continuous biomass carbonization technique at 14t/day production capacity of single unit. Now the system can be batch produced. There have been 7 biomass carbonization system manufacturers in China, 4 of them also produce integrated biomass fuel gas generation system.

The biomass carbonization technology decomposes biomass materials into fuel gas, tar, wood vinegar, and carbon powder. The produced fuel gas can be used after cleaning for engine generators. Carbon powders, wood vinegar, and tar can be supplied as chemical raw materials as well. Therefore the technology can largely increase biomass value and improve cost effectiveness of carbonization enterprises.

5.1.5.3 Technical obstacles

One of the most urgent technical problems is to develop continuous carbonization furnace with industrial scale and technical standards. Current systems have serious problems in productivity, conversion efficiency, and appearance design. There is a large room to improve. In addition, comprehensive utilization of the technical process output, such as fuel gas, wood tar, wood vinegar, and biomass charcoal, can be important aspect of the carbonization technology R&D. The comprehensive application of the process output can greatly improve project cost effectiveness and environmental benefits. Both biomass carbonization technical process and manufacturing should be focused.

By 2012, the continuous type biomass carbonization process and its byproducts are expected to be developed and manufactured. By 2014, commercial system demonstration and industrial applications can be well developed in China.

5.1.6 Assessment of technology development trends

Based upon the above mentioned assessment methods, this report will analyze the status and development trends for various crop residues for energy technologies. Based on the analysis, these technologies are graded to obtain their development trend assessment scores as for 2008, 2015, and 2020 respectively.

Table 5-2 Assessment result for agricultural and forestry residues for energy technologies, status and development trends

Year	Technologies	Direct firing generation	Gasification power	Co-firing generation	Pellet fuels	carbonization
2008	Technology maturity	24	16	0	24	16
	Technical obstacle impact	25	15	0	15	15
	IPR ownership	10	20	10	20	20
	Total scores	59	51	10	59	51
2015	Technology maturity	32	32	32	32	32
	Technical obstacle impact	40	25	40	25	25
	IPR ownership	20	20	20	20	20
	Total scores	92	77	92	77	77
2020	Technology maturity	40	40	40	40	40
	Technical obstacle impact	40	40	40	40	40
	IPR ownership	20	20	20	20	20
	Total scores	100	100	100	100	100

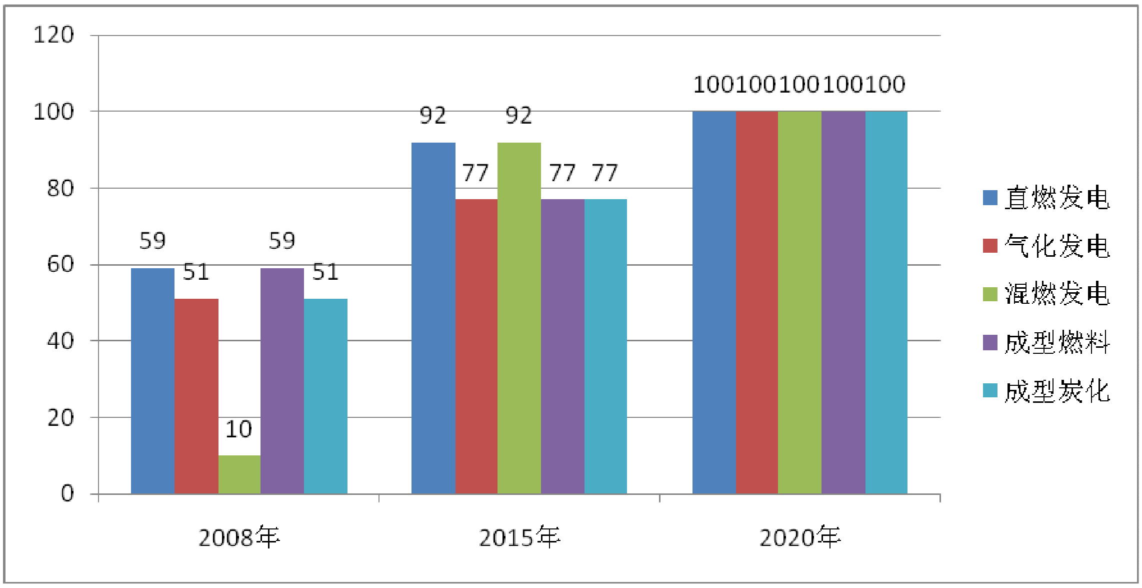

Figure 5-13 Assessment results for agricultural and forestry residues for energy technology, status and future trends

We can see from the above figure that in 2008, technical obstacles of biomass co-combustion generation technology had the largest impact on industrial development, while direct firing and pellet fuel technologies had the mildest effect. This follows the practical situation of current industrial development. By the end of 2008, the installed capacity of biomass direct firing generation had been 600MW and nearly 1 million tons of biomass pellet fuels had been produced. In contrast, co-firing generation technology failed progress but market even dwindled. One of the major technical obstacles lied in lack of successful metering equipment such that tariff incentive policies were unable to implement for co-firing power generation technology. For example, two of CHP plants in Jiangsu used to apply the co-firing technology to generation electricity. Because of no supporting tariff incentives, the incremental cost for biomass fuels was unable to cover. Currently they stopped the co-firing process and the installed biomass co-firing boilers are changed to direct-firing systems.

We can also see that from the figure, by 2015 all the biomass technologies will become mature and significant technical obstacles will be basically resolved by focusing on improving efficiency and reducing biomass power cost. By 2020, these technologies are expected to be developed to a complete technology system and be deployed widely in China.

5.2 Energy from livestock waste

5.2.1 The process

Large biogas system refers to single digester of $50m^3$ or larger, or total biogas digesters of 100m3 or larger with daily biogas production capacity over 50m3, installed with raw material preprocessing and with comprehensive processing capacity for biogas, biogas residues, and biogas liquids.

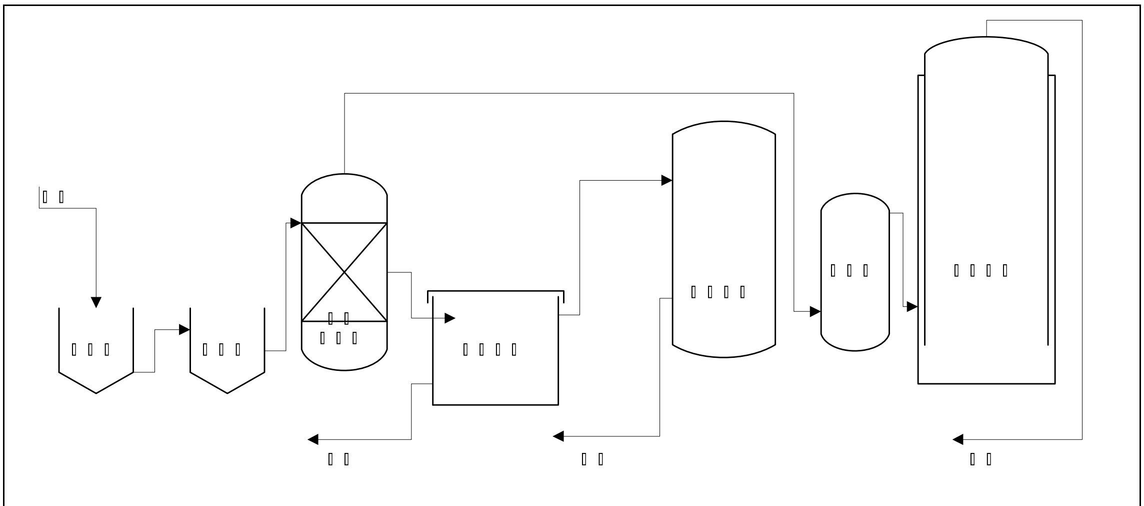

Figure 5-14 Biogas technical process

Large biogas systems can generally be divided into two purposes: for energy and for environmental protection.

5.2.2 The industry

Biogas from biomass materials for power generation has been fast developed in China since 2005. By the end of 2008, a total of 173MW biogas power capacity has been installed, including 79MW or 45.5% capacity from light industries (alcohol and brewery, starch, lemon acid, and paper making), 45MW or 25.3% from municipal waste (landfill gas, sewage biogas), and another 31MW or 17.8% capacity from livestock farm biogas systems.

So far, only three grid-connected livestock farm biogas projects have been developed at Mengniu with capacity of 1MW, Beijing Deqingyuan chicken farm with 2MW, and Shandong Minhe Group with installed capacity of 3MW. Among the most common challenges for biogas power projects include small size, difficult to connect onto power network, and lack of incentive policies.

5.2.3 Technical obstacles

Technical obstacles for biogas power generation can be identified into two categories: biogas production and efficient large power engine generator system. Biogas production process in China is less developed compared with the developed countries in terms of technical process, bacterium making, automatic control system, and generator systems. The less developed biogas power technology results in unsatisfactory biogas yield, small unit digester yield, and power generation efficiency. According to current R&D activities, it is expected to breakthrough in bacterium making, installation, and manufacturing by 2012 and industrial deployment of the technologies by 2015.

The largest capacity of made-in-China biogas generation system is 500kW. Power generation efficiency of the system can be 10-15% lower than the international market products. It is estimated that by 2015 the efficiency of current 500kW power generation system can be improved to catch up the international advanced standard. 1MW unit is expected to be developed by 2012 in China and deployed in the market by 2015.

5.2.4 Assessment of technology development potentials

Based upon the above mentioned assessment methods, this report will analyze the status and development trends for various livestock farm biogas power generation system, off grid and in grid technologies. Based on the analysis, these technologies are graded to obtain their development trend assessment scores as for 2008, 2015, and 2020 respectively.

Table 5-3 Assessment of status and development trend of livestock farm biogas power generation technologies

Year	Technologies	Standalone biogas power systems	Grid connected biogas power systems
2008	Technology maturity	16	16
	Technical obstacle impact	25	25
	IPR ownership	10	20
	Total scores	51	60
2015	Technology maturity	32	32
	Technical obstacle impact	40	25
	IPR ownership	20	20
	Total scores	92	77
2020	Technology maturity	40	40
	Technical obstacle impact	40	40
	IPR ownership	20	20
	Total scores	100	100

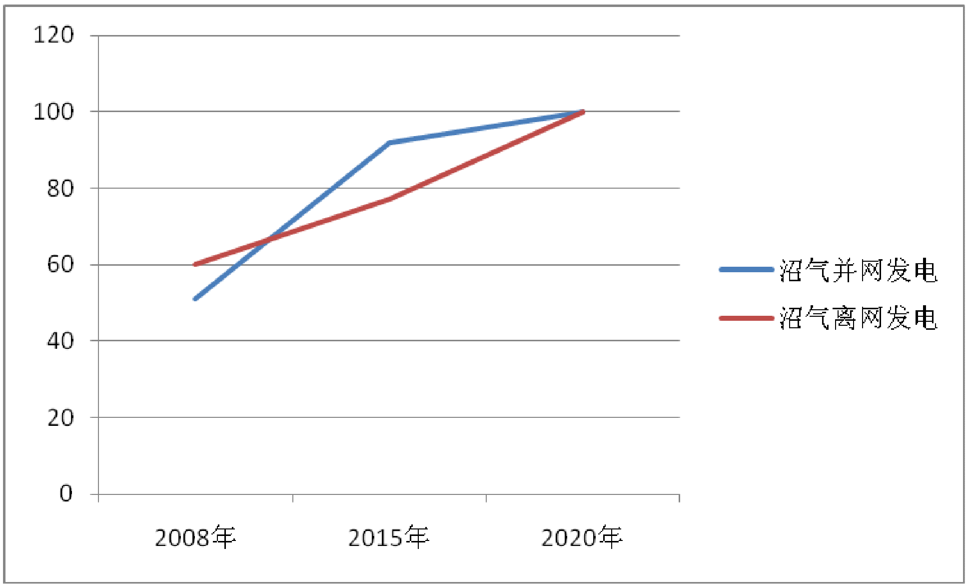

Figure 5-15 Livestock farm biogas for energy technologies, status and development trends assessment

According the above figure 5-15, the assessment score for in-grid biogas power generation technology is lower than that for off-grid systems, because of the fact that there are only three on-line livestock farm biogas power systems so far in China. Besides manufacturing problems, the most significant obstacle is lack of practical technical codes for small online biogas systems. By 2015, the technical obstacles for online biogas power generation will be solved. Because of the complexity of off-grid biogas generation system in power output and biogas uses, more technical issues need to be solved. Therefore the score for off-grid systems is lower than online system. By 2020, scores for both of the technologies will converge to the level of technology maturity.

5.3 Power generation from municipal solid waste

5.3.1 Power from garbage incineration

5.3.1.1 The technical process

Municipal solid waste incineration is to use high temperature thermal chemical process to treat city garbage. It is to combust the solid waste as fuel in the furnace at temperature 800-1000C. The combustible part is conversed into high temperature fuel gas and few stable solid dregs by reacting with oxygen. When the solid waste contains sufficient heat value, it can maintain combustion itself without extra fuel. The high temperature fuel gas resulted during the incineration will be used to produce high temperature and high pressure steam through the inner heat conversion system to drive steam engine to generate electricity. The stable dreg produced during the incineration can be directly land filled. Bacterium, odor substances and virus contained in the solid waste can be completely destroyed through incineration or degraded. After processing, harmful gas will be discharged into air. Therefore, municipal solid waste incineration is a sanitation process of city garbage and an effective method to process the waste into energy.

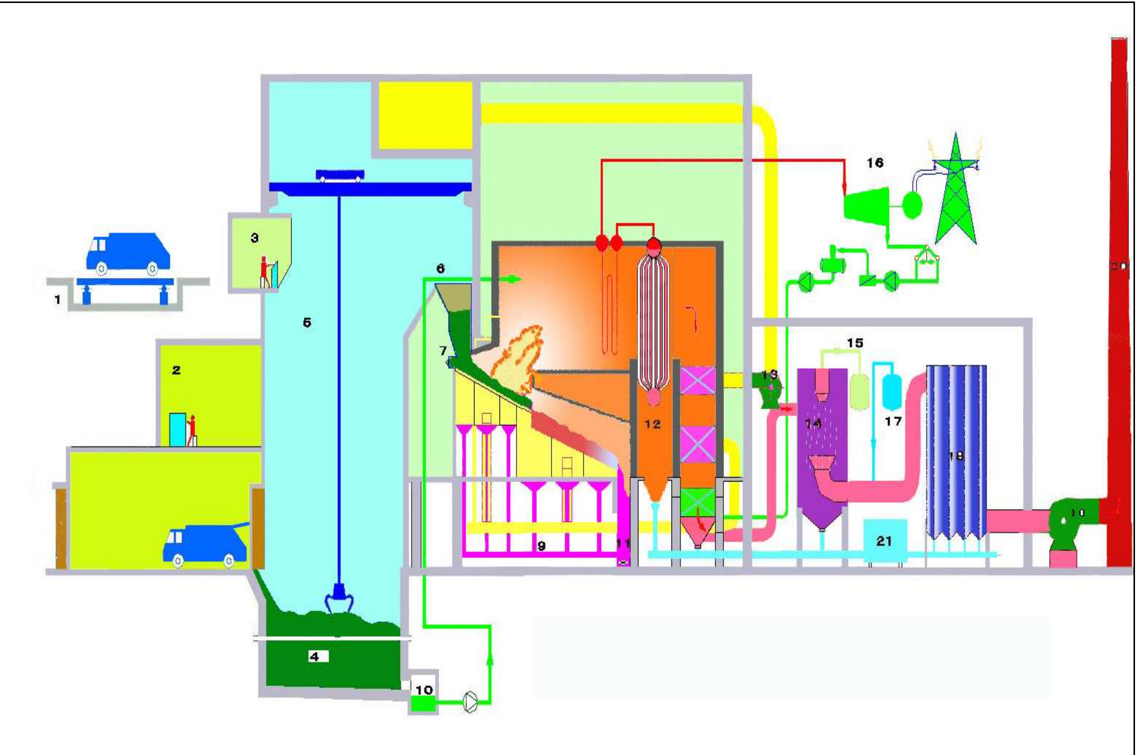

Figure 5-16 Technical process chart of power generation from garbage incineration

5.3.1.2 The industry development

According to the 2009 China City Construction Statistics Year Book, by the end of 2008, municipal solid waste from China's 655 cities will be 154 million tons in total with 100 million tons or 66.8% processed. There are more than 500 garbage yards have been set up including 407 landfill sites in China. There are also 14 dunghill sites and 78 incineration facilities are established, besides other comprehensive treatment capacities in China.

Table 5-4 Established solid waste incineration facilities in 2008

Technology	Number of Facilities	Installed capacity (MW)
Grate incinerator	36	490
Fluid bed	37	530
Others	5	39
Total	78	1059

5.3.1.3 Technical obstacles

Grate type incinerator is popular in the international market. In order for high temperature and effective decomposition of poisoning substance dioxin, certain amount of fuel oil and fuel gas must be injected into the furnace. About half of incinerators in China use this technique. This type of incinerators can effectively decompose dioxin due to even in-furnace temperature and high temperature at the furnace exit. Cost of the grate type incinerators can be 20-30% lower. The technique is developed by Zhejiang University and Tsinghua University, which is suitable for

China, therefore is widely accepted. However, because the process needs to add certain proportion of coal, effective metering and monitoring can be a problem, similar to other co-firing techniques. There is no tariff subsidy for the solid waste incineration power plant using the technique in China.

Lack of equal incentive for renewable technologies is not a technical obstacle, but policy problem. Currently Chinese administration is working to solve this problem and find solutions. It is expected that by 2010 some relevant incentive regulations can be available, that will help to promote diversified solid waste treatment techniques.

5.3.2 Power generation from landfill gas

5.3.2.1 Technical process

A landfill gas power generation system is composed of gas collector system, cleaning and pressure system, gas engine and grid integration system. After collection, the landfill gas is separated and filtered to remove coarse particles. It is sent to an engine to generate electricity. Waste gas can be emitted through pipes into the air.

To effectively collect landfill gas, collection method must be improved through an active collector system instead of just emission collectors. After a thorough investigation at a landfill field, vertical or horizontal landfill gas collector pipelines should be well planned and installed. The landfill gas can be collected by the pipelines to treatment facilities. Meanwhile, to collect maximum of landfill gas, anti-seeping, covering, and drainage measures must be taken to facilitate effective landfill site management.

Figure 5-17 A landfill site in China

5.3.2.2 The industry development

In recent years, landfill gas collection and treatment has gained greater attention in China. Some landfill field adopted integrated active landfill gas collection and combustion system to generate electricity by using the gas as clean fuel. To name a few, Hangzhou Tianziling, Wuxi Taohuashan, Nanjing Shuige, and Guangzhou Datianshan landfill sites are utilizing landfill gas to produce in-grid electricity. Anshan Yangeryu landfill field is using the landfill gas for vehicles after cleaning treatment.

5.3.2.3 Technical obstacles

Two major technical obstacles of landfill gas for electricity are identified. One of them is lack of highly efficient and powerful biogas generation system, which is already discussed previously in above paragraphs.

Another major technical obstacle is to find solution of landfill seeping liquid treatment. The seeping liquid contains significant amount of harmful substances and causes pollution. Conventional waste water treatment techniques are unable to process the landfill liquid effectively, which discharges the liquid into the city sewage system. The technical method is also costly and gives extra burden for existing sewage treatment systems. Novel landfill seeping liquid processing techniques are under research and development in Shanghai and Shijiazhuang. Some positive results have been achieved. It is expected that by 2011 technical breakthrough can be accomplished and deployed by 2014.

5.3.3 Assessment of technological development trend

Based upon the above mentioned assessment methods, this report will analyze the status and development trends for various landfill gas generation technologies and systems. Based on the analysis, these technologies are graded to obtain their development trend assessment scores as for 2008, 2015, and 2020 respectively.

Table 5-5 Landfill gas power generation technologies, status and development trend assessment

Year	Technologies	Waste combustion for electricity	Landfill gas power generation
2008	Technology maturity	32	24
	Technical obstacle impact	25	15
	IPR ownership	10	10
	Total scores	67	49
2015	Technology maturity	32	32
	Technical obstacle impact	25	40
	IPR ownership	20	20
	Total scores	77	92
2020	Technology maturity	40	40
	Technical obstacle impact	40	40
	IPR ownership	20	20
	Total scores	100	100

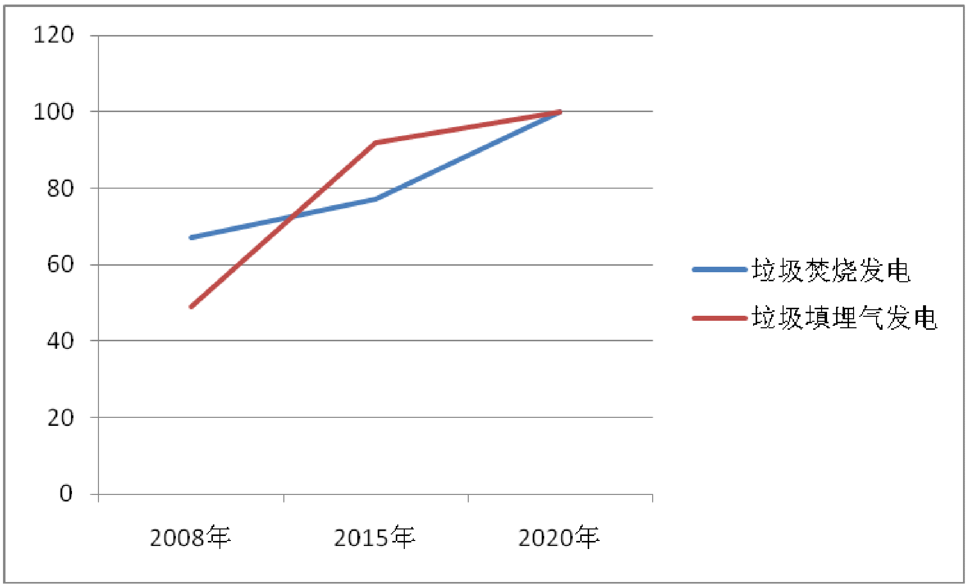

Figure 5-18 Assessment result of landfill gas power generation technology, current status and future development

According the above figure, the assessment score for in-grid landfill gas power generation technology is lower than that for solid waste incineration generation systems, because of the fact that there are lacks of small biogas power generation system, equipment, and standards. By 2015, the technical obstacles for online landfill gas power generation will be mature than incineration technology. By 2020, scores for both of the technologies will converge to the level of technology maturity.

5.4 Liquid biofuel technologies

Liquid biofuels can utilize diversified biomass feedstock, have various technical processes, and produce different biofuel products. According to available biofuel production techniques, liquid biofuels can be produced from cellulose biomass, starch, sugar, animal grease, and micro-organic oil, etc. In the near future, major biofuel products can include fuel ethanol, biodiesel, biological oil (biomass thermal decomposed oil), catalyzed and hydrogen added biodiesel, Fischer-Tropsch synthesis biodiesel, biological methane, biological methane, biological DME, and biological hydrogen, etc. See the following figure.

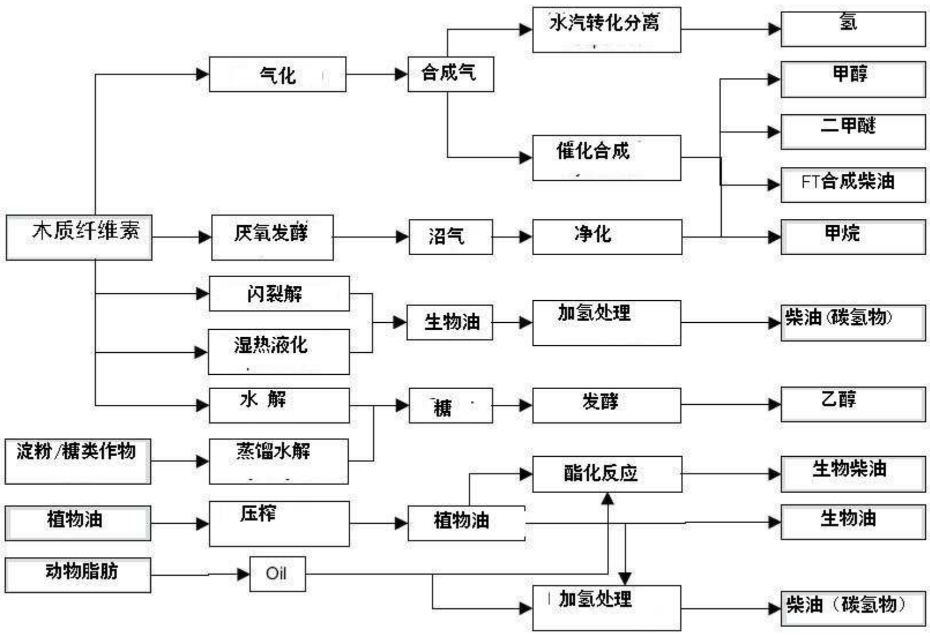

Figure 5-19 Technical process of biofuels from biomass feed stocks

(Courtesy: IPCC Third Working Group, 2007)

Currently, fuel ethanol from grain and sugar and biodiesel from oil feedstock can be competitive in the market, while other biofuel techniques are still immature due to the higher cost compared with fossil gasoline and diesel products. They will become competitive in the long-term perspective. Among them, fuel ethanol from cellulose materials gains highly attention and are expected to be the next generation of biofuel technology.

5.4.1 Fuel ethanol

5.4.1.1 Technical process

Biofuel ethanol is widely produced from corn, sugarcane, edible grain (starch), and sugar feedstock in the international market. In China, cassava, sweet sorghum stalks, crop straws, and other non-grain biomass are also used to produce fuel ethanol in China. Popular technical process for fuel ethanol is fermentation, while synthesis technique has not been widely applied in fuel ethanol production.

Fuel ethanol from starch feedstock becomes the most popular ethanol product, which can be produced by three technical sub processes: macromolecules are hydrolyzed into monosaccharide molecules such as glucose or xylose; the monosaccharide molecule is sugar degraded into 2-molecule pyruvate; and the pyruvate acid is deoxidized to 2-molecule ethanol and CO2 released. Figure 5-20 is a typical technical process of ethanol from corn or wheat starch materials. Fuel ethanol from sugar cane does not need boiling and sugar degrade process.

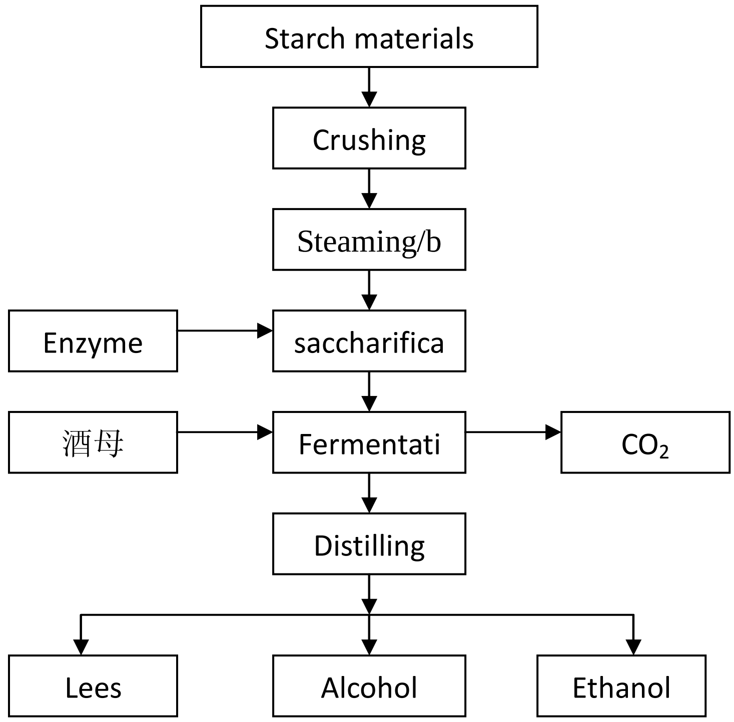

Figure 5-20 Technical process of ethanol from corn or wheat

Fuel ethanol from sweet sorghum is to use sugar juice contained in the sweet sorghum stalk. After pressing the stalk, sugar content such as glucose and fructose will be fermented to produce ethanol. This technique is easy to operate. The technical process is depicted in the figure 5-21.

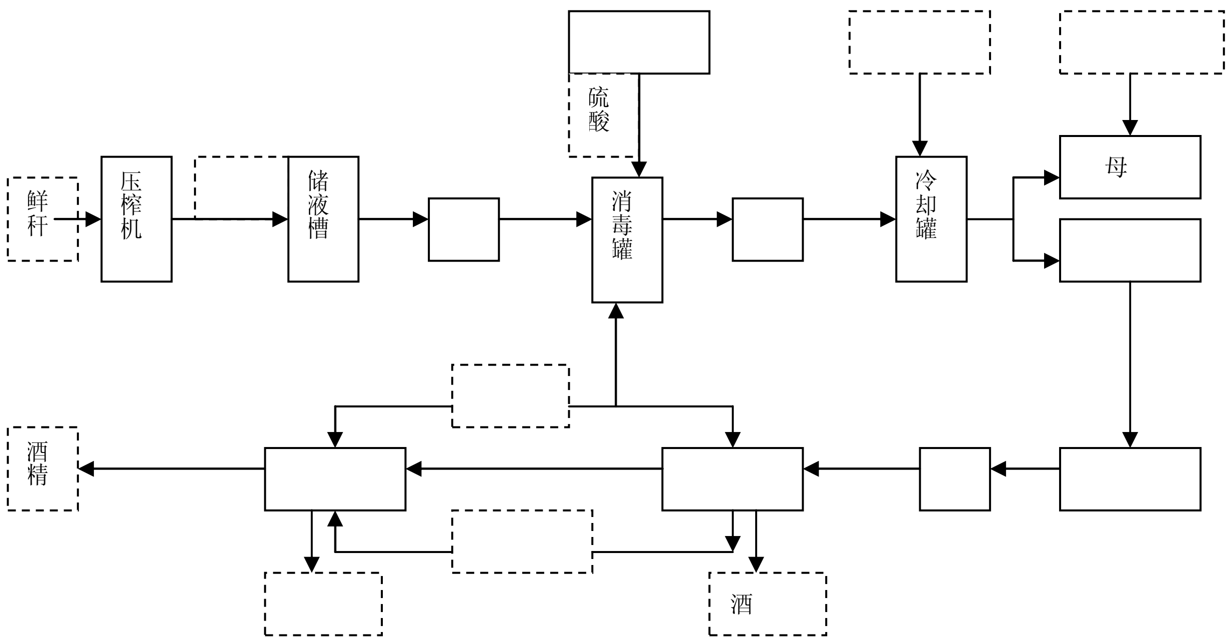

Figure 5-21 Technical process to produce fuel ethanol from sweet sorghum

Fuel ethanol from cellulose is considered the most promising technology. Advantages of the technique will include abundant feedstock resources, with great potential of economy and environmental benefits. The technical process of ethanol from cellulose is to hydrolyze the cellulose into monosaccharide and then converse into ethanol by fermentation. A general process is depicted in the following figure 5-11. Critical techniques of the process are material preprocessing, hydrolyzing to obtain sugar contents, and fermentation.

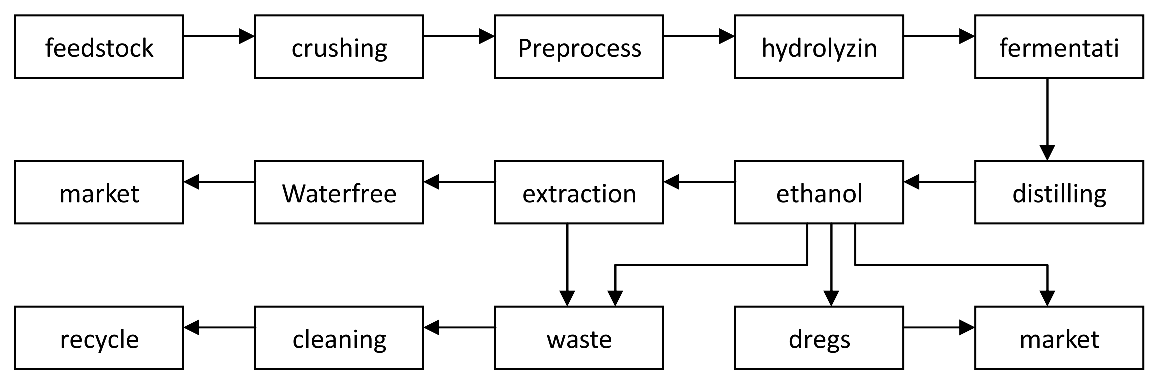

Figure 5-22 Technical process of fuel ethanol from cellulose

The following table gives a comparison of fuel ethanol process from different feedstocks.

Table 5-6 Comparison of ethanol technical processes from different raw materials

Process	Starch	Sugars	Cellulose
preprocessing	Crushing, boiling, pasting	Crushing, mixing	Crushing, physical or chemical processing
hydrolyzation	Acid or catalyze to get sugar content, single output, no fermentation restraints	No hydrolyzing process, no fermentation restraints	Difficult to hydrolyze, multiple output, with fermentation restraints
fermentation	Starch enzyme, yeast fermentation into hextose	Ethanol resistant yeast fermentation into hextose	Special yeast fermentation into pentose or hextose
extraction	Distill, rectify, and purify	Distill, rectify, and purify	Distill, rectify, and purify
By products	Feedstuff, biogas, CO2	Fertilizer, biogas, CO2	Cellulose (fuel), CO2

5.4.1.2 The industrial development

Since 2010, China has invested nearly 5 billion Yuan to establish four capacities of fuel ethanol from aged grains, i.e. Jilin Fuel Ethanol Co. Ltd, Henan Tianguan Group, Anhui Fengyuan Biochemicals, and Heilongjiang Huarun Alcohol Company. Except Tianguan Group uses wheat as feedstock, other three companies consume corn as raw materials. Total installed production capacity of the four facilities is 1.02 million tons and expanded to the current 1.32 million tons (see table 5-7). In 2009, China produced 1.72 million tons of fuel ethanol to be mixed into 17.2 million tons of E-gas using in eleven provinces. This has substituted vehicle gas about 1.4 million tons, which made China the third largest fuel ethanol producer and user country after Brazil and the United States.

Table 5-7 Fuel ethanols from aged grain producers in China

Producer	**Completed**	**Feedstock**	**Annual production (10^4t)**	**Sales market**
Jilin fuel ethanol Co. Ltd	2003	Corn	30	Jilin (10), Liaoning (20)
Henan Tianguan Group	2001	Wheat	30	Henan (13), and other 9 cities in Hubei and 4 cities Hebei
Anhui Fengyuan Biochemicals	2005	Corn, potatoes	32	Anhui (10), and other 7 cities in Shandong and 2 cities in Hebei and Jiangsu
Heilongjiang Huarun Alcohols		Corn	10	Heilongjiang

Ethanol from cassava can be a mature technology and many on demonstration. Cassava plantation and ethanol production from cassava become priority of pilot projects since the technology is mature in the market. In 2007, COFCO biomass energy established a 200,000t fuel ethanol from cassava project. So far, another similar project is also planned in Guangdong and Hainan provinces. Cassava is widely planted in China. In 2006, the NDRC conducted a special investigation to make biofuel ethanol plans. According to the investigation, five Chinese provinces including Hubei, Hebei, Jiangsu, Jiangxi, and Chongqing have development potential for cassava plantation and sufficient marginal land resources. Therefore, fuel ethanol production in these provinces has advantages. So far, projects of ethanol from cassava are under preparation in the above provinces.

Ethanol from sweet sorghum is under research and development, and small scale demonstration. For fuel ethanol from non-grain feedstock, Beijing Taitiandi energy technology development company and Heilongjiang Huanchuan Siyi ethanol Co. ltd conducted the “Ethanol from Sweet Sorghum Stalks” demonstration project under the support of China “863” national high-tech program. Since 2003, sweet sorghum plantation and small scale ethanol production experiment has been carried out. By 2005, their production capacity has been 5000 tons and produced 20,000 tons of paper slurry. In addition, some private companies are actively involved in the program by planting thousands MU sweet sorghum and established thousands tons ethanol production capacities. China Ocean Oil, Jilin Fuel Ethanol, and other state owned large companies are also planted sweet sorghum for producing fuel ethanol. International oil giants such as BP and Shell carried out experiments in China for fuel ethanol from sweet sorghum technology.

Ethanol from cellulose technology is under R&D. So far, cellulose ethanol technologies become priority in the world market. Several demonstrations have been developed by EU and the US. Sub industrial capacities and commercial demonstration projects have been planned. For example, Canadian Logen company established the world first large cellulose ethanol experiment facility in Ottawa with planned capacity of 3 million gallon per year, which utilizes wheat straw as feedstock. East China University of Science and Technology conducted cellulose waste for ethanol project under the national high-tech program. By using biological conversion and thermal conversion technologies, the experiment facility can produce 600 tons fuel ethanol a year. Henan Tianguan and CAS process institute also established 3000t/y capacities in Henan and Shandong respectively. Experiments are under way. Anhui Fengyuan Group worked with Chinese universities to develop preprocessing, enzyme technologies and achieved initial progress. A 1000t straw for ethanol project has been under middle experiment. In 2006, COFCO established a joint venture facility with Novozymes to produce fuel ethanol from corn stalks. Technology development in preprocessing, cellulose conversion, and enzyme production has achieved practical progress. In November of the same year, the project successfully produced 1 ton fuel ethanol from 7 tons of corn stalks. As high as 92% cellulose is successfully conversed by enzyme to 5% mature alcohol yield, 37% cellulose alcohol efficiency, and consumed 7t steam per ton ethanol, and total energy consumption of 1010kg per ton ethanol. The experiment facility demonstrated that all the technical indicators are at advanced level. In addition, many other R&D activities carried out by research institute and universities (such as Nanjing University of Technology and Tsinghua University) are progressing. However, in general, the technology is still at early stage. Many critical technical problems need to be solved.

5.4.1.3 Technical obstacles

So far, technical process of ethanol from starch and sugar materials is becoming well developed, but sweet sorghum and cellulose ethanol technologies are still immature. Some technical obstacles for commercial deployment still exist.

Advantage of sweet sorghum stalk for ethanol lies in its simple production process, while disadvantages include energy consuming in squeezing, sugar content in residues (5%-10%), fresh stalk or extract storage problem, and waste water treatment, etc. These problems will increase the ethanol production cost and can be affected by harvest season factors. One of the most critical issues is to maintain sugar content during storage. Fermentation of sweet sorghum can be either solid or liquid fermentation. Liquid fermentation is energy consuming and environmentally unfriendly, but it needs less time for the fermentation, while the solid method discharges less waste water and residues and contains high alcohol yield. Therefore it is suitable to be applied in northern China areas. However, the current solid fermentation technique utilizes traditional “kiln type” brewery process with very long formation time and hence less cost-effective.

Ethanol from sweet sorghum stalks can be classified as cellulose ethanol technology. It utilizes cellulose and half cellulose in the stalk to hydrolyze the carbohydrate into fermentable sugar and further fermentation to produce fuel ethanol. Solid fermentation is popular process by either separable sarccharification or synchronizing sarccharification fermentation technique. Current research on technical processes is to improve the yield of fermentable sugar during the cellulose feedstock hydrolyzing process and to improve fermentation technique and increase equipment efficiency so as for higher ethanol yield and better economy.

The major challenge of ethanol from cellulose lies in separation of cellulose from lignin and conversion of cellulose into sugar and ethanol, and low cost enzyme. **Future technology development of fuel ethanol from cellulose will be:**

(1) Comprehensive preprocessing. Although there are currently many cellulose feedstock preprocessing techniques, few can completely separate the cellulose from enwrapped hemicelluloses and lignin. Therefore, multiple techniques are necessary to improve the technical process for more effective separation and without destroy their molecule structure such that less enzyme restraint will be used. This will benefit following enzymolysis and fermentation process. This will also in certain degree reduce the treatment cost and improve the cellulose to ethanol conversion efficiency.

(2) Improvement of saccharification process. Hydrolyzation efficiency and monoaccharide yield of cellulose feedstock can directly affect alcohol yield during the fermentation process. Enzyme hydrolyzation can be advantageous compared with acid accharification process and will become future technical choice. However, the enzyme hydrolyzation consumes large amount of cellulose feedstock. It has problems of high cost, small scale, and complicated technical process. Application of solid fermentation technique is expected to solve the problem, which will enable large scale application of cellulose biomass. In addition, proper choice, mixing, and improvement of enzyme applications will help improve hydrolyzation efficiency and applicability of cellulose and semi cellulose feedstock sources.

(3) Screening of fermentation bacterium strains. Special screening of bacterium strains will facilitate fermentation efficiency and improve suitability for particular cellulose feedstock. For example, selection of gene mutation bacterium strains for highly sugar content resistant cellulose feedstock can overcome the restraining effect during the cellulose hydrolyzation process and improve fermentation efficiency and ethanol yield. Screening and incubating highly efficient direct fermentation bacterial strains to enable them to adapt special substrate will facilitate simple production process and reduce production cost. Heat resistant microzyme can work with ordinary fermentation enzymes to alleviate the impact of temperature on bacterium growth and improve the fermentation efficiency.

(4) Improvement of fermentation process. In order to alleviate the restraining react of ethanol on bacterium growth and on ethanol yield, vacuumed, air separation, and membrane separation techniques can be utilized to continuously extract ethanol produced during the fermentation to make the ethanol concentration in the fermentation tank no more than required content to improve fermentation tank productivity and reduce steam consumption during the distillation process. Additionally, using continuous cell recycling technical process will also help less bacterium consumption and reduce production cost.

(5) R&D on solid fermentation process. Although the solid fermentation process may have disadvantages in low water activity, slow bacterium growth, and uneven nutrient transmission and metabolites exudates, as well as difficulties in fermentation process control, pure bacterium culture, and large scale production; however its advantages will include simple technical process, low production cost, low energy consumption, and easy treatment of fermentation residues. Solid fermentation is expected to be applied in mass production. In addition, solid fermentation has been applied in cellulose enzyme process and resulted in significant cost reduction.

(6) Optimizing technical process. As above mentioned, cellulose materials in natural plants can be very different in terms of chemical, physical, and biological characteristics. It is impossible to apply only few best techniques for common production of fuel ethanol from cellulose feedstock. The technical processes must be optimized according to special cellulose material features for better productivity.

5.4.2 Biodiesel

5.4.2.1 Technical process

There are several biodiesel technical processes available, including direct mixing, micromulsion, high temperature thermal decomposition, and transesterification. Currently, the transesterification method is popular for biodiesel production that utilizes animal and plant oil and restaurant waste oil as raw materials to transeterify methanol and ethanol into fatty acids and produce glycerin as byproduct. To produce biodiesel can use diversity of feedstock materials, which can include waste animal and plant oil, industrial waste oil, and oily crops such as camella oleosa seed, soybean, jatropha curcas, and pistasia chinensis, etc.

The most popular biodiesel technique is chemical method. That uses plant oil (or animal oil) to transestrify with methanol or ethanol under the catalysis by acid or alkali or by biological enzyme to make fatty acid fuel. A general biodiesel production process is depicted in figure 5-23. In general, impurities in the waste oil must be cleaned. In the biodiesel from jatropha process, shell jatropha curcas seeds must be removed before squeezing the oil. The shells can be comprehensively utilized. A typical biodiesel production process can be seen in the following figure 5-24.

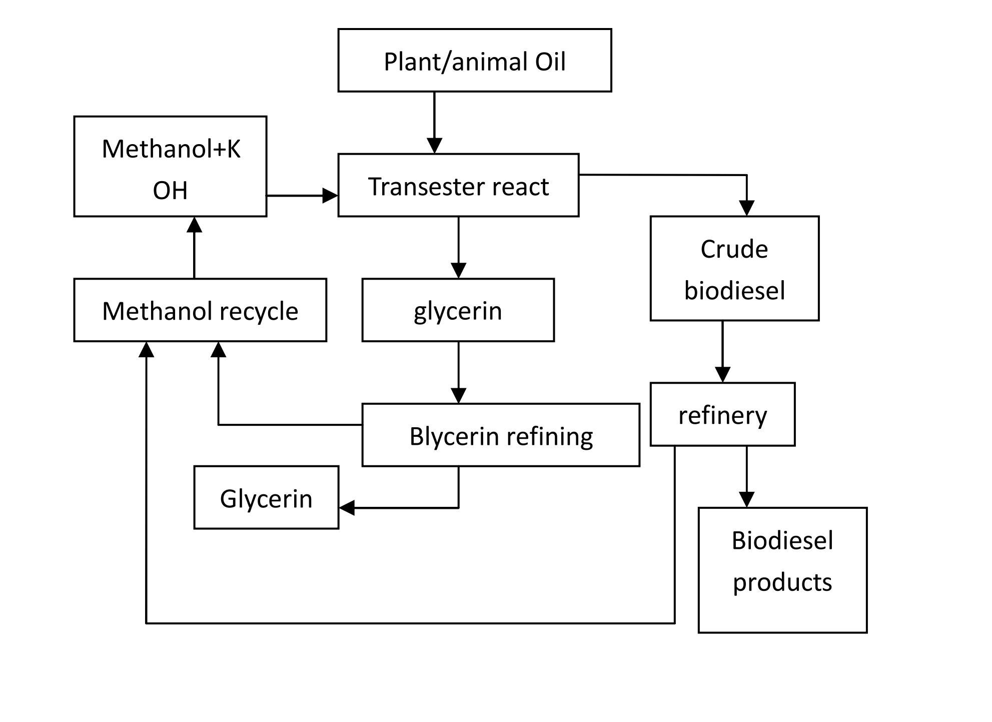

Figure 5-23 Technical process of biodiesel by chemical method

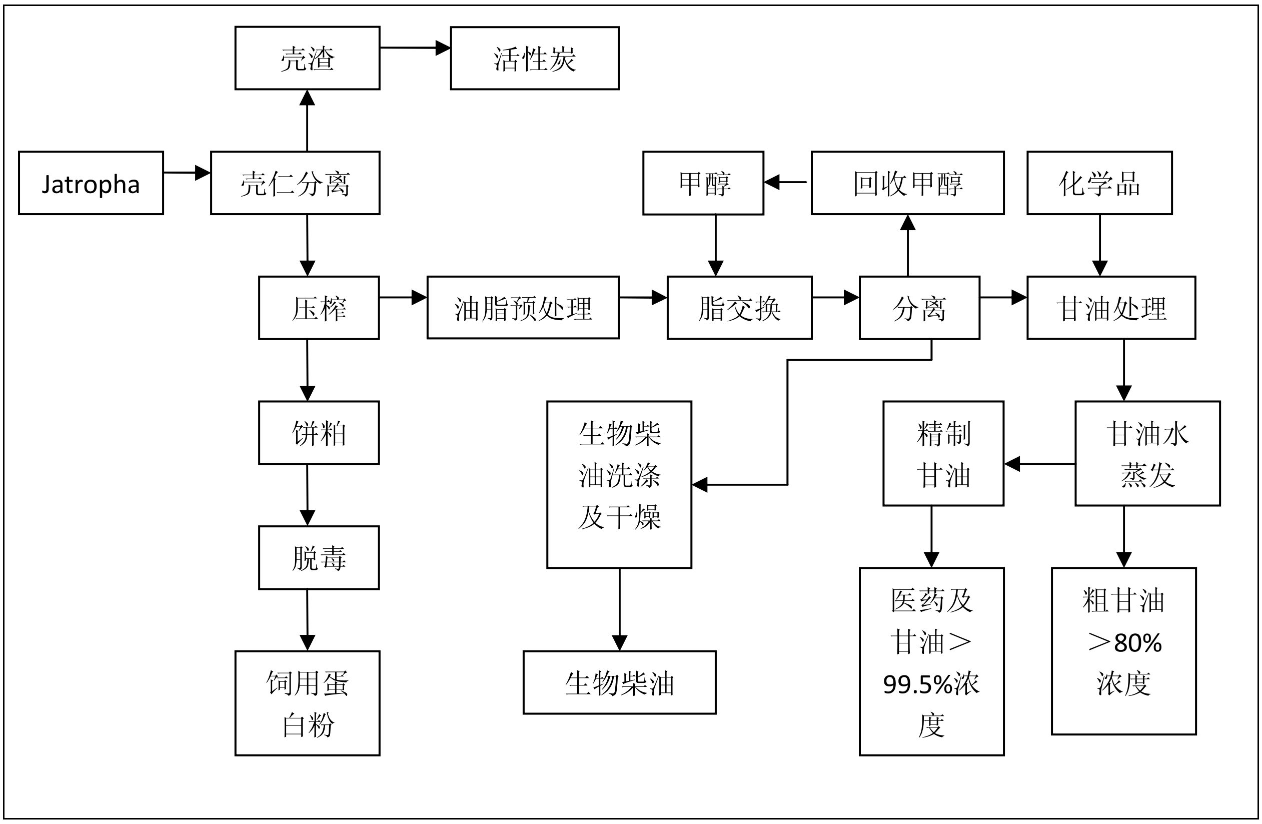

Figure 5-24 Technical process of biodiesel from Jatropha curcas

5.4.2.2 The industrial development

Biodiesel industry in China has just started during the tenth five year planning period in 2001-2005 when some private biodiesel plants produce biodiesel from restaurant waste oil, natural oil plant seeds, and waste animal grease as common materials. The produced biodiesel product was just used as fuel for agricultural machines, not as vehicle fuel in the market. For example, China's first biodiesel plant was established in Hebei's Wu'an by Hainan Zhenghe Biomass Energy Company. The plant produced biodiesel from waste oil from restaurant and refineries, as well as oil plant seeds. The production capacity was 10kt/year. In the same year, Sichuan Gushan Lipin Chemical Co. installed a 10kt/y biodiesel capacity in Mianyang city. The company utilizes waste oils and animal grease to produce biodiesel and sell the product in the market. In November 2001, Fujian Zhuoyue Energy also installed a 2kt/y biodiesel production facility in Fujian's Longyan by utilizing restaurant waste oil as raw materials.

While momentum success in fuel ethanol from non-grain feedstock, industrial scale biodiesel demonstration becomes a mature technique. From 2006 to 2010, China's biodiesel industry grows fast and dozens of biodiesel facilities with capacity of several thousand tons per year have been developed. In addition to utilizing restaurant waste oil as common materials, plantation of Jatropha curcas, Pistacia chinesis Bunge, and other oil plants has been established. According to a statistics, by the end of 2007, about 20 biodiesel companies with thousands tons annual production capacities have been installed, most of them produce biodiesel from waste oils. (See Table 5-8). In spite of the available "Recommended diesel engine fuel and biodiesel (B100) standard issued in 2007, there is still no technical code for mixing fossil diesel with biodiesel for vehicle, nor biodiesel is included in the vehicle sales system. All produced biodiesel product is sold to local mining company users and little to fuel sellers.

Table 5-8 Established major biodiesel facilities in 2007

Biodiesel producer	Location	Capacity 10^4t/year	Feedstock	Technical process
Longyan Zhuoyue New Energy Co.Ltd	Fujian Longyan	5	Sewage oil	Chemical solid catalyzing, continuous production
Xiamen Zhuoyue Biomass Energy Co. Ltd	Fujian Xiamen	5	Sewage oil, hogwash oil	Chemical solid catalyzing, continuous production
Haina Baichuan Bioengineering Co. Ltd	Hunan Yiyang	2	Sewage oil, hogwash oil	Enzyme fermentation & continuous production
Shanghai 10000t/y Enzyme Biodiesel Facility	Shanghai	1	Sewage oil	Enzyme fermentation & continuous production

Sanshui Zhenghe Refinery Chemicals	Guangdong Fuoshan	2	Sewage oil	Liquid acid & alkali method & continuous process
Sichuan Gushan Lipin Chemicals Co. Ltd	Sichuan Mianyang	3	Sewage oil	Liquid acid & alkali method & continuous process
Wuxi Huahong Biofuels Co. Ltd	Jiangsu Wuxi	2	Sewage oil	NA
Zhejiang Dongjiang Energy Technology Co. Ltd	Zhejiang Tongxiang	5	Sewage oil	NA
Liuzhou Minghui Biofuels Co. Ltd	Guangxi Liuzhou	2.4	Restaurant waste oil, plant oil, Oliver oil	NA
Henan Xinghuo Biomass Energy Co. Ltd	Henan Shangqiu	5	Waste oil	NA
Beijing Gushan Lipin Chemicals Co. Ltd	Beijing	5	Sewage oil	NA
Southwestern Aviation Technology Group Biodiesel Co. Ltd	Guiyang	2	Sewage oil	NA
Zhongshui Biodiesel Co.	Guiyang	2	Sewage oil	NA
Yuanhua Energy Technology (Fujian) Co. Ltd	Fuzhou	6	Sewage oil & Jatropha curcas oil	Solid alkali catalyzing & continuous process
Total capacity	—	47.4	—	—

To promote biodiesel industry development in China, a group of biodiesel from oil plant and waste oil demonstration projects were subsidized by NDRC's special fund program for biomass technologies in 2006. In the early 2007, Sinopec and COFCO signed with National Forestry Administration on joint efforts in developing forestry biomass energy applications and launched biomass energy plantation bases. According to the agreement, energy plantation bases in Yunnan, Sichuan, Hunan, Anhui, Hebei, and Shannxi plan to plant 200 million MU energy forest in the coming 15 years. In 2007, NDRC approved 3 biodiesel from Jatropha curcas demonstration projects invested by the three major Chinese oil giants, which include China CNPC Nanchong refinery's 60,000t/y biodiesel project, Sinopec Guizhou 50,000t/y biodiesel project, and China Ocean Oil Hainan's 60000t/y biodiesel facility.

5.4.2.3 Technical Obstacles

One of the principal obstacles for biodiesel production is short of sustainable supply of oil feedstock. Lack of satisfactory catalyst also affects biodiesel capacity.

According to industrial estimate that by 2007 there were hundreds of large or small biodiesel producers in China, most of them were just started small workshops using waste oil as raw materials. Due to the small production capacity and limited waste oil resources, and lack of mature oil plantation bases, only few of the biodiesel companies can have scaled and continuous production practice. Among the reasons, firstly reliable waste oil collection channels have not been established. There is lack of stable and sufficient waste oil supply. Furthermore, energy plantation, management and scale development need to solve some technical problems. Current supply from energy crops are constrained by limited scale, low yield, dispersed distribution, rough management, and unsatisfactory breading, planting, and harvesting techniques. For example, jatropha curcas utilization is still at natural species selection and early breeding. R&D activities are concentrating on biological characteristics, gene analysis, adaptability analysis, and productivity. Stable production is far from practical. In addition, as most biofuel feedstock comes from agriculture and forestry, agricultural production in China is still rely heavily on natural conditions. Therefore, production and product quality will be dependent on weather conditions. in particular, current biodiesel from waste oil and oil plants may have problems of biodiesel quality and standardization. Even biodiesel from Jatropha curcas can have different product qualities with diversified specifications on fatty acids, iodine; dissociate fatty acids, and saponification values.

In terms of technical process, lack of excellent catalysts can affect biodiesel quality, yield, feedstock adaptability, and on production environment. First of all, homogeneous catalysis is currently most common biodiesel technical process, in which alkali or acid catalysts are often used. Homogeneous acid and alkali-catalyzed transesterification techniques become mature in the US and European market, even though some advantages on complicated process, high cost, high energy consumption, and difficulty in separating catalyst residues with yields, as well as pollution problems. Furthermore, although heterogeneous catalyst process satisfactorily solve the separation problem and reduce pollutant, however there is no the best industry applicable heterogeneous catalyst available. Further research and development on industrially applicable catalysts is required. In addition, catalyst technique can have wide choices on feedstock, including plant oil, waste oil, and even sewage oil and hogwash oil, etc. Furthermore, enzymatic synthesis for biodiesel has technical advantages of adaptable reaction condition, small amount of alcohol, easy separation of catalyst with yield, glycerol recyclable, and no pollutant discharges, etc. Comprehensive utilization of resources during biodiesel production can be very important for reducing technical cost and therefore become an important research area. The enzymatic synthesis for biodiesel can achieve high yield. But the technique encounters high cost and difficulties in scale production. Many technical obstacles exist and require further study. Finally, super critical synthesis technique uses methanol to react with animal fat at super critical temperature conditions, which has advantages of much faster reaction speed, without catalyst, and efficient fatty acid synthesis. Therefore the technique enjoys fast process, suitability for feed stocks, simple purification, and high fatty acid yield, as well as simple process and environmentally friendly characteristics. It can be a promising future in technical development.

5.4.3 Assessment for technology development trends

Based upon the above mentioned assessment methods, this report will analyze the status and development trends for various biomass energy technologies including ethanol from cassava, sweet sorghum, cellulose feedstock and biodiesel from waste oils, jatropha curcas. Based on the analysis, these technologies are evaluated for their development trend assessment scores as for 2008, 2015, and 2020 respectively.

Table 5-9 Assessment of liquid biofuel technologies, status and future trends

Year	Technical development	Ethanol from cassava	Ethanol from sweet sorghum	Ethanol from cellulose	Biodiesel from waste oils	Biodiesel From Jatropha curcas
2008	Maturity	16	8	8	24	8
	Obstacles	25	25	0	40	25
	IPR	20	20	0	20	10

	ownership					
	Total	61	53	8	84	43
2015	Maturity	32	24	16	32	16
	Obstacles	40	40	15	40	25
	IPR ownership	20	20	10	20	10
	Total	92	84	41	92	51
2020	Maturity	40	32	16	40	32
	Obstacles	40	40	25	40	25
	IPR ownership	20	20	20	20	20
	Total	100	92	61	100	77

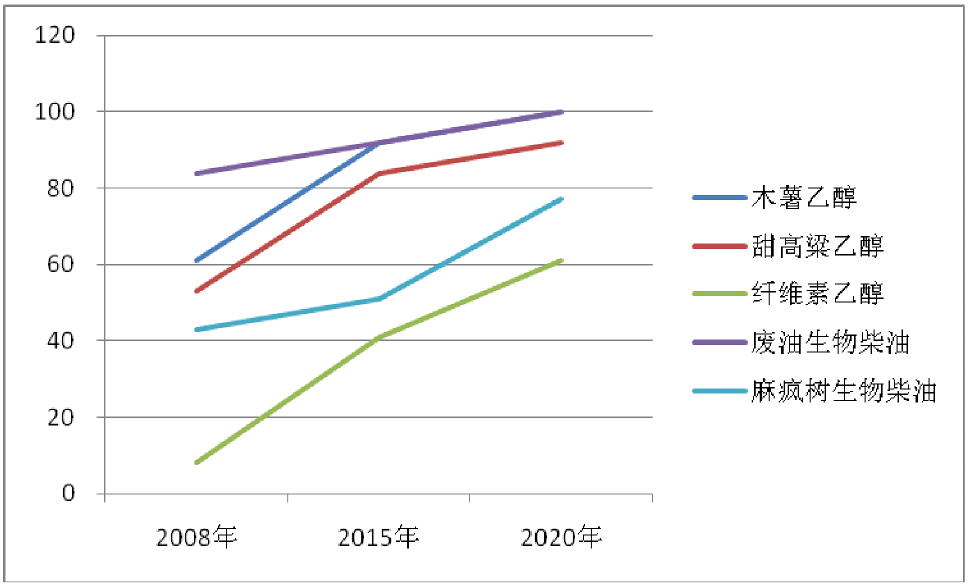

Figure 5-25 Assessment result of liquid biofuels technology status and future development

According the above figure, the assessment score for biodiesel technology is higher than ethanol technologies and cellulose ethanol and jatropha curcas biodiesel ranked the lowest, mainly due to the lack of cost effective cellulose preprocessing techniques, hydrolyzation, and jatropha curcas plantation management techniques. It is expected that by 2015, the technical process for waste oil biodiesel and ethanol from cassava technologies will become mature. By 2020, biofuel technologies will be developed for commercial applications while ethanol from cellulose feedstock shall be in commercial demonstration stage.

6. Benefit analysis for the technology roadmap

Benefit assessment include analysis on cost effectiveness, environmental benefit, and social benefit, both status and future development.

6.1 Benefit assessment for agricultural and forestry biomass for energy technologies

6.2 Investment and cost analysis

Economic feasibility of biomass technology is critical for wide applications. This report analyzed the detailed investment and cost effectiveness of biomass technologies. Take the example of power generation from biomass direct combustion, the average unit kW investment reduced from 9500 Yuan/kW in 2008 to 8075 Yuan/kW and the cost reduced from 0.639 Yuan/kWh in 2008 to 0.563 Yuan/kWh in 2020.

Table 6-1 Biomass fuel power generation investment and cost changes

Indicators	**2008**	**2015**	**2020**
Investment (Yuan/kW)	9500	8550	8075
Cost (yuan/kWh)			
Labor cost	0.049	0.056	0.064
Fuel cost	0.443	0.391	0.486
In which ： biomass cost	0.434	0.382	0.478
Financial cost	0.022	0.020	0.019
Depreciation cost	0.111	0.100	0.095
Maintenance cost	0.003	0.003	0.002
Other cost	0.011	0.011	0.011
Operating cost	0.506	0.460	0.563
Total cost	0.639	0.580	0.676

The following table 6-2 gives agricultural and forestry biomass power generation investment and production cost trends, as well as comparison to coal generation cost, while the figure 6-1 shows the cost changes of various biomass energy technologies.

Table 6-2 Investment and cost trends of energy production from agricultural and forestry residues

Technologies	Unit	2008	2015	2020
Investment				
Direct combustion	Yuan/kW	9500	8550	8075
Biomass gasification	Yuan/kW	8500	7650	6800
Co-firing generation	Yuan/kW	600	540	540
Pellet fuels	Yuan/ton	621	497	435

Biomass carbonization	Yuan/ton	843	674	590
Cost				
Direct combustion	Yuan/MWh	639	522	609
Biomass gasification generation	Yuan/MWh	624	495	446
Co-firing generation	Yuan/MWh	357	319	321
Pellet fuels	Yuan/ton	482.1	465.8	456.0
Biomass carbonization	Yuan/ton biomass	646	615	587
Cost comparison to coal generation				
Direct combustion	%	128.2	69.6	81.1
Biomass gasification generation	%	122.9	60.6	32.8
Co-firing generation	%	27.3	3.5	-4.6

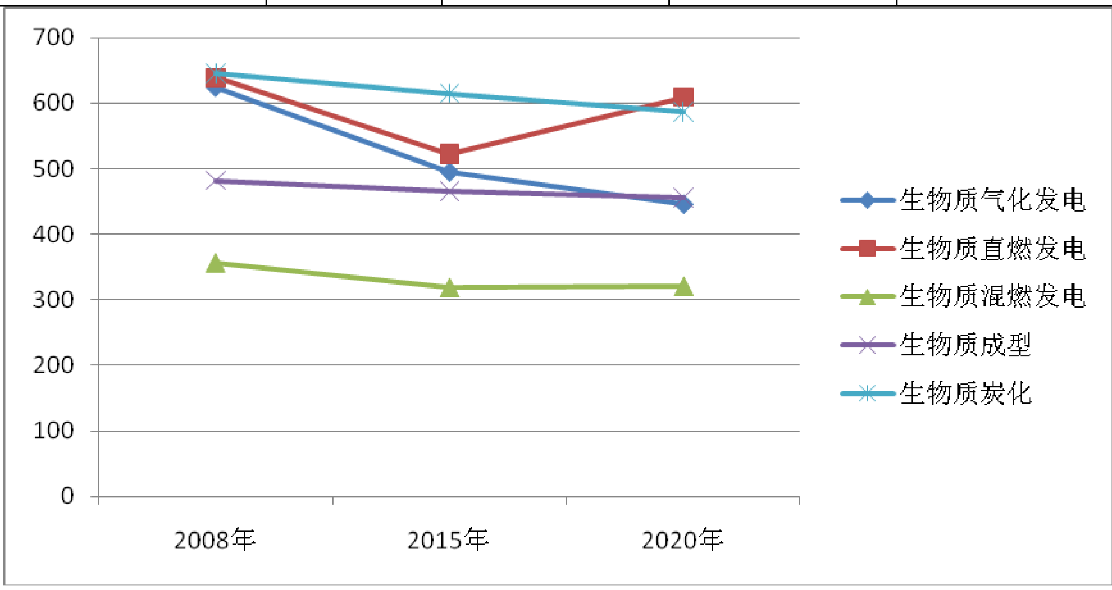

Figure 6-1 Cost trends of energy production from agricultural and forestry residues

The increase in cost for direct combustion generation is mainly due to wage increase in addition to cost miner increase of biomass fuels. However the per unit capacity investment reduction help cost reduction and improved efficiency and hence counteract cost effect and make total cost lower than that in 2008.

6.2.1 External benefit analysis

To look at advantages and disadvantages of a biomass technology, we need not only to analyze its economic achievement (cost) but also the benefits created by the technology in terms of social and environmental contributions. As the biomass technologies analyzed in this report involve rural economy and farmer income, social benefits of the technologies need to be fully considered, while the social and environmental benefits are analyzed quantitatively in order to obtain project economy, environmental benefit, social benefit, their current status and future trends.

Table 6-3 Benefits from agricultural and forestry residues for energy technologies

Indicators	Year	Direct combustion generation	Gasification generation	Co-firing generation	Biomass pellet fuels	Carbonization
Project capacity 104t biomass fuel /project	2008	19.5	3.4	14.6	1.2	3.0
	2015	17.2	2.9	14.6	1.2	2.9
	2020	14.3	2.5	14.6	1.2	2.7
Employment (persons/104t biomass fuel)	2008	105.6	106.7	102.3	182.6	120.0
	2015	81.4	83.0	77.3	156.5	126.3
	2020	67.7	69.4	62.3	182.6	133.3
Farmer income (Yuan/person.year	2008	24000.0	21600.0	21600.0	21160.0	18400.0
	2015	24000.0	21600.0	21600.0	21160.0	17480.0
	2020	24000.0	21600.0	21600.0	21160.0	16560.0
Environmental benefit (ton CO_2/ton biomass fuel)	2008	0.77	0.70	1.15	0.29	0.19
	2015	0.87	0.84	1.15	0.29	0.19
	2020	1.05	0.98	1.15	0.29	0.21
Energy benefit (tce/t material)	2008	0.3	0.2	0.4	0.4	0.3
	2015	0.3	0.3	0.4	0.4	0.3
	2020	0.4	0.3	0.4	0.4	0.3

6.2.2 Overall benefit analysis

Economic achievement, environmental benefit and social contribution will be evaluated by using the method described in Chapter II. Following assessment results are derived.

Table 6-4 Benefit assessment result for agricultural and forestry residues for energy technologies

Technology	**Direct Combustion**	**Gasification**	**Co-firing with coal**	**Pellet fuel**	**Carbonization**
2008 total score	30	31	68	73	37
Resource collection	0	88	27	100	90
Economy	0	5	100	90	66
Employment	4	5	0	100	22
Farmer income	100	57	57	49	0
Environmental benefit	60	53	100	10	0
Energy benefit	12	0	78	100	25
2015 total score	22	32	74	64	20

Resource collection	0	14	100	55	12
Economy	5	7	0	100	62
Employment	100	63	63	56	0
Farmer income	71	67	100	10	0
Environmental benefit	8	0	71	100	1
2020 total score	29	50	66	63	55
Resource collection	2	90	0	100	89
Economy	0	49	87	52	100
Employment	4	6	0	100	59
Farmer income	100	68	68	62	0
Environmental benefit	89	81	100	8	0
Energy benefit	33	13	63	100	0

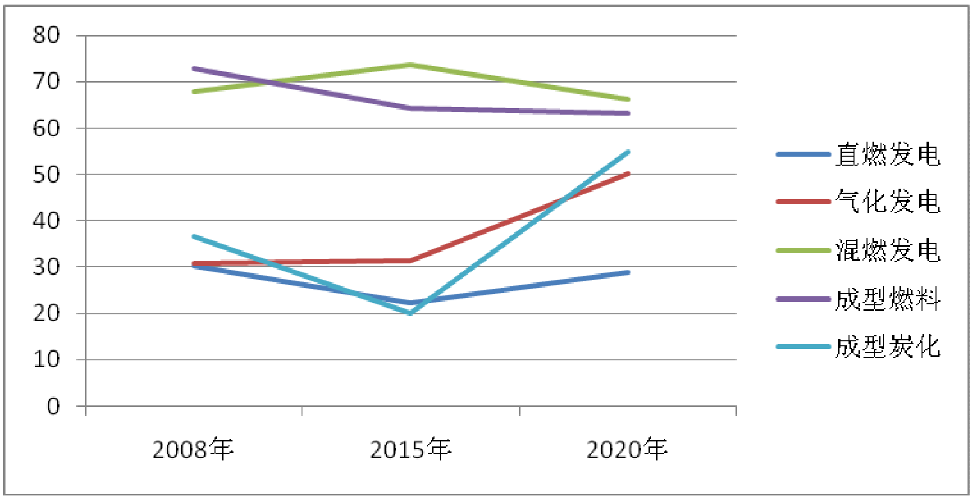

Figure 6-2 Assessment of benefits from crop residues for energy technologies

According to the above figure, direct combustion biomass power generation technology, which consumes the most crop residues and applied widely in China, is evaluated as the poorest economy technology, while the most difficult co-firing power generation technology ranked second and far ahead to the second. The most important reason for the assessment result lies in the technology maturity. However, the metering system is critical for co-firing technology applications for subsidy policy implementation. The unsuccessful development of the metering system hindered the co-firing technology. On the other hand, because direct combustion technology is relatively mature, although it is lower economic strength than the co-firing, it develops much faster than co-firing technology.

In addition, along with continuous technology breakthroughs, overall economic performance of gasification and carbonization technologies become increasingly improved, especially the carbonization technology is expected to be widely applied as mature technology after 2015, by then its economic performance will surpass the gasification power generation.

Through the above investment, cost and external performance analysis, the following conclusions can be derived:

1. Technology investment for energy from crop residues will tend to decrease with time.
2. Production cost of crop residue biomass technology will tend to going down.
3. It is expected that by 2015 all the three major biomass power generation technologies will be lower than the cost of coal generation. This estimate shows the economic feasibility of applying the biomass power generation technologies.
4. Biomass technologies of applying agricultural and forestry residues for energy not only provide energy product but also achieves positive environmental and social benefits.
5. The environmental benefit of agricultural and forestry biomass will add more values along time.
6. With increased usage of biomass collection machinery, social performance of agricultural and forestry biomass technologies can be weaken. However each biomass technology project will continue to provide job opportunities in rural areas, which will benefit for rural economy and more farmer income.

6.3 Technology benefit assessment for livestock farm waste for energy technologies

6.3.1 Investment and cost analysis

By analyzing grid-in and off power network biogas power generation technologies, investment and cost performance of the technologies is depicted in the following table. It shows that cost of both the technologies will continue to decrease. The cost of grid connection biogas power generation technology will decrease by 18%, and the cost of off-grid biogas power is expected to decrease by just around 8%.

Factors for the cost reduction are mainly because that in-grid biogas power generation is usually large in capacity and the engine generator systems are far more powerful than off-networked systems. Along with improved technologies and techniques, efficiency of large turbine systems will be increased greater than the small systems so that in-grid biogas power generation technologies will be more efficient than the off-line technology and so cost reduction.

Table 6-5 Livestock farm biogas generation technology cost and future trends

Technologies	Unit	2008	2015	2020
Investment				
In-grid biogas generation	Yuan/kW	31100	24900	20200
Off-grid biogas generation	Yuan/kW	25900	22100	18200
Operational cost				
In-grid biogas generation	Yuan/MWh	1.101	0.906	0.830
Off-grid biogas generation	Yuan/MWh	1.328	1.275	1.223
Comparison to coal generation				
In-grid biogas generation	%	293.33	194.18	147.11
Off-grid biogas	%	374.23	314.12	264.02

generation				

6.3.2 External benefits

Livestock farm biogas power generation projects can not only achieve economic performance but positive environmental and social benefits, especially for more job opportunities and more farmer income in rural areas in China. Comprehensive benefits of both technologies are demonstrated in the following table.

Table 6-6 Livestock farm biogas project benefits assessment

指 标	Year	In-grid biogas power generation	off-grid biogas power generation
Project size (10^4t biomass/project)	2008	9.77	0.38
	2015	8.94	0.38
	2020	8.69	0.38
Jobs provided (jobs/10^4t biomass)	2008	1.53	13.32
	2015	1.68	13.32
	2020	1.73	13.32
Environmental benefit (ton CO_2/ton biomass)	2008	0.10	0.10
	2015	0.11	0.10
	2020	0.12	0.10
Energy performance (tce/t biomass)	2008	0.03	0.03
	2015	0.04	0.03
	2020	0.04	0.03

6.3.3 Overall benefit analysis

By using the assessment method indicated in the section II, biogas power generation technologies are scored in terms of their economic performances, environmental benefits, and social benefits as in the following table.

Table 6-7 Assessment scores of livestock farm biogas projects

Technologies	Grid-connected biogas power generation	off-grid biogas power generation
2008 total score	65.0	15.0
Resource collection	100.0	0.0
Economy	100.0	0.0
Employment	0.0	100.0
Farmer income	0.0	0.0
Environmental benefit	100.0	0.0
Energy performance	100.0	0.0

2015 total score	80.0	20.0
Resource collection	100.0	0.0
Economy	100.0	0.0
Employment	0.0	100.0
Farmer income	0.0	100.0
Environmental benefit	100.0	0.0
Energy performance	100.0	0.0
2020 total score	80.0	20.0
Resource collection	100.0	0.0
Economy	100.0	0.0
Employment	0.0	100.0
Farmer income	0.0	100.0
Environmental benefit	100.0	0.0
Energy performance	100.0	0.0

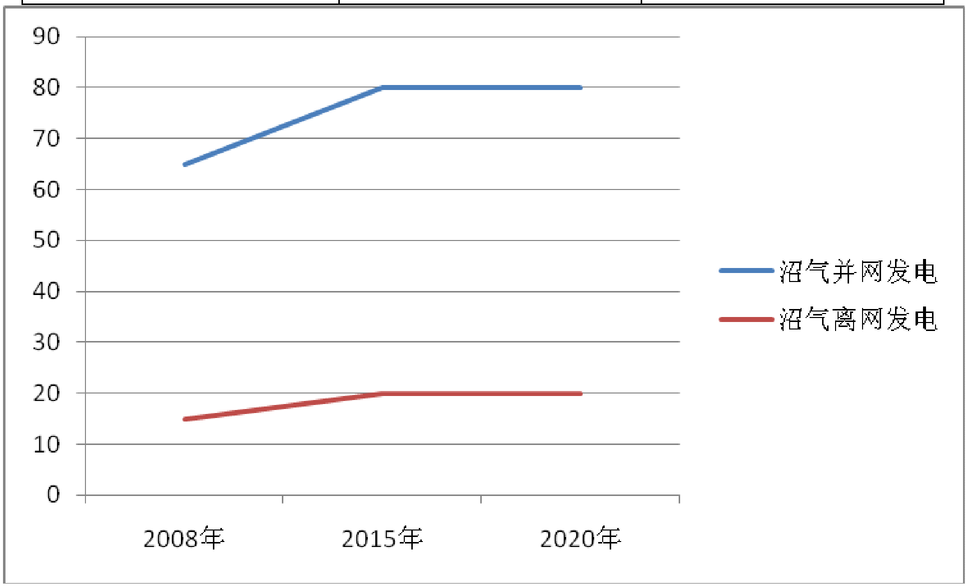

Figure 6-3 Benefit assessment result of livestock farm biogas power generation technology

From the above figure and data we can see that although the comprehensive performance of grid connected biogas power generation was better than the off-grid technology in 2008, the current applications of in-grid systems are far behind stand-along projects. One of the major reasons is to lack of technical codes and immature technology that affected grid connected system development. Along with the elimination of technical and legislative obstacles, grid-connected biogas power generation technology will develop faster than the off-line systems.

The following conclusions are derived from comprehensive benefit analysis:

1. Both of the livestock biogas power generation technology will decrease their investment and cost by 35% and 30% respectively. However, by 2020, their investment will still be higher than the conventional power technology.

2. Cost of both in-grid and off-grid livestock biogas power generation technologies will be going

down by 2020, but slower than the decrease of per capacity investment. By 2020, both production costs of the biogas generation technologies will still higher than the cost of coal generation by 141% and 264% respectively.

3. If only considering cost effective performance, both the technologies will still less competitive in the power market.
4. Application of the livestock farm biogas power generation technologies will benefit alleviation of green house gas emission and acid rain (SO2) damage significantly.
5. The technology employment will help to provide efficient and clean household fuel and benefit improvement of rural life quality and contribute to China's rural development program.
6. Because the grid-connected biogas power generation technology will have better performance than the off-network system, it should be encouraged at areas applicable.
7. No matter applying what livestock farm biogas power systems, fuel gas supply at rural areas should be prioritized. This will not only improve local farmer life quality but also help project economic performance.

6.4 Solid waste for energy technology benefit assessment

6.4.1 Investment and cost analysis

From the following table 6-8, we can see that cost of solid waste incineration power generation technology will continue to going down, but electricity from landfill gas will become more expensive.

The cost reduction of solid waste incineration project is due to the improved techniques and manufacturing so that power generation productivity can be improved continuously. Along with larger industrial market, cheaper equipment will also bring about production cost reduction.

China encounters scarce land resource especially at urban areas. Landfill construction needs large areas of expensive land. In addition, pollution of landfill site to underground water and soil has drawn greater attention. This requires sophisticated landfill field construction techniques and results in more expensive landfill site construction and management.

Table 6-8 Solid waste power generation technology cost and changes

Technologies	Unit	2008	2015	2020
Investment				
Solid waste incineration power generation	Yuan/kW	2.49	2.12	1.87
Landfill gas power generation	Yuan/kW	1.04	2.08	3.11
Cost				
Solid waste incineration power generation	Yuan/MWh	0.404	0.297	0.232
Landfill gas power generation	Yuan/MWh	0.270	0.475	0.680
Comparison to coal generation				

Solid waste incineration power generation	%	44.33	-3.55	-30.89
Landfill gas power generation	%	-3.68	54.23	102.50

6.4.2 External benefits

The priority of solid waste power generation lies more in environmentally friendly waste treatment than energy supply. Therefore environmental and social performance will become more important. The table 6-9 is a analysis result on comprehensive benefits of the two solid waste power generation technologies.

Table 6-9 External benefits of power generation from solid waste

Performance Indicators	Year	Incineration	Landfill gas
Project size (10^4t biomass/project)	2008	37.27	45.87
	2015	33.88	41.70
	2020	33.88	41.70
Jobs provided (jobs/10^4t biomass)	2008	2.15	21.80
	2015	2.36	23.98
	2020	2.36	23.98
Environmental benefit (ton CO_2/ton biomass)	2008	0.35	0.03
	2015	0.38	0.02
	2020	0.38	0.02
Energy performance (tce/t biomass)	2008	0.12	0.01
	2015	0.13	0.01
	2020	0.13	0.01

6.4.3 Comprehensive benefits

By using the assessment method indicated in the section II, solid waste power generation technologies are scored in terms of their economic performances, environmental benefits, and social benefits as in the following table.

Table 6-10 Comprehensive benefits of power generation from solid waste

Technologies	Incineration	Landfill gas
2008 total score	20.0	60.0
Resource collection	0.0	100.0
Economy	0.0	100.0
Employment	0.0	100.0
Farmer income	0.0	0.0

Environmental benefit	100.0	0.0
Energy performance	100.0	0.0
2015 total score	70.0	20.0
Resource collection	0.0	100.0
Economy	100.0	0.0
Employment	0.0	100.0
Farmer income	0.0	0.0
Environmental benefit	100.0	0.0
Energy performance	100.0	0.0
2020 total score	70.0	20.0
Resource collection	0.0	100.0
Economy	100.0	0.0
Employment	0.0	100.0
Farmer income	0.0	0.0
Environmental benefit	100.0	0.0
Energy performance	100.0	0.0

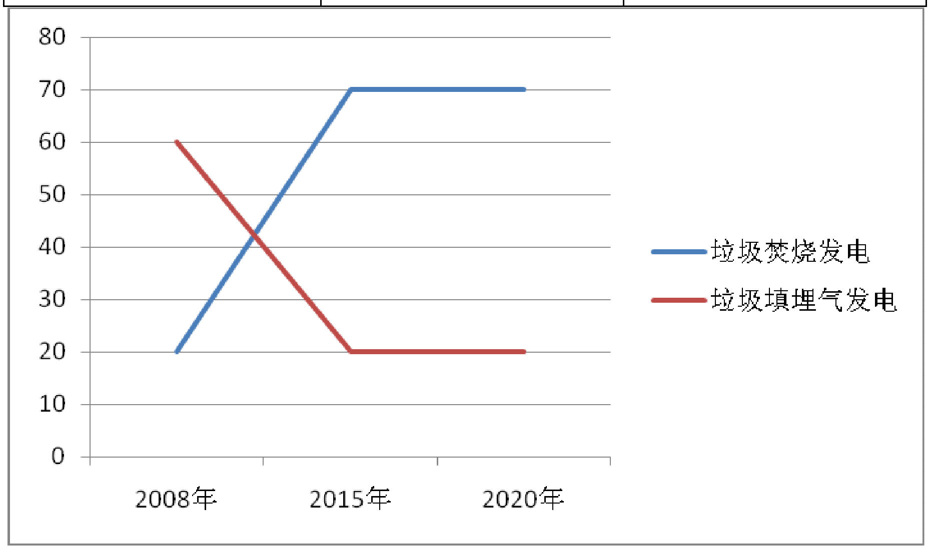

Figure 6-4 Assessment result of solid waste power generation technologies

By the end of 2009, a total of 78 solid waste incineration power plants have been developed with annual waste treatment capacity of 10 million tons, accounting only for 7% of total municipal solid waste yield each year. Currently, the overall benefit of the incineration facilities, especially the economic performance, is much lower than landfill power generation technology. By mature incineration technology developed and efficient manufacturing industry, and more expensive land cost and tougher environmental protection regulations, solid waste incineration power generation will become more attractive than the landfill gas power generation technology. It is expected that by 2015, more incineration generation capacities will be installed than landfill gas systems.

The analysis is summarized as follows:

1. It has been noted that investment and production cost of the two solid waste power generation

technologies shall change to inverse trends in the future.

2. By 2020, project investment for solid waste incineration power generation will be going down by 25% and power generation cost will decrease by 43%. By 2015, compared with coal generation, incineration power cost will be at equal level and by 2020 the cost will be 30% lower than coal generation.

3. By 2020, landfill gas power generation project investment will be three times higher than that in 2008, mainly because of more expensive land cost. Therefore, the landfill gas power cost will also increase by 2.5 times, which is twice of coal generation compared to the similar cost in 2008.

6.5 Evaluation of liquid biofuel technology benefits

6.5.1 Investment and cost analysis

From the following table 6-11, investment in liquid biofuel technology has a tendency of decreasing, while ethanol from cellulose feedstock will have the largest investment cost reduction and least reduction for ethanol from cassava and biodiesel from waste oil technologies. It is worth to note that by 2020, cellulose ethanol and jatropha curcas biodiesel technologies will have strong competitiveness in the biofuel market in terms of project investment.

Operational cost of various liquid biofuel technologies will also tend to decrease significantly. By 2020, fuel ethanol from sweet sorghum will have the lowest operational cost, while cellulose ethanol and jatropha curcas biodiesel will still expensive in operation though project investment is low. Therefore we expect that the latter two liquid biofuel technologies will still be less competitive for commercial operation.

In the overall table, by 2020, the overall cost of ethanol from cassava, sweet sorghum, and biodiesel from waste oils will be lower than fossil gasoline and diesel products, while cellulose ethanol and oil plant biodiesel will be more expensive than the respective fossil fuels. This shows that even by 2020, the latter two liquid biofuel technologies will still have cost obstacles for commercial projects. From the national policy point of view, economic incentive policies are necessary for cellulose ethanol and plant oil biodiesel technologies.

Table 6-11 Liquid biofuel technology investment and cost changes over future years

Year	2008	2015	2020
Investment (10^4 Yuan/10^4t product)			
Cassava ethanol	3686	3391	3207
Sweet sorghum ethanol	6846	5819	4792
Cellulose ethanol	5266	4213	3160
Biodiesel from waste oils	3686	3502	3318
Biodiesel from Jatropha	3686	3502	3318
Total cost (Yuan/t product)			
Cassava ethanol	5141	5033	4048
Sweet sorghum ethanol	4452	4060	3909
Cellulose ethanol	7940	7812	6746

Biodiesel from waste oils	5963	5821	5681
Biodiesel from Jatropha	7081	6901	6723
Comparison to gasoline and diesel (%)			
Cassava ethanol	29	1	-33
Sweet sorghum ethanol	11	-19	-35
Cellulose ethanol	98	56	12.4
Biodiesel from waste oils	49	16	-5
Biodiesel from Jatropha	77	38	12.1

6.5.2 External benefit analysis

Industrial development of liquid biofuel will not only provide energy products, but positive economic, social and environmental benefits, especially in providing job opportunities for local farmers. The overall benefits of liquid biofuels will be summarized in the following table.

Table 6-12 External benefits of liquid biofuel technologies

Indicators	Year	Cassava ethanol	Sweet sorghum ethanol	Cellulose ethanol	Biodiesel From waste oils	Biodiesel From Jatropha
Project size (10^4t biomass/project)	2008	142.86	10.00	2.14	5.32	6.38
	2015	125.00	8.00	1.50	5.26	6.32
	2020	117.65	7.14	1.20	5.21	6.25
Jobs provided (jobs/10^4t biomass)	2008	89.61	47.78	143.72	67.51	889.59
	2015	102.41	59.72	205.32	68.23	899.06
	2020	108.81	66.89	256.65	68.95	908.52
Environmental benefit (ton CO_2/ton biomass)	2008	0.23	0.08	0.23	1.56	1.56
	2015	0.27	0.10	0.33	1.58	1.58
	2020	0.28	0.12	0.42	1.59	1.59
Energy performance (tce/t biomass)	2008	0.15	0.05	0.15	2.07	2.07
	2015	0.17	0.07	0.21	2.09	2.09
	2020	0.18	0.07	0.26	2.11	2.11

6.5.3 Assessment of overall benefits

By using the assessment method indicated in the section II, liquid biofuel technologies are scored in terms of their economic performances, environmental benefits, and social benefits as in the following table.

Table 6-13 Overall liquid biofuel technology benefits

Technologies	Cassava ethanol	Sweet sorghum ethanol	Cellulose ethanol	Biodiesel From waste oils	Biodiesel From Jatropha
2008 total score	59	59	41	62	60
Resource collection	0	94	100	98	97
Economy	80	100	0	57	25
Employment	64	100	70	0	99
Farmer income	100	0	99	62	34
Environmental benefit	5	0	5	100	100
Energy performance	5	0	5	100	100
2015 total score	47	60	29	70	68
Resource collection	0	95	100	97	96
Economy	74	100	0	53	24
Employment	62	100	71	0	96
Farmer income	100	0	99	88	87
Environmental benefit	6	0	6	100	100
Energy performance	5	0	5	100	100
2020 total score	49	62	20	64	59
Resource collection	0	95	100	97	96
Economy	95	100	0	38	1
Employment	58	100	71	0	90
Farmer income	39	21	0	93	100
Environmental benefit	6	0	10	100	100
Energy performance	5	0	9	100	100

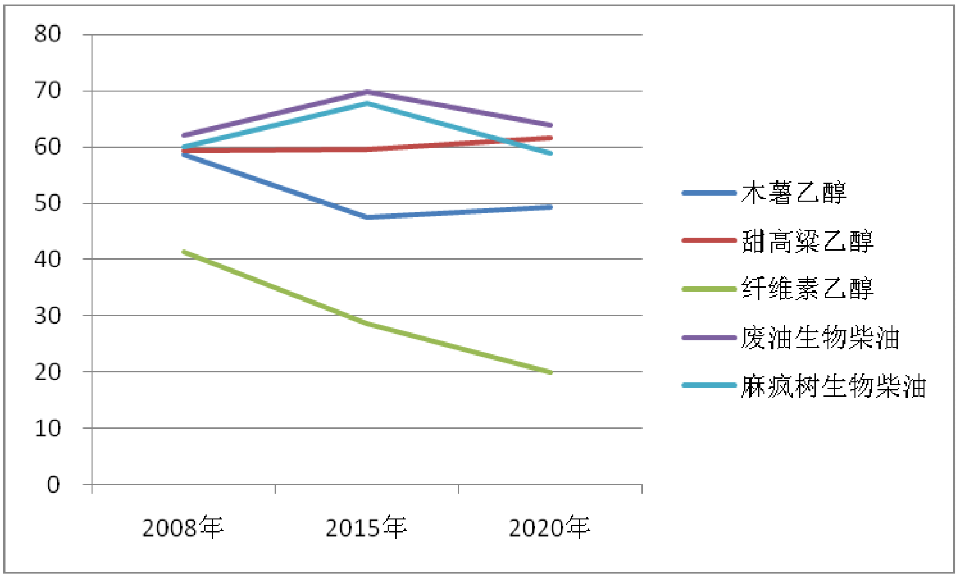

Figure 6-5 Assessment result of liquid biofuel technologies

The quantitative analysis is summarized as follows:

1．In 2008, among all the liquid biofuel technologies, biodiesel form waste oils had the best overall performance, which match the case of current biofuel development. Without government incentives, biodiesel from waste oils has been developed to certain production scale based on projects developed by Chinese enterprises. Satisfactory economic performance of the projects can be a main driving force. It is considered that even by 2020, the technology will still be leading the overall benefits and we can expect that the technology will continue its fast development. Although only about 2 million tons of waste oil resource available each year, increasingly more part will be used to produce biodiesel in the future.

2．In 2008, ethanol from sweet sorghum and ethanol from cassava performed equally. But by 2020, we expect that sweet sorghum ethanol will have better performance than cassava fuel ethanol. There are two reasons to support this expectation. First, sweet sorghum has greater resource potential by large scale plantation. Scale industry can be expected. Second, sweet sorghum can be planted in salt and alkali land with low production cost. Therefore it is assumed that by 2020 the industrial size of sweet sorghum ethanol will largely surpass the ethanol production from cassava.

3. Compared to production in 2008, biodiesel from Jatropha curcas will have reduced overall benefit by 2020, mainly due to increased labor cost. In general, the overall performance of the technology will still ranked high among other biofuel technologies. Future development can be very positive.

7. Technology development roadmap

7.1 Resource availability

By 2020, 360 million tce biomass resources will be available each year in China. To fulfill the biomass energy target, 179 million tce biomass energy resources will be required, which is 50% of the total resource available. **Therefore, we can conclude that sufficient biomass resources can support the 2020 biomass target.**

Table 7-1 Available biomass energy resources

	2015			2020		
	Total resource availability	Required resources	%	Total resource availability	Required resources	%

	(10^4tce)	(10^4tce)		(10^4tce)	(10^4tce)	
Crop residues	24700	3337	13.51%	24700	9743	39.44%
Livestock waste	5513	1980	35.91%	6621	3621	54.68%
Solid waste	2757	1966	71.30%	3314	3259	98.34%
Feedstock for Fuel ethanol	459	355	77.27%	1038	1012	97.45%
Feedstock for biodiesel	294	198	67.56%	416	266	64.06%
Total	33723	7836	23.24%	36089	17901	49.60%

From the percentage of required resources in the total available resources in figure 6-1, we can see that biomass for energy applications have diversified resource utilizations. Large amount of municipal solid waste and livestock waste are utilized by 2020. This follows the principle of resource priority. Treatment of livestock dejecta and urban garbage to energy is the priority in future biomass technology development. For liquid biofuel technologies, fuel ethanol from non-grain feedstock will be a major application. Energy plantation for the biofuel feedstock will be specially developed and provide more resources for the technologies.

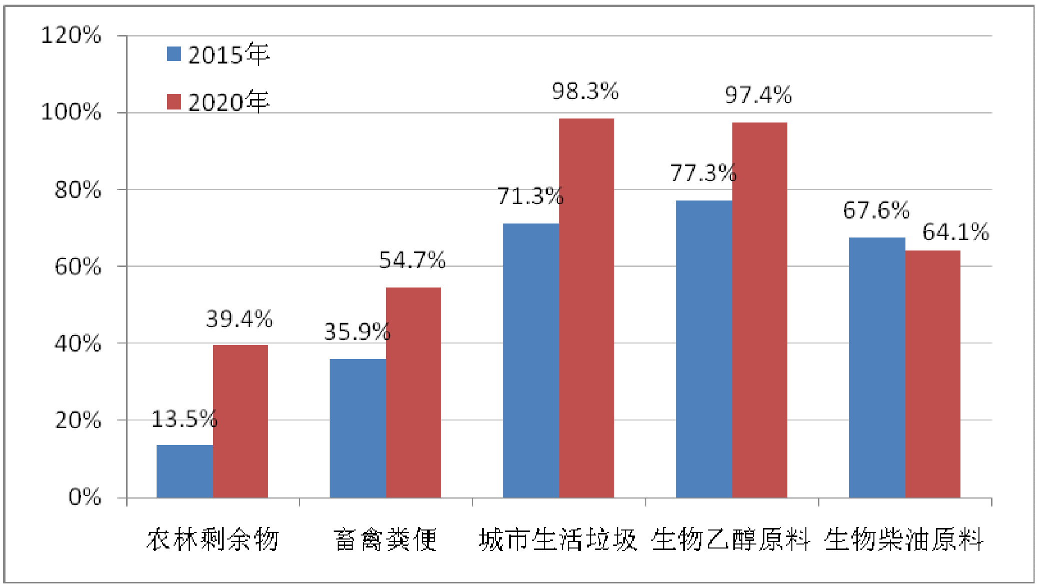

Figure 7-1 Biomass resource demand and availability

7.2 Technical routes

Figure 7-2 illustrated rankings on technical applications of various biomass energy technologies. From the figure we can see that by 2020 all the biomass technologies will converge to the score of 100, i.e. technical obstacles of the biomass technologies will be eliminated and a complete biomass technology system will be established in China. Applications of the biomass technologies will support the biomass industry development objectives.

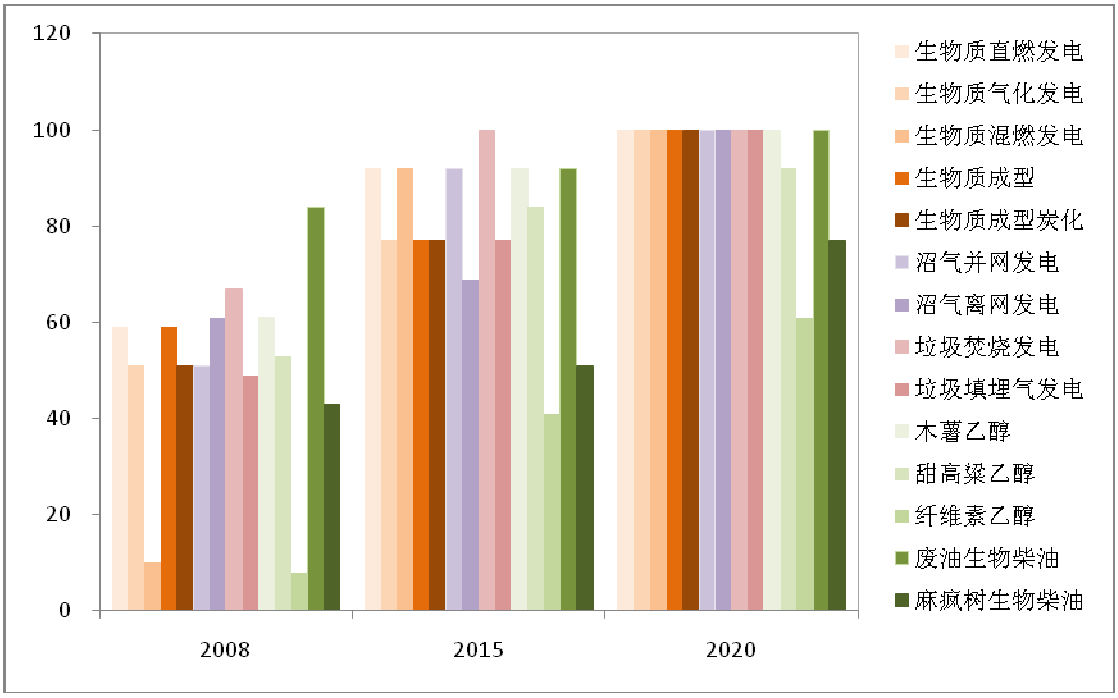

Figure 7-2 Overall biomass energy technology development and trends

The analysis on biomass technology status and future development will be summarized as follows:

Biomass energy industry in China is just developed at early stage. Technical obstacles exist for all the biomass technologies. These technical obstacles affected biomass industry development in China.

1. Before 2012, R&D activities will focus on some critical technologies and manufacturing techniques, such as biomass direct combustion boilers, coal-biomass co-firing metering system, MW grade fuel gas engine systems, etc.

2. By 2015, except few biomass technologies such as fuel ethanol from cellulose, most of the biomass technologies will complete R&D and demonstrations and are ready for industrial applications.

3. From 2014 to 2015, most of the biomass technologies will be at application promotion period. Meanwhile, relevant standards and technical codes, as well as manufacturing capacities will be greatly progressed. A biomass technology system will be gradually established in China.

4. From 2015 to 2020, this will be a fast development period for biomass technologies in China. The biomass technologies will form their rather completed technical system.

5. Liquid biofuels (cellulose ethanol, biodiesel)

Table 7-2 illustrated biomass technology development timetable.

Table 7-2 Existing biomass energy technology development timetable

Critical technologies	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2020**
High-temperature and high pressure biomass direct combustion boilers	R&D		Pilot and demonstration			Industrial deployment	
Biomass co-firing metering instrument	R&D on prototype systems		Demonstration projects		Industrial deployment		
Biogas fuel technology	R&D			Demonstration projects		Industrial deployment	
Large capacity and efficient biogas generator systems	500KW turbine system at international advanced level		1MW system demonstration			1MW turbine system deployment	
Grid integration technique for small biomass power systems	Grid integration and technical standards for small biomass power systems			Demonstration projects		Industrial deployment	
Biomass gasification and fuel gas cleaning technology	Demonstration projects completed				Industrial deployment		
Continuous biomass carbonization system	R&D and Demonstration projects		Demonstration projects		Industrial deployment		
Carbonization yield comprehensive utilization techniques and equipment	R&D		Demonstration projects		Industrial deployment		
Biomass pellet fuel techniques	National demonstration project at different areas for typical feedstock		Industrial deployment				
Landfill leakage treatment techniques and equipment	R&D		Demonstration projects		Industrial deployment		

Biomass fuel collection, storage and transport machines	Develop and manufacture systematic biomass collection and storage machineries		Industrial deployment	
Fuel ethanol	Commercial demonstration of sweet sorghum and cassava ethanol techniques. Commercial demonstration of ethanol from cellulose feedstocks.		Industrial deployment	
Biodiesel from waste oils	Complete system of waste oil collection, utilization, and industrial management.	Promoting waste oil utilization technology		
Biodiesel from oil plants	Jatropha plantation bases and demonstration. Biodiesel production from Jatropha curcas.		Industrial deployment	
New biofuels	R&D	Industrial demonstration projects		Industrial deployment
Ethanol from cellulose feedstock	Commercial demonstration of sweet sorghum and cassava ethanol techniques. Commercial demonstration of ethanol from cellulose feedstocks.		Industrial deployment	

7.3 Benefit analysis

By 2020, above biomass energy technologies will be developed to a mature stage and can support China's biomass energy objectives. However, scale development of the biomass technologies will not only depend on technical maturity, but their economic and external benefits in the market.

According to the assessment method described in the section II, technology overall performance scores are obtained as in the following table 7-3. Based on the data obtained, overall benefit development variations are depicted in the figure 7-3.

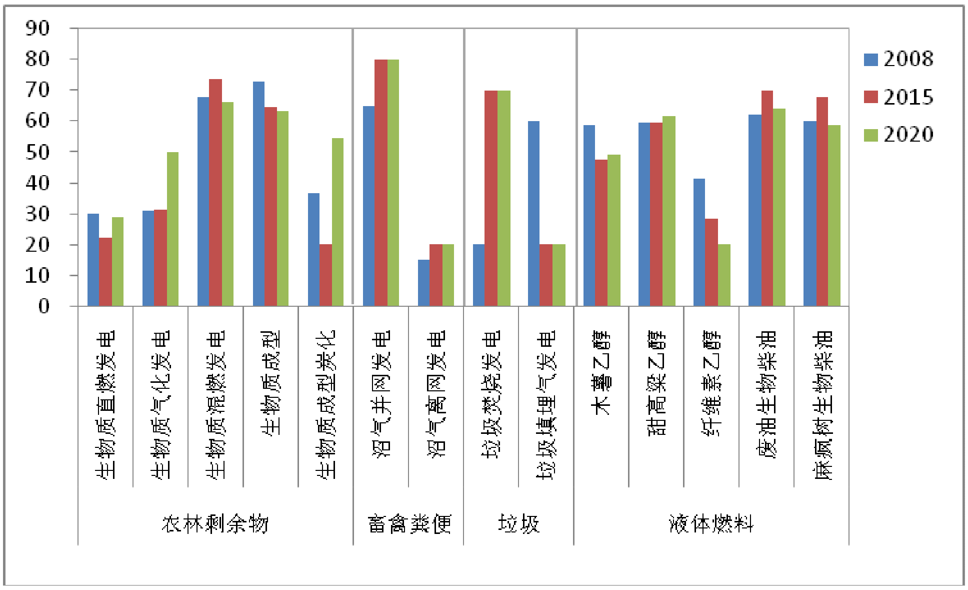

Figure 7-3 Biomass energy technology benefits and future trends

The analysis is summarized as follows:

1. By 2020, overall performance of most of biomass energy technologies will be improved (benefits of most of technologies are satisfactory. Market deployment of the biomass technologies is possible.).
2. By 2020, overall performance of biomass direct combustion power generation can be the same with that in 2008, mainly due to worsen economic performance, while the energy and environmental benefit can be better.
3. Landfill gas power generation will encounter significant performance down because higher land cost results in poorer project economy and stricter environmental regulations increases project investment and hence results in less economic achievement.
4. Solid waste incineration power generation will have much better overall performance and become a dominant technology in China's municipal solid waste treatment for energy.
5. Co-firing generation will have greater overall performance than direct combustion. Once the metering obstacle is solved, the technology will become a mainstream for scale deployment of crop biomass power generation.
6. By 2020, overall performance of crop residue biomass gasification and carbonization technologies will be significant and become a powerful driving force for rural energy solutions of efficient and clean fuel.
7. Development of biomass energy technologies should follow the principle of fully utilizing

local resources. Based on available biomass resources, development plan should also consider local economy and social development, farmer income, weather conditions, transportation, and environmental protection.

8. When local biomass resources can support multiple technologies, they must be selected according to overall performance. For example, for crop residues for energy technologies, priority technologies should be co-firing, pellet fuel, carbonization, gasification generation, and direct combustion. For livestock waste resource, in-grid biogas power generation technology should be firstly considered. And solid waste incineration power generation should be the top technology for municipal solid waste biomass energy alternatives.

Table 7-3 Overall benefit assessment for biomass energy technologies

Technology	Direct combustion	Gasification power	Co-firing power generation	Pellet fuel	carbonization	In-grid biogas power	Off-grid biogas power	Solid waste incineration	Landfill gas generation
2008	30	31	68	73	37	65	15	20	60
Resource collection	0	88	27	100	90	100	0	0	100
Economy	0	5	100	90	66	100	0	0	100
Employment	4	5	0	100	22	0	100	0	100
Farmer income	100	57	57	49	0	0	0	0	0
Environmental benefit	60	53	100	10	0	100	0	100	0
Energy performance	12	0	78	100	25	100	0	100	0
2015	22	32	74	64	20	80	20	70	20
Resource collection	0	89	16	100	89	100	0	0	100
Economy	0	14	100	55	12	100	0	100	0
Employment	5	7	0	100	62	0	100	0	100
Farmer income	100	63	63	56	0	0	100	0	0
Environmental benefit	71	67	100	10	0	100	0	100	0

Energy performance	8	0	71	100	1	100	0	100	0
2020	29	50	66	63	55	80	20	70	20
Resource collection	2	90	0	100	89	100	0	0	100
Economy	0	49	87	52	100	100	0	100	0
Employment	4	6	0	100	59	0	100	0	100
Farmer income	100	68	68	62	0	0	100	0	0
Environmental benefit	89	81	100	8	0	100	0	100	0
Energy performance	33	13	63	100	0	100	0	100	0

8. Supporting measures

8.1 Resource investigation and development plans

Biomass resource investigation on availability, competing uses, and resource distribution will be fundamental for biomass energy development. Relevant administrations should make prompt efforts in scientific and systematic biomass resource investigation and assessment in order to make comprehensive biomass development plans, define objectives and targets, and guide rational resource exploitations in the future.

To ensure implementation of the national strategy of "without competing use of arable land and without affecting grain production" in biomass development, land use plans for energy plantation should be formulated in order to protect China's forest, vegetation, and wet land.

8.2 Technology research and development system

Biomass energy is an emerging industry. Many critical technologies are at early development stage. It is important to establish and strengthen technology R&D capacity building activities. Two of efforts should be focused: supporting biomass technology R&D system and strengthening technical training activities.

The national government should integrate existing resources to establish the technology platform by establishing a national RE center and a series of common technology research and development capacities. Biomass technology development should also focus on basic research, while strengthening manufacturing and production technical process development. National investment should lead to technical advancement and industrial development.

Support should be strengthened on biomass technology talent development and technical training program. Biomass technology should be included into the university curricula and technical training program so that levels of technical experts, engineers, and skilled workers should be developed.

8.3 Pilot and demonstration

To promote biomass energy industry in China, national and local government should actively deploy biomass energy development pilot and demonstration projects based on local resources, technical strengths, and development strategies. The pilot and demonstration projects will focus on establishing biomass industry and improving service system. Through pilot and demonstration, technology advancement will be promoted, management and technical service improved, and biomass energy industry speeded up. A complete industrial chain will be developed for biomass supply, processing, market development, and technical service systems.

8.4 Tariff incentives

Since 2006, China has been applied a feed-in tariff system for biomass power projects at 0.25Yuan/kWh. Additional subsidies of 0.10Yuan/kWh for biomass direct combustion power generation projects are also available. These incentive policies have encouraged biomass power project development. However due to the diversified biomass technologies at different application stages, the two differentiated tariffs are insufficient to support all biomass power technologies. Meanwhile, due to the big gap in the benchmark coal generation tariffs between different provinces, their biomass power prices can be very different. Balanced biomass power tariffs among provinces can be an important study focus. The national price administration should work out a diversified system of effective biomass power project tariffs to promote further biomass energy development, based on local biomass technology characteristics and according to balanced biomass technology development principle.

8.5 Financial and tax incentive policies

Due to the high cost and weak market competitiveness, financial and tax incentives are common instruments in the world to encourage biomass technology applications.

It is clearly indicated in the revised Renewable Energy Law that national financial administration shall set up a renewable energy development foundation. The funding sources can be from financial special fund for each fiscal year and from RE tariff surcharges levy. The State Council's financial administration shall further define the special fund and RE development foundation budget and detailed spending regulations to ensure financial support for biomass energy and other renewable energy development. In addition, financial and tax administrations shall set up tax incentives for promoting biomass energy development and utilization and provide income tax and VAT tax incentives for biomass energy technology research and development, manufacturing, and project development enterprises.

8.6 Standards, testing, and certification system

Standardization, testing, and certification systems are necessary to ensure product quality. Along with biomass technology development, biomass energy product standards, project acceptance standards, power grid integration standards, and other biomass technical codes shall be developed based on R&D and demonstration activities to set up solid foundations for scaled biomass industry in China.

China will support to establish a national biomass energy product testing center to carry out regular biomass energy product testing, quality surveillance, to improve product quality.

For large scale produced biomass energy products, a certification system should be established based on the standard and product testing to guide enterprises to a regulated production and market operation so that biomass technologies can be scale applied in the market.

8.7 Market development

National power grid operators and oil seller companies shall follow the RE Law to fulfill their obligations in fully purchase of electric power from renewable sources and biofuels. Infrastructures for power grid and oil products shall be fully studied and improved. Biomass power market environment shall be improved. Biomass energy product purchase and sales activities should be strengthened to promote large scale biomass power, biogas, and biofuel applications. So far, biomass power projects are generally at small scale without or difficult to obtain permission of power grid interconnection. Large scale biogas projects, biomass pellet fuel, and other clean biofuel products should be promoted for commercial applications. Based on the characteristics of dispersed biomass resources, localized production, and wide farmer involvement, small biomass energy projects should be encouraged by establishing biomass resource collection networks. Enterprises and local government should make active efforts to effectively increase farmers' job opportunities and their income.