Chapter 8
Liquid Biofuels

Chang Shiyan, Zhao Lili, Zhang Ting, and Zhang Xiliang

Abstract Over the last 10 years, the development of biofuels in China has undergone three distinct stages. By the end of 2010, the utilization of fuel ethanol reached 1.86 million tonnes in China and that of biodiesel was about two million tonnes. This chapter analyzes the biomass resource potential in China and reviews conversion technologies and policies. A scenario-based analysis on projecting the use of biofuels by 2050 is carried out. The major conclusions include the following: (1) Biofuel production will continue to grow in China until 2050, and the actual supply capacity will be about 32.4–79.7 million tonnes of oil equivalent (mtoe) in 2050; (2) biodiesel will continue to rise, accounting for over 50 % of total biofuel production after 2030; and (3) second-generation biofuels will serve as important alternatives in the long term. Several suggestions regarding biofuels are also proposed.

Keywords Biofuel • China • Policy

Throughout the world, biofuels developed rapidly during the period of 2000–2010, with the yield increasing 6.25-fold from 16 to 100 billion L (IEA 2011). According to projections in the *Biofuels Technology Roadmap* published by the International Energy Agency (IEA) in 2011, 27 % of global transportation fuels by 2050 will derive from biofuels, resulting in a CO_2 reduction of 2.1 billion tonnes. It is predicted that biofuels will play a crucial role in the global transportation fuel mix and that they will contribute greatly to reductions in carbon emissions.

Bioenergy accounts for a large share in the primary energy mix in China, thanks to the country's rich biomass resources. Over the past 10 years, China's liquid biofuels industry has gone from nonexistent to then undergoing rapid growth;

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however, that was followed by a period of stagnation. Biofuels have been included among national development strategies for science and technology and for industrial optimization.

8.1 Current Status

8.1.1 Fuel Ethanol Grows Slowly: 2010 Utilization Volume Far Less Than Planned

Over the last 10 years, the development of biofuels in China has undergone three distinct stages. At the start year of 2001, the Chinese government approved the construction of four fuel ethanol plants, with an initial capacity of 1.02 million tonnes. In 2002, five cities (Zhengzhou, Luoyang, and Nanyang in Henan Province and Harbin and Zhaodong in Heilongjiang Province) were chosen to launch the Vehicle-Use Ethanol Gasoline Pilot Testing Program. In 2004, the National Development and Reform Commission (NDRC) and seven other departments expanded the test areas for fuel ethanol to cover the whole areas of five provinces (Heilongjiang, Jilin, Liaoning, Henan, and Anhui) and partial areas of four provinces (Hubei, Shandong, Hebei, and Jiangsu). From 2004 to 2006, the use of biofuels grew rapidly. In December 2006, to promote the entry regulations for biofuels, the NDRC and Ministry of Finance (MOF) issued the “Circular on Strengthening Construction Management of Fuel Ethanol and Promoting Healthy Development of Industries.” After the regulations were enforced, the diffusion of biofuels slowed significantly and the increase in production came mainly from expanding the capacity with existing projects. By the end of 2010, the utilization of fuel ethanol amounted to 1.86 million tonnes in China (Zhao et al. 2011) (Fig. 8.1); that was only 18.5 % of the goal targeted in the Medium- and Long-Term Development Plan for Renewable Energy in China (2007).

8.1.2 Biodiesel Utilization Exceeded the Goal: Volume Far Behind Accumulated Capacity

In China, biodiesel is produced mainly from waste oil. The annual production capacity for biodiesel is estimated to be two million tonnes (China Renewable Energy Society 2011). Plants using waste oil as feedstock face many difficulties in terms of feedstock collection and marketing, and so the actual utilization of biodiesel is only 400,000 tonnes (Zhao et al. 2011) (Fig. 8.1). Following

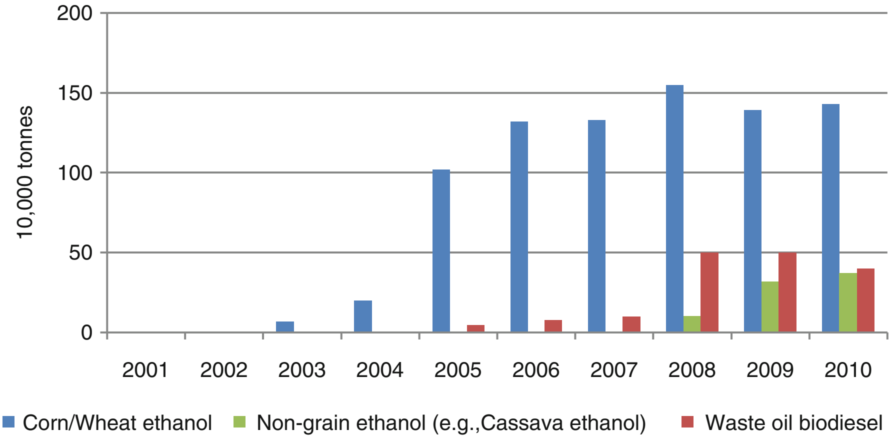

Fig. 8.1 Status of biofuel development in China

research and demonstration efforts, some projects have undergone expansion using oil-bearing energy crops, such as *Jatropha*, as feedstock. In 2007, three *Jatropha* biodiesel projects were approved by NDRC, including those of Petrochina Nanchong Petrochemical Co., Ltd. (60,000 tonnes/annum), SINOPEC Guizhou Oil Products Company (50,000 tonnes/annum), and CNOOC Hainan Biodiesel Project (60,000 tonnes/annum). The Hainan Biodiesel Project has been put into operation.

8.2 Biomass Resource Potential

Biomass resource is the basic input for liquid biofuel conversion. Although biomass is renewable, there is uncertainty about the volume of the resource available for large-scale, cost-effective use within a certain time frame. It is very important to carry out an assessment of biomass resource. In this context, biomass resource can be categorized as either a plantation resource or a non-plantation[1] resource, according to the input factors of production (especially land). Plantation resources consist of plants used for energy purposes, whereas non-plantation resources consist of all kinds of residues and wastes during planting and processing, mainly cellulosic biomass.

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[1] The concept of the non-plantation resource comes from Bhattacharya et al. (2005) and Li et al. (2005). The scope of non-plantation resources is very large, and this chapter does not examine such areas as animal waste and industrial organic waste since the focus here is on liquid biofuels.

Table 8.1 Biomass resource inventory

Resource	Feedstock	Fuel products
Plantation resources	Non-grain agricultural energy crops Cassava, sweet sorghum, sweet potato, etc.	Fuel ethanol
	Oil-bearing trees *Jatropha*, Chinese Pistache, etc.	Biodiesel
	Lignocellulosic energy crops Fast-growing trees and grasses	Cellulosic ethanol, biodiesel or bio-oil
Non-plantation resources	Agricultural residues Primary residues Secondary residues from agricultural processing	Cellulosic ethanol, biodiesel, or bio-oil
	Forestry residues Primary residues: logging and forestation residues, logging and slash of firewood forest, stump refreshing and rejuvenation residuals of shrub forest, fostering and intermediate cutting residuals, updating and trimming residuals of municipal greening Secondary residues: residues from forestry processing	Cellulosic ethanol, biodiesel, or bio-oil
	Tertiary residues Residues from municipal solid waste	
	Others Used waste oil	Biodiesel

8.2.1 Biomass Resource Inventories

The General Office of the State Council and NDRC issued a succession of notices in 2007 about the production of oilseed crops and healthy processing of maize. These notices emphasized stricter regulations being imposed on the conversion of rapeseed for biodiesel and projects for processing maize into fuel ethanol would no longer be established. It was stated in the Medium- and Long-Term Development Plan for Renewable Energy (2007) that no new fuel ethanol projects using edible feedstock would be part of near-term planning efforts. Instead, the rational use of non-grain raw materials for producing fuel ethanol was encouraged. In the near term, the priorities for producing fuel ethanol were placed on non-grain feedstock, such as cassava, sweet potato, and sweet sorghum; such oil-bearing plants as *Jatropha* and Chinese Pistache were to be used for producing biodiesel. It was stated that the used-oil-recovery system in the catering industry should be gradually established. For the long term, cellulosic biomass-derived biofuels would be actively promoted. In accordance with the above policies, the plantation resources discussed in this chapter do not include such crops as corn and wheat nor do they include oilseed crops, such as rapeseed (Table 8.1).

Table 8.2 Collectable volume of crop straw (2010)

Agricultural product		Production/ 10,000 tonnes[a]	Coefficient/ tonne/ tonne[b]	Generation of straw/ 10,000 tonnes	Collectable coefficient/ tonne/ tonne[c]	Collectable volume/ 10,000 tonnes
Grain	Rice	19,576	1.00	19,576.00	0.75	14,682.00
	Wheat	11,518	1.17	13,476.06	0.74	9,972.28
	Corn	17,725	1.04	18,434.00	0.95	17,512.30
	Bean	1,897	1.50	2,845.50	0.88	2,504.04
	Tuber	3,114	0.50	1,557	0.8	1,245.6
Cotton		596.1	2.91	1,734.65	0.9	1,561.19
Oil-bearing crop	Peanut	1,564.4	1.14	1,783.42	0.88	1,569.41
	Rapeseed	1,308.2	2.87	3,754.53	0.88	3,303.99
	Sesame	58.7	2.01	117.99	0.88	103.83
Fiber crop		31.7	1.73	54.84	0.87	47.71
Sugar crop	Sugarcane	11,078.9	0.1[d]	1,107.89	0.88	974.94
	Beetroot	929.6	0.43	399.73	0.88	351.76
Tobacco		300.4	0.71	213.28	0.8[e]	170.63
Total				65,054.89		53,999.68

Notes:

[a] Data are from the National Bureau of Statistics of China (2011)

[b] The definition of coefficients comes from Xie et al. (2011a, b). National average values for the straw coefficients are applied in this context

[c] The collectable coefficients are quoted from Cai et al. (2011)

[d] Data are from the Research Group of China's Renewable Energy Development Strategy (2008)

[e] Estimated value

8.2.2 Non-plantation Resources Have Large Potential with Various Competitive Uses

8.2.2.1 Non-plantation Resource Potential

Agricultural Residues

The rough volume of agricultural residues in China may be estimated based on the output of the main crops, straw coefficients, and collection coefficients. The equation is as follows:

$$\mathrm{CA}_j = \sum_{i=1}^{n} P_{ij} \times \mathrm{PRR}_{ij} \times \alpha_{ij} \tag{8.1}$$

where i is the crop type, which equals 1, 2, 3, …, 13 in the context; j signifies years; CA_j is the collectable volume of crop straw; P_{ij} is the crop output; PRR_{ij} is the straw coefficient; $P_{ij} \times \mathrm{PRR}_{ij}$ is straw generation; and α_{ij} is the straw collection coefficient. The overall crop straw volume of China in 2010 was about 651 million tonnes, and the collectable volume amounted to 540 million tonnes (Table 8.2).

Forestry Residues

Forestry residues come from multiple resources, including logging and forestation residues, residues from the forestry processing industry, fostering and intermediate cutting residuals, residues from economic forest cultivation and cutting, and logging and processing residues of bamboo forests. The volume of forestry residues of China is roughly 855 million tonnes at present, among which 461 tonnes are collectable (Table 8.3).

Other Non-plantation Residues

In addition to agroforestry residues, waste oil is another important feedstock used to produce liquid biofuels in China (Table 8.4).

8.2.2.2 Competitive Uses of Non-plantation Resources

Crop residues are important organic and energy resources. In the agricultural production cycle, they play a crucial role in maintaining soil fertility, avoiding soil erosion and supporting continuous crop production (Xie et al. 2011a, b). In addition to being returned to the field, crop straw can be put to many uses. Crop residues have been long used as primary forage for raising stock and as fuel for heating and cooking in rural China. Two projects encouraged the utilization of crop residues as part of China's industrial adjustment policy were Returning Crop Straw to Fields and Comprehensive Use of Crop Straw (including silage, ammoniated straw for raising cattle, edible fungi breeding, man-made board from crop straw, lignocellulosic fuel ethanol from crop straw, non-grain exploitation and development of forage, straw biogas, straw pyrolysis, gasification, and pelleting) and Processing and Product Development of Low-Quality Wood Fuel and Its Residues. In utilizing forestry residues, the stumping residues of shrubs can be used in such areas as livestock feeding, weaving, and boarding production. The residues produced from logging in mills (including laths, sawdust, wood shavings, blocks, and fragments) can be used in man-made board production, animal feeding, and papermaking. Figure 8.2 presents an analysis of competitive uses of agroforestry residues. Because of competitive uses, the volume of crop straw for energy use[2] is only 81 million tonnes, and that for forestry residues is 124.41 million tonnes. If other uses of biomass (direct combustion, gasification and power generation of agroforestry residues, centralized gasification of straws, and straw briquettes[3]) are considered, the residue resources for liquid biofuels production amount to only 185 million tonnes.

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[2] Following the definition of Cai et al. (2011), the traditional use of residues as burning fuels is not included.

[3] In 2010, the volume of agroforestry residues for modern bioenergy use was about 21 million tonnes.

Table 8.3 Forestry residue potential

Type		Production	Unit	Coefficient[a]	Unit	Generation of residues	Collectable coefficient[a]	Collectable volume/10,000 tonnes
Logging residues	Commercial timber	1,5769.7[b]	10,000 m^3	0.47[b]	tonne/m^3	7,380.22	0.7[c]	5,166.15
	Noncommercial timber	9,045.8[b]	10,000 m^3	0.59[b]	tonne/m^3	5,291.79	0.7[c]	3,704.26
Forest tending and thinning residues		19,545.22[d]	10,000 hm^2	2.2[e]	tonne/ha	43,021.81	0.25[c]	10,755.45
Firewood-harvesting material		174.73[d]	10,000 hm^2	16.00[c]	tonne/ha	2,795.68	0.80[c]	2,236.54
Shrub stubble and rejuvenation residues		5,365.34[d]	10,000 hm^2	3.33[f]	tonne/ha	17,866.58	1[c]	17,866.58
Urban greening update and pruning residues		–	–	–		5,500[c]	0.5[c]	2,750
Processing residues		–	–	–	–	3,600[c]	1[c]	3,600
Total		–	–	–	–	85,456.08	–	46,078.99

Notes:

[a] The definitions of generation volume and collectable volume of forestry residues are the same as with agricultural residues. The coefficients of generation and collection are estimated empirically

[b] According to the forest logging limits set by the State Council, the quota for forest logging in China is 248 million m^3 annually, including 158 million m^3 of commercial timber and 90 million m^3 of noncommercial timber. Based on the data of various forest zones, the volume of logging and processing residues may be calculated by the biomass ratio of forest woods, with 40 % being commercial timber and 50 % noncommercial timber. The biomass is defined as 1.17 tonnes/m^3

[c] Data come from Zhang and Lv (2008)

[d] Data come from the Seventh National Forest Resource Inventory

[e] The coefficient is estimated based on the residue volume of 340–403 million tonnes concluded by Wang et al. (2006)

[f] Most shrub forests are rejuvenated by stumping. The biomass obtained from shrub stumping amounts to 8–12 tonnes/hm^2 (10 tonnes/hm^2 is taken in the context), with stumping taking place every third year

Table 8.4 Collectable waste oil

Type	Feedstock	Consumption	Coefficient	Generation of residues/ 10,000 tonnes	Collectable coefficient	Collectable volume/ 10,000 tonnes
Waste oil	Food oil	2,680[a]	0.2–0.3	670[b]	0.5[c]	335

Notes:

[a] The population in 2010 was 1.34 billion (National Bureau of Statistics of China 2011), and the assumed per capita consumption of food oil was 20 kg/annum

[b] The value of 0.25 is taken as the residue coefficient

[c] Estimated value

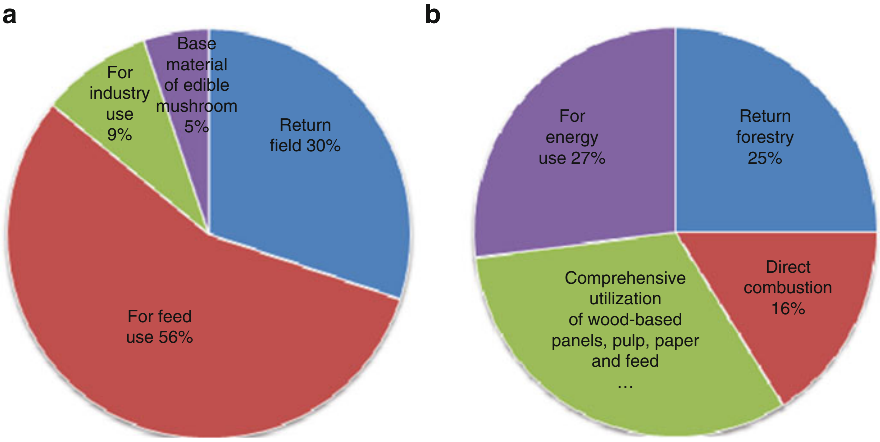

Fig. 8.2 Competitive uses of (**a**) agricultural residues and (**b**) forestry residues. *Notes*: The data for agricultural residues are derived from Cai et al. (2011), including the ratio of residues returned to the field, the volume of residues used as forage, industrial feedstock, and base material for edible mushroom growing and also the volume for rural energy use (direct combustion of residues); the ratios of forestry residues come from Chang et al. (2009)

8.2.2.3 Non-plantation Resources Potential and Increase

The increased use of non-plantation resources is uncertain. More and more residues will be used for energy conversion in China through the industrialization of China's bioenergy development, technological advances in converting agroforestry residues, and reduction in the cost of residue collection. Through related policies and planning, research results indicate that a number of positive factors will facilitate the long-term increase in non-plantation resources (Table 8.5).

Agricultural residues consist primarily of grain crop residues. Taking 2010 as an example, the grain yield accounted for 77 % of several main agricultural products. It is estimated that the collectable straw from grain crops amounted to 85 % of the total collectable straw. Therefore, the long-term volume of collectable crop straw may be estimated based on long-term grain production:

$$\mathrm{CA}_{kj} = P_{kj} \times \beta_{kj} \tag{8.2}$$

Table 8.5 Policies and research results on potential growth of non-plantation resources

Type	Index	Reference	Content
Crop straw	Food yield	State Council (2008)	The cultivated area is greater than or equal to 1.8 billion mu (*120 million ha*), which is the binding target by 2020. Grain yields will increase from 316.2 kg/mu in 2007 to 350 kg/mu in 2020. And the overall grain production capacity should be greater than 540 million tonnes in 2020
		Institute of Agricultural Economics and Development, Chinese Academy of Agricultural Sciences (2007)	Projections indicate that China's food production will continue to grow and will reach 597 million tonnes in 2050 (Medium Scenario)
	Straw volume	Ministry of Agriculture (2007)	It is projected that China's main crop straw production will reach 900 million tonnes in 2015, of which about half can be used as the feedstock of bioenergy
		Shi (2011)	It is projected that crop straw production in 2030 will increase by 64 % compared with 2007, i.e., 137 million tonnes
Forestry residues	Forest coverage	State Forestry Bureau (2009)	China's forest industry sets up three targets in addressing climate change as follows: by 2010, the national forest coverage rate amounts to 20 %; by 2020, the national forest coverage increases to 23 %; by 2050, the forest coverage rate will amount to and stabilize at more than 26 %
	Logging residues	State Council (2011)	Forest cutting quota (excluding bamboo cutting quota) during the period of the Twelfth Five-Year Plan is 271.054 million m^3 per year, of which 218.359 million m^3 is for commercial timber harvesting and 52.695 million m^3 for public welfare forest harvesting (rearing, rejuvenation, and others)

where $k = 1, 2$ (agricultural residues, forestry residues); j signifies years; CA_{1j} is the collectable volume of crop straw; P_{1j} is the production of crops; and β_{1j} is the coefficient of comprehensive collectable crop straw. The collectable crop straw volume will be roughly 599 million tonnes by 2050 if "1" is applied, which is the

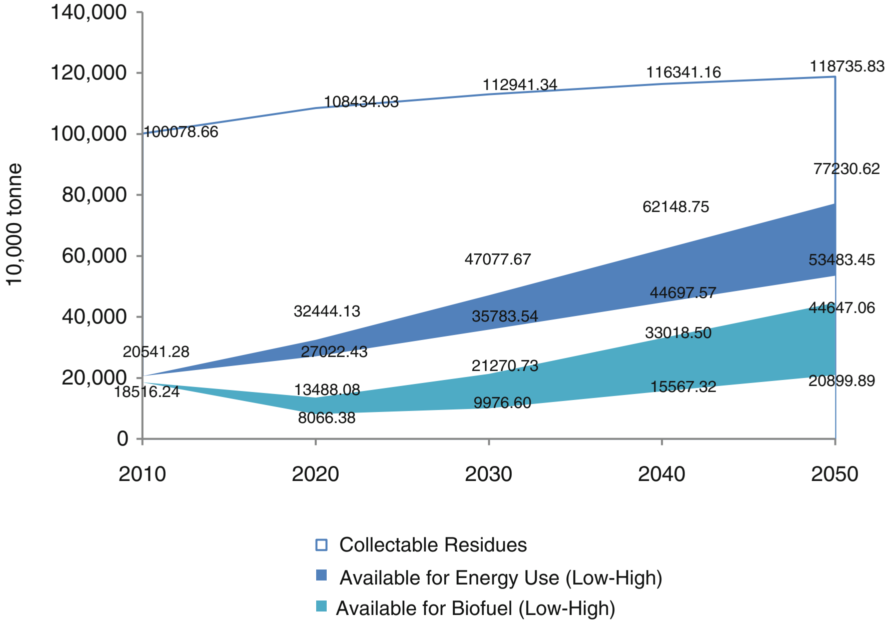

Fig. 8.3 Agroforestry resource potential in China

coefficient of comprehensive collectable crop straw for 2010. Similarly, the volume of forestry residues may be calculated based on the expected forest area. P_{2j} is the area of forest, and β_{2j} is the coefficient of comprehensive collectable forestry residues.

It is estimated that the potential of China's agroforestry residues will be roughly 1.187 billion tonnes by 2050. However, only 535–772 million tonnes could be put into energy use. The amount available for liquid biofuels will be about 209–446 million tonnes, taking into account the competitive uses of residues (Fig. 8.3, Appendix 8.1).

8.2.3 Plantation Resource Potential Uncertain Owing to Multiple Constraints

The plantation resources for liquid biofuels consist of non-grain sugars, starch plants, oil-bearing plants, lignin cellulosic plants, and oil-bearing microalgae (Xie 2011). Non-grain sugars and starch plants include sweet sorghum, cassava, and sweet potatoes. Oil-bearing plants include *Jatropha* and Chinese Pistache and so on. Lignin cellulosic plants consist of short-rotation woody crops, such as poplars, and fast-growing herbaceous plants, such as switchgrass.

8.2.3.1 Potential of Plantation Resource

Method

The main difference between energy crops and non-plantation resources is the requirement for land and possible resulting land-use changes. The potential for energy crops can be determined by the prospective area for crop plantation and the average crop production per unit land (Japan Institute of Energy 2007; Haberl et al. 2010). The direct equivalent method (Sidebar 8.1) is used in this study to calculate the energy crops potential in China. For those resources whose heat values cannot be estimated directly, including non-grain sugar materials, starch plants, and oil-bearing plants, the potential is estimated according to the heat value of their fuel products. The potential of lignocellulosic plants is assessed based on their own heat values. The estimation is made based on the following equation:

$$P_{lj} = \mathrm{Pro}_{lj} \times \mathrm{ML}_{lj} \times \mathrm{LHV}_{lj} \tag{8.3}$$

where l is the type of energy crop; j signifies years; P_{lj} is the potential of energy crops; Pro_{lj} is the average production per unit of marginal land; ML_{lj} is the area of marginal land available for energy crop plantation; LHV_{lj} is the low heat value of possible fuel products if l is sugar, starch plants, and oil-bearing plants; and LHV_{lj} is their own low heat value when l is lignocellulosic plants.

Sidebar 8.1: Three Methods for Calculating Biomass Potential

The resource potential of energy crops is calculated based on bioenergy potential. The following methods are usually applied:

1. Primary energy method
   The resource potential is estimated based on the heat value of biomass itself, ignoring the energy loss in biomass conversion. The method is applied generally in estimating the global biomass resource potential. Haberl et al. (2010) assumed that all biomass resources are calculated on their dry mass and that the carbon shares in different resources are the same, i.e., 0.5 tonnes per tonne of biomass, equivalent to 18.5 MJ/kg.
2. Method of theoretical conversion ratio
   For sugar and oil-bearing plants, de Wit and Faaij (2010) proposed estimating the potential according to the heat value of sugar and oil obtained by pressing the feedstock, i.e., the volume of biomass resource is multiplied by the compression ratio and by the heat value of sugar or oil. This method is more accurate than the primary energy method.

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3. Direct equivalent method (hybrid method)
   In estimating the renewable energy resource potential, IPCC (2011) utilized the primary energy method in the field of bioenergy. However, in the fields of wind, solar, and nuclear energy, IPCC calculated the potential based on the heat values of the products—an approach called the direct equivalent method. This method is also applied in regional analysis in the case of feedstock that can be subdivided into various types and where the manner of production with each type is different from the others. For example, in estimating China's biomass resource potential, the Research Group of China's Renewable Energy Development Strategy (2008) and Shi (2011) applied the primary energy method to calculate the potential of agroforestry residues and fast-growing energy plants; however, they employed the method of theoretical conversion ratio to calculate the potential of sugar, starch, and oil-bearing plants, and that corresponded to the results with the direct equivalent method. For the purpose of comparison with other studies, the present chapter uses the same methods as those originally adopted.

Main Energy Crops

The energy crops grown in China vary in terms of plantation conditions, marketing, and production per unit land area, as shown in Table 8.6.

Resource Potential of Energy Crops

The potential of China's energy crop resources depends on the area of available marginal land and average production per unit land area. According to the present techno-economic trend, energy crop resources will increase in the future, though with uncertainty over the volume of increasing resources. In terms of driving factors, the main factors for supply increase are the expansion of available marginal land and the increase of output per unit land. Energy crops may be improved by such methods as crossbreeding, physically induced mutation breeding, chemically induced breeding, cell engineering, and genetic engineering, which result in increased output per unit land. In the long term, the area of available marginal land for energy crop planting is the hard constraint.

There is considerable uncertainty regarding the area of marginal land in China for energy crop planting. Figures in the literature range from 83 to 203 million ha (Appendix 8.2). This chapter adopts 113 million ha as a reasonable value. Among unused land, the marginal land available for agriculture is 7.02 million hm^2, marginal land available for forestry is 37.36 million hm^2, and arable land available

Table 8.6 Main characteristics of energy crops grown in China

Energy crops		Current plantation	Current market	Yield	
				tonnes/ha	tonnes/ha
Sugar and starch crops	Cassava	Cassava was harvested over a total area of 387,400 ha in 2008, with the total output of 7.9394 million tonnes (Fang et al. 2010). Main producing areas are Guangxi, Guangdong, Hainan, Yunnan, and Fujian provinces, among which Guangxi accounts for over 60 % of the national harvest area and fresh cassava production. At present, four dominant cassava-growing zones have been primarily established: west Hainan and west Guangdong; south Guangxi, east Guangxi, and central Guangdong; west Guangxi and south Yunnan; east Guangdong and southwest Fujian (Huang et al. 2008)	The proportion of cassava used as forage (including that self-used by farmers) in 2007 was 30 %; the remaining 70 % was used for producing starch, ethanol, starch sugar, etc. (Tian et al. 2010)	20.55 (average in 2008) 45–75 (high yield)	2.94–4.11 (fuel ethanol)[a] 6.43–15 (fuel ethanol)[a]
	Sweet sorghum	Pilot plantations have been carried out in Huachuan of Heilongjiang, Urumqi of Xinjiang, Anqing of Shandong, Hohhot of Inner Mongolia, and Chaoyang of Liaoning Province, and among others. Sweet sorghum breeding and cultivation techniques have been included in national high-tech research development plans	No mature market is available. A small amount of sweet sorghums is used for making alcohol and as animal feed	60–80 (straw)	3.75–5 (fuel ethanol)[b]

(continued)

Table 8.6 (continued)

Energy crops		Current plantation	Current market	Yield	
				tonnes/ha	tonnes/ha
	Sweet potato	Sweet potato cultivation area was 4.76 million ha in 2008, with the production of 102 million tonnes (Department of Rural S&T, Ministry of Science and Technology 2009)	50 % for livestock feed, 15 % for industrial processing, 14 % as food, 6 % for breeding, and 15 % falling into decay (Jin et al. 2011)	21.47 (average value)	2.39–3.07 (fuel ethanol)[c]
Oil-bearing trees[d]	*Jatropha*	Demonstration planting bases in Panzhihua of Sichuan, Hainan, Guangxi, and other places have been established	No mature market has been established. A small portion is used for pharmaceutical purposes	1.5–3 (3–5 years after afforestation in the southwest) 6.75–9 (3–5 years after afforestation in Hainan)	0.5–1 (biodiesel)[e] 2.25–3 (biodiesel)[e]
Cellulosic plants	Switchgrass, *Miscanthus*, *Arundo donax*[f]	The United States is cultivating new varieties of switchgrass for bioenergy use through crossbreeding, molecular breeding, and other means. Research institutions in China also began the planting and cultivation of energy grass. For example, according to the Grassland and Environmental Research Development Center, Beijing Academy of Agriculture and Forestry, switchgrass is able to adapt to the barren desertification of marginal land (surface sand, coarse sand, and gravel soil) in north China, but direct seeding on marginal lands is difficult; seedling transplanting is required (Fan et al. 2010)	Can be used for biomass power generation, heating, solid fuel, and liquid fuel raw materials	3.77 (switchgrass)[g] 11.45 (*Arundo donax*)[g]	0.89 (switchgrass)[g, h] 2.7 (*Arundo donax*)[g, h] 2.67–4.5[i]

Fast-growing energy forest	The adaptability of fast-growing energy forest on natural conditions and land is lower	Can be used as feedstock for biomass power generation, briquette and liquid fuel can also be used for feed, weaving, and making plates, and other purposes	2–98.8[j]	0.47–23.4[h]

Notes:

[a] Assuming that 1 tonne of ethanol may be produced from 5–7 tonnes of feedstock

[b] Assuming that 1 tonne of ethanol may be produced from 16 tonnes of crop straw

[c] Assuming that 1 tonne of ethanol may be produced from 7 to 9 tonnes of feedstock

[d] China is rich in oil-bearing trees. According to *Approaches for Inspection and Approval of Forestry Bioenergy Feedstock Bases* (2011), issued by the State Forestry Administration, the major oil-bearing plants in China include *Jatropha*, shiny leaf yellowhorn, Chinese Pistache, *Swida wilsoniana*, *Vernicia fordii*, Chinese tallow tree, and soapnut tree. Thus far, 200,000 hm^2 of oil-bearing energy forestry base has been established

[e] Assuming that 1 tonne of biodiesel may be produced from 3 tonnes of feedstock

[f] Lignocellulosic energy grasses mainly include switchgrass, Chinese silvergrass, *Anaphalis margaritacea* var. *yedoensis*, and bamboo reed

[g] Data come from Hou et al. (2011), which were based on experiments carried out on a large-scale plantation in the land desertified by sand dredging in the Beijing suburbs

[h] Estimation is made based on the higher lignocellulosic ethanol conversion rate (300 L/tonne) (Ralph et al. 2010)

[i] Global average volume and predicted volume for 2050 of lignocellulosic ethanol produced from fast-growing energy grasses, estimated by IEA (2011)

[j] Diversified energy trees are quite different in terms of yield, though all of them are high in production, according to Zhang and Lv (2008)

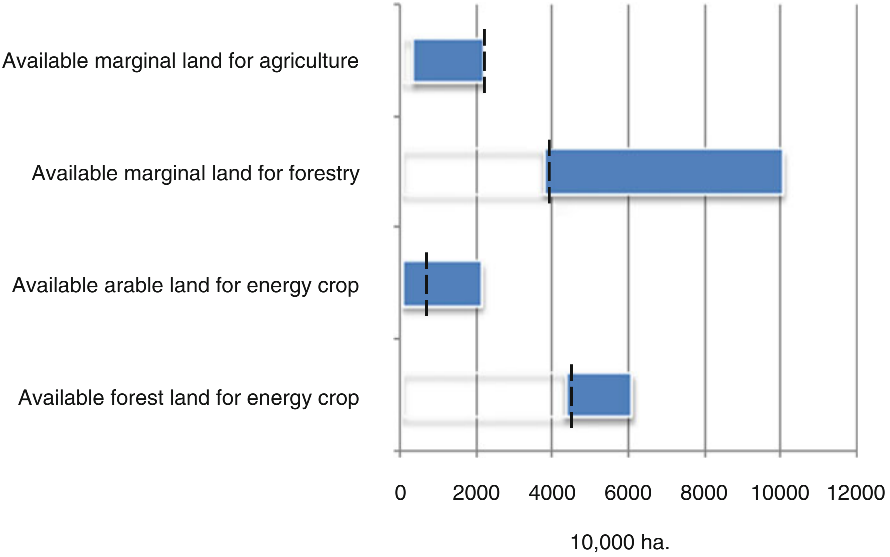

Fig. 8.4 Marginal land in China. *Notes*: the values used in this chapter are indicated by *dotted lines*

for energy crops is 20 million hm^2. In addition, forestland available for energy crop planting is 48.2414 million hm^2 (Fig. 8.4).

The potential of energy crop resources in China is roughly 17.29 EJ (Table 8.7), based on an estimation using the direct equivalent method.

8.2.3.2 Uncertainty Analysis of Plantation Resources

Estimating the biomass resources potential is complex and influenced by numerous factors. Results vary as a result of different research categories and assumptions. Taking the global biomass resources potential as an example, the estimated potential for 2050 varies between 5 and 1,272 EJ—a roughly 240-fold gap of 1,200 EJ (Haberl et al. 2010).

Land resource potential is a vague concept. It is not just a scientific notion but also a concept that involves economic and political factors. For example, an area regarded as appropriate for energy plants in terms of planting technology is different from a suitable planting area using economic criteria (e.g., opportunity cost) and different again from an appropriate area from the perspective of environmental conservation and policies. Accordingly, owing to the variety of categories, the area of available energy crop planting land potential ranges from 60 to 3,700 million hm^2—a 60-fold gap (Haberl et al. 2010) (Fig. 8.5).

Table 8.7 Resource potential of energy crops

Energy crop	Marginal land	Area (10,000 ha)	Yield (tonnes/ha)	Lower heating value (LHV)[a] (GJ/ha)	Potential (EJ)
Sugar and starch energy crops	Available marginal land for agriculture	702	3 (fuel ethanol)	80.10	0.56
	Available arable land for energy crops	2,000	3 (fuel ethanol)	80.10	1.60
Oil-bearing trees	Available unutilized land for oil-bearing trees	2,200	1 (biodiesel)	37.8	0.83
	Available forest land for oil-bearing trees	1,400	1 (biodiesel)	37.8	0.53
Lignocellulosic energy crops	Available unutilized land for lignocellulosic energy crops[b]	1,536.06	15 (feedstock)	277.50	4.26
	Available forest land for lignocellulosic energy crops[b]	3,424.14	15 (feedstock)	277.50	9.50
Total					17.29

Notes:

[a] The heat value of fuel ethanol is defined as 26.7 GJ/tonne, that of biodiesel 37.8 GJ/tonne, and that of lignocellulosic plants 18.5 GJ/tonne (Haberl et al. 2010)

[b] To avoid calculation overlaps, the area available for lignocellulosic plants equals the area of unused land available for forestry plus the area of forestry land available for energy plants minus the proportion for oil-bearing energy plants

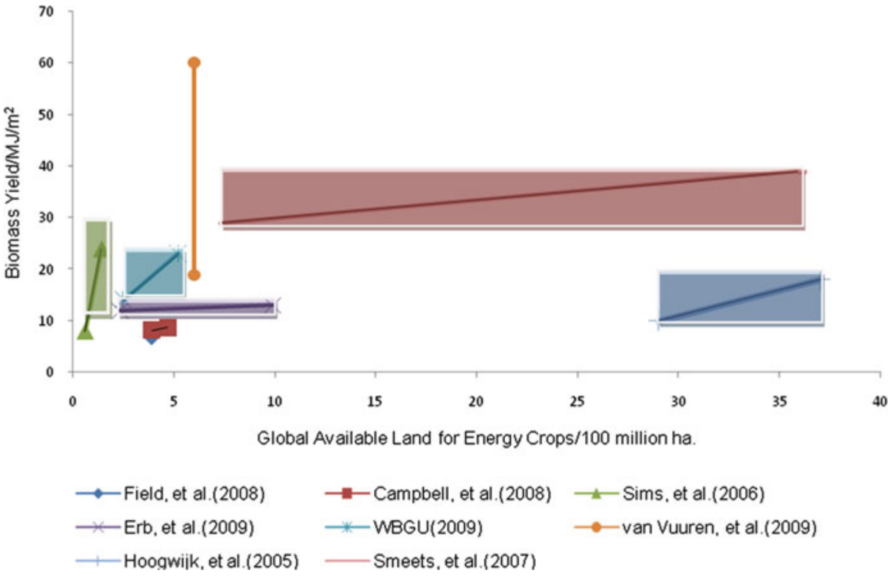

Fig. 8.5 Global marginal land and yield (*Data source*: Haberl et al. 2010)

The development of liquid biofuels depends on the volume of available marginal land. Owing to the negative impact on food security of biofuel production from grains, the principle of “neither competing for food with people, nor competing for arable land with crops” was formulated in the *Development Planning of Agricultural Biomass Energy Industry* by the Ministry of Agriculture (Sidebar 8.2). All studies on marginal land in China have taken social and environmental factors into consideration. The Research Group of China Renewable Energy Strategy (2008) defines marginal land as high-quality land in the category of unused land and lower-quality land in the category of used land. This chapter follows the classification system of the Research Group but with some modifications. Marginal land in this chapter is classified into three categories: (1) unused but usable land suitable for forestation and agricultural planting, (2) existing forestland of oil-bearing trees and potential land suitable for forestry,[4] and (3) low-grade land available for energy crop planting that grows low-yield non-grain products but can be improved by planting structure adjustment. It should be noted that there is even difficulty in utilizing unused but arable land (arable land reserves) to plant energy crops. The exploitation of arable land reserves is difficult since the reserves are mainly distributed in the northeast, northwest, and Huanghuai area. The northeastern reserves are mainly wetland, and drainage systems must be set up to exploit them, but such moves are constrained by wetland conservation policies. The northwestern area suffers from drought, and exploration is therefore constrained by lack of water resources. The largest area of reserved arable land is waste pastureland, which is mainly found in mountainous and hilly areas (Zhang et al. 2004). Accordingly, accurate figures for the area of marginal land available for energy crop planting need further investigation (Appendix 8.2).

Sidebar 8.2: National Reservation Policies for Arable Land (Forestland) and Land Classification in China

The land resources in China are quite limited. In recent years, arable land resources have been decreasing yearly owing to such factors as nonagricultural construction use, ecological restoration, natural disasters, and agricultural structure adjustment, though exploiting land resources enhances the development of China’s economy (Fig. 8.6). The Law of Land Administration emphasized, “It is strictly prohibited to convert land from agricultural to construction use. The total amount of land used for construction should be

(continued)

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[4] The definition of “forestland” comes from the Regulations for the Implementation of Forestry Law of the People’s Republic of China: it consists of arbor forest with a crown density above 0.2, and it includes bamboo forest, shrubbery, and sparse woodland as well as land suitable for forestry planned by county-level or higher governments, i.e., wild mountains and areas suitable for forestry, sand wasteland suitable for forestry, and others.

(continued)
restricted to a certain level. The priority should be put on preserving arable land." Owing to the growing population and other factors, the total demand for food will continue to rise and will amount to 572.5 billion kg by 2020; the demand and supply will be imbalanced in the long run, according to the State Council (2008). For long-term national food security, China puts further emphasis on the strategy of arable land preservation by setting the goal of 1.8 billion mu (120 million hm^2) as the critical area for arable land.

The main policies for arable land (forestland) conservation in China are indicated in Table 8.8.

The Law of Land Administration classifies land into that for farm use, construction use, and unused land. Land for farm use refers to that directly used for agricultural production, including cultivated land, wooded land, grassland, land for farmland water conservancy, and water surfaces for breeding. Land for construction use refers to that on which buildings and structures are erected, including land for urban and rural housing and public facilities, land for industrial and mining use, land for building communications and water conservancy facilities, land for tourism, and land for building military installations. Unused land refers to land other than that for agricultural and construction uses. Adopting additional information from Current Land Use Classification and National Plan for Forestland Conservation Utilization (2010–2020), the category system of China's land is shown in Fig. 8.7.

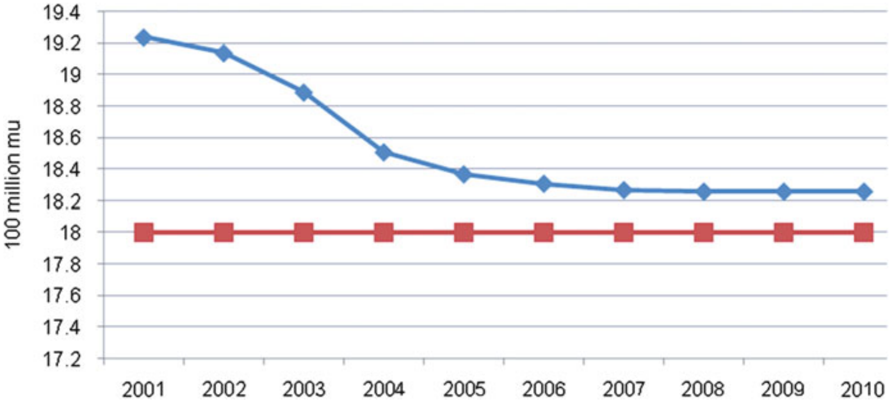


Fig. 8.6 Historical volume of China's arable land

Table 8.8 Main policies for arable land (forestland) conservation in China

Policies	Promulgated by	Date of issue	Related text
Law of Land Administration	Eleventh Session of the Standing Committee of the Tenth National People's Congress	Aug. 20, 2004	Strict control is placed on converting farmland to construction use; the total amount of land for construction use is controlled and cultivated land receives special protection
Regulations on the Protection of Basic Farmland	Decree No. 257 of the State Council	Dec. 27, 1998	The state practices a system of protecting basic farmland. Policies of overall planning, rational utilization, combination of utilization, nurturing, and strict protection shall be adhered to in protecting basic farmland
Eleventh Five-Year Guidelines for National Economy and Social Development	Fourth Session of the Tenth National People's Congress	Mar. 14, 2006	120 million hm^2 was set as a binding target for the total volume of arable land
State Council (2008)	Executive Meeting of the State Council	Jul. 2, 2008	By 2020, the area of arable land should be no less than 1.8 billion mu (12 million hm^2). The quality of basic land should be enhanced, and the area should not been reduced
National Plan for Forest land Conservation Utilization (2010–2020)	Executive Meeting of the State Council	Jun. 9, 2010	By 2020, the volume of forestland will increase to 312 million hm^2, accounting for 32.5 % of the total land area of China. By 2020, the volume of forests will reach 223 million hm^2—an increase of 40 million hm^2 compared with 2005. Forest coverage will amount to 23 % or above

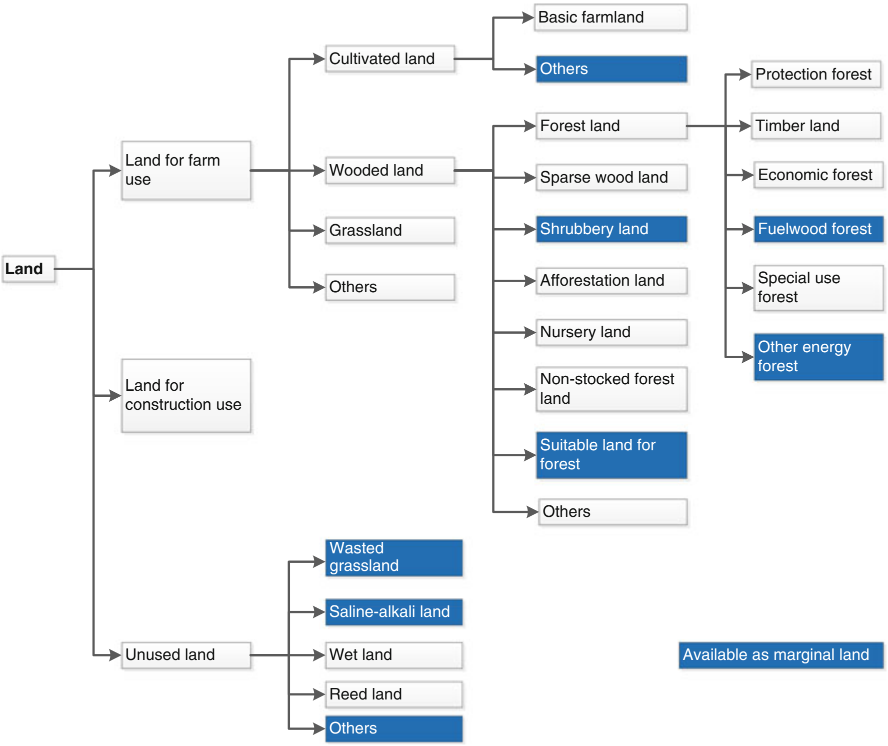


Fig. 8.7 China's land categories and potential marginal land

8.3 Conversion Technology Development and Industrial Policies for Liquid Biofuels

Biofuels may be classified in terms of feedstock, conversion processes, and fuel products (Fig. 8.8). Chinese scholars usually define the fuel ethanol produced from non-food sugar and starch energy crops and biodiesel produced from oil-bearing trees as "1.5-generation" liquid biofuels. They define cellulosic ethanol and Fischer-Tropsch (F-T) biodiesel as second-generation liquid biofuels. Biodiesels from algae are classified as third-generation liquid biofuels.

8.3.1 Non-grain 1.5-Generation Liquid Biofuels

8.3.1.1 Current Status of Non-grain 1.5-Generation Liquid Biofuels

Although the technical route is relatively mature, most raw materials for the world's fuel ethanol are derived from maize and sugarcane, which has aroused considerable

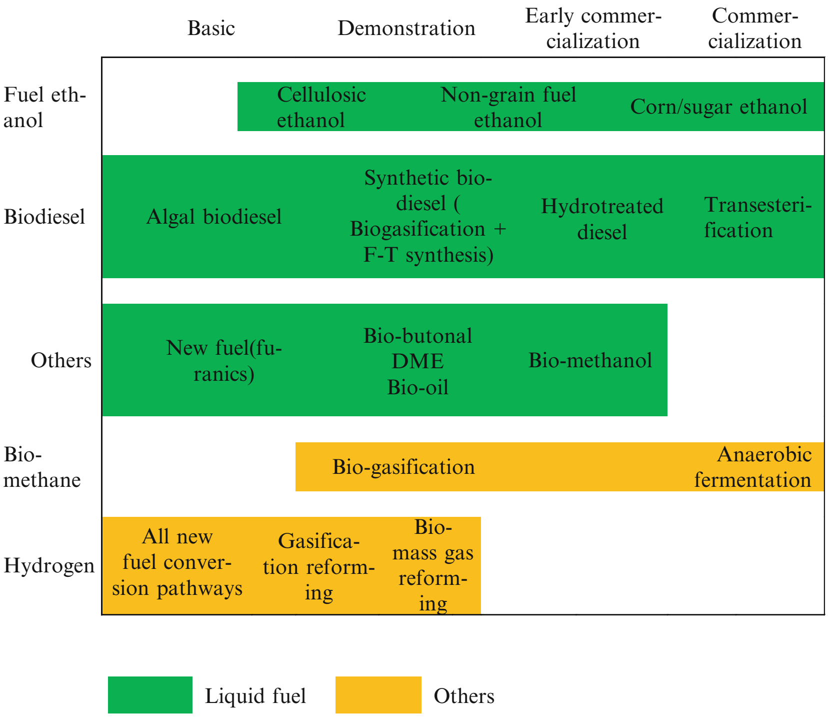


Fig. 8.8 Development stages of bioenergy technology pathways (*Source*: modified from Bauen et al. 2009)

debate in terms of food safety. To solve the problem in supplying raw materials, the global community is actively exploring high-yield non-grain crops as alternatives. Based on soil and weather conditions, China plans to grow such non-food crops as sweet sorghum and cassava on marginal land. Compared with the proven conversion technology with feedstock grain crops, such as maize and wheat, the technical chain of ethanol production using non-grain crops remains at the demonstration or application and promotion stage. Research is needed with respect not only to fuel conversion technology but also in breeding and cultivating the crops and evaluating land suitability.

A cassava fuel ethanol project with a 200,000-tonne capacity has been set up and promoted in Guangxi. In Huachuan, Heilongjiang Province, a demonstration project with a 5,000-tonne capacity for producing ethanol from sweet sorghum has been established. The project applies solid-state fermentation (SSF) technology, and it requires such simple equipment as stalk grinders, combined heating and blending machines, and beer wells. Because of the low investment and variable costs, this technology can be promoted in underdeveloped rural area (Xiao and Yang 2006). Tsinghua University developed a new SSF technology to address the difficulties in storing and transporting sweet sorghum in industrialized ethanol production. A demonstration project with a 127-m^3 capacity has been established and put into operation in Inner Mongolia.

Biodiesel is prepared mainly by transesterification, including chemical catalysis, enzyme catalysis, and supercritical methods. The chemical conversion technology has certain disadvantages, such as high investment for equipment, acidic and alkaline emissions, large-scale water scrubbing, and great energy consumption. Thus, the environmentally friendly process of biological enzyme catalysis has gained a great deal of attention. However, a technology bottleneck is hindering industrialization: the feeding methanol and byproduct (glycerine) inhibit enzyme activity and lead to fast deactivation of the enzyme. To overcome this problem, the Laboratory of Renewable Resources and Bioenergy at the Department of Chemical Engineering of Tsinghua University has developed a new technology. This has been applied by Hunan Rivers Bioengineering Co., Ltd. in establishing a set of biodiesel conversion facilities with an annual capacity of 20,000 tonnes. These were put into commission in 2006.

At present, the total production cost of biodiesel produced from energy crops, such as *Jatropha* and Chinese Pistache, is quite high owing to the expense of the feedstock (Table 8.9).

8.3.1.2 Policies for Non-grain Liquid Biofuels Industry

China has promulgated a variety of policies for the industrial development of non-grain liquid biofuels. But most of the policies related to fuel ethanol were issued before 2007. Few policies were released in the period 2007–2009. The policies for the biodiesel industry are actively implemented to a certain extent, but they have led to some undesirable effects owing to the lack of a supporting scheme for the whole industrial chain (Fig. 8.9). Details of the policies appear in Appendix 8.3.

8.3.2 Second-Generation Biofuel Technology

8.3.2.1 Current Status of Second-Generation Biofuel Technology

Second-generation biofuel technology is defined as technology that makes use of wider resources, such as lignocellulosic biomass, for liquid biofuel production. The technology consists of biochemical, thermal chemical, and hybrid processes. According to statistics of the IEA (2010), the global output of second-generation biofuels is estimated to be 680,000 tonnes, and by 2016 the production will exceed 1.6 million tonnes (Figs. 8.10 and 8.11). The United States is the world leader in second-generation biofuel development, both in terms of capacity and technological development (Fig. 8.12).

Table 8.9 Overview of non-grain 1.5-generation liquid biofuels technology and industry

Technology	Potato bioethanol	Sweet sorghum bioethanol	Waste oil biodiesel	*Jatropha* biodiesel
Development stage	Early commercialization	Demonstration and promotion	Early commercialization	Small-scale pilot projects
Current status	China currently has world's largest cassava bioethanol production facilities	Pilot project with 5,000-tonne capacity been established; NDRC approved preparation for a 100,000-tonne bioethanol project using sweet sorghum stalk as feedstock, undertaken by ZTE Energy Company in Inner Mongolia (Liu et al. 2011)	About 40 biodiesel plants use waste oil in China	3 million mu (200,000 hm^2) of energy woodland for biodiesel production planned (Wang 2011); CNOOC's project with 60,000-tonne capacity put into operation in Dec. 2009 with waste oil as main feedstock
Cost estimation (RMB/tonne)	4,887–6,802	5,444–5,968	7,000	8,000
Of which: proportion of feedstock cost (%)	55.8–68	70.5–73	79.37	75
Technological bottleneck	Stable feedstock cultivation, immature supply mode	Underdeveloped equipment and operations for continuous production	Underdeveloped collection system	Immature fostering and collection technology with underdeveloped system
Potential development in near future	Need for a sound industrial system	Need for a sound industrial system	Need for a sound industrial system	Need for better breeding and cultivating technology as well as a sound industrial system

Source: Modified by author based on Wang et al. (2010a, b)

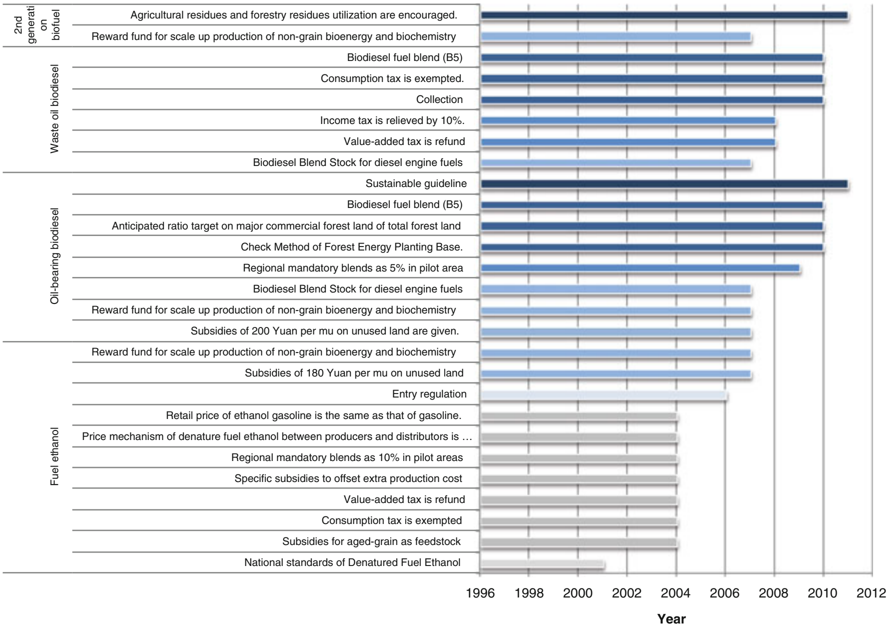
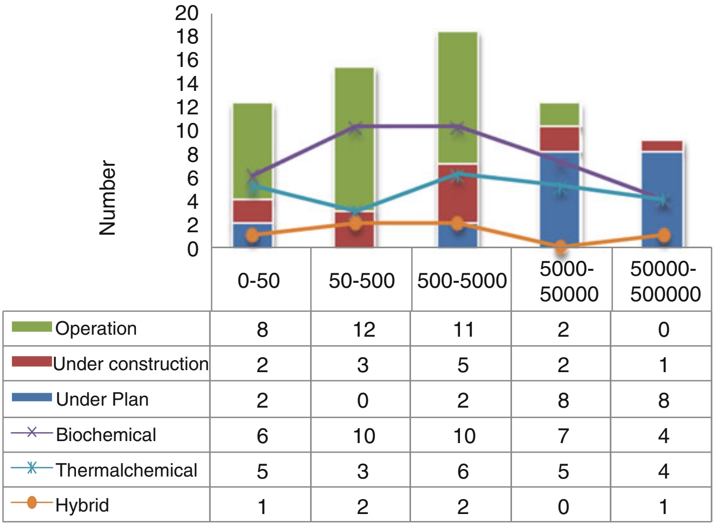


Fig. 8.9 Historical overview of biofuel policies in China



	0-50	50-500	500-5000	5000-50000	50000-500000
🟩 Operation	8	12	11	2	0
🟥 Under construction	2	3	5	2	1
🟦 Under Plan	2	0	2	8	8
✕ Biochemical	6	10	10	7	4
✳ Thermalchemical	5	3	6	5	4
● Hybrid	1	2	2	0	1

Fig. 8.10 Global number of second-generation biofuel projects (*Data source*: IEA 2010)

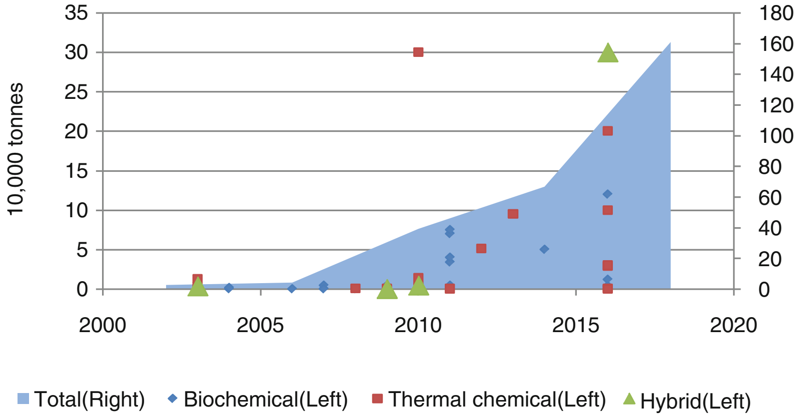


Fig. 8.11 Projection of global biofuel production based on current projects (*Data source*: IEA 2010)

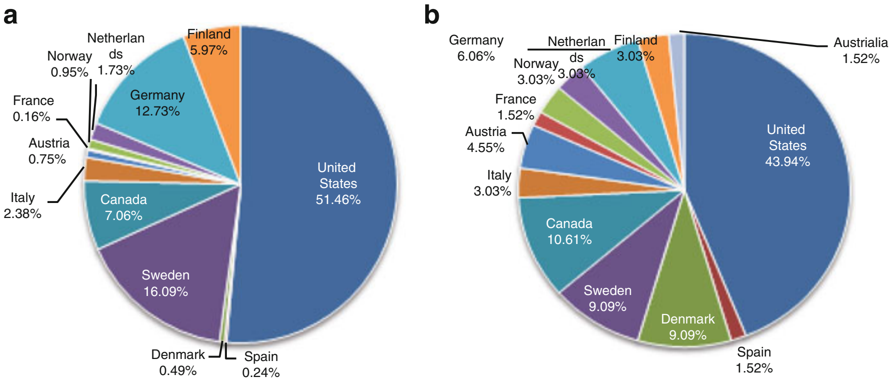


Fig. 8.12 (**a**) Projected production and (**b**) number of second-generation biofuel project by 2016. *Note*: Second-generation projects in China are excluded (*Data source*: IEA 2010)

Biochemical Process

The biochemical process is commonly used in second-generation technology for ethanol production. As seen in Fig. 8.10, 37 of 66 projects (56 %) in operation or under planning adopt the biochemical process. This process uses a hydrolysis-fermentation method to produce fuel ethanol, and it consists of acid hydrolysis and enzyme hydrolysis. The main difference between first- and second-generation biofuels lies in the front-end pretreatment and hydrolysis (Sims et al. 2010). According to the different ways of integrating the hydrolysis and fermentation, the technical pathways are classified as follows: separate (sequential) hydrolysis and fermentation, separate hydrolysis and cofermentation, simultaneous saccharification

Table 8.10 Key pilot projects for cellulosic ethanol in China

Organization	Location	Feedstock	Test capacity (tonnes)	Technology
COFCO Biochemical Co., Ltd.	Zhaodong, Heilongjiang	Corn stover	500	Enzyme hydrolysis
Henan Tianguan Enterprise Group Co.	Nanyang, Henan	Corn stover	3,000	Acid and enzyme hydrolysis
East China University of Science and Technology	Jixian, Shanghai	Sawdust and rice straw	600	Dilute acid hydrolysis

and fermentation, simultaneous saccharification and cofermentation, and consolidated bioprocessing. In 2006, COFCO Biochemical Co., Ltd. started building a 500-tonne cellulosic ethanol demonstration plant in Zhaodong, Heilongjiang using a hybrid saccharification and fermentation process. The Institute of Nuclear and New Energy Technology of Tsinghua University and the University of Oxford have jointly developed a synchronous simultaneous multienzyme synthesis and hydrolysis and separate fermentation process (Li and Chan-Halbrendt 2009).

Despite its simple principle, the process of enzyme hydrolysis faces many technical problems in industrialization. The cost of cellulase accounts for 56–60 % of the total cost of bioethanol production. Accordingly, advances in developing cellulase for bioethanol production need to embrace two aspects—enhancing its economic performance and improving its technical performance. The Danish firm Novozymes declared they had achieved success with Cellic CTec2, which reduces the cost of cellulase to US$0.5/gal, such that biofuel producers can achieve industrialization of the process with total costs of under $2/gal (RMB 3.6/L). Based on Novozymes' cellulosic-production tests, Mogensen (2009) made predictions on cellulosic ethanol production by China for 2010–2015 based on estimates of material and energy equilibrium and equipment investment. Mogensen concluded that 74 gal of cellulosic ethanol could be produced per dry tonne of biomass at a cost of $2.59/gal in 2010; the figure for 2015 was 92 gal at a cost of $1.5/gal.

In May 2006, SINOPEC, COFCO, and Novozymes initiated a commercial fuel ethanol production project using corn stover as feedstock. The project developed a new conversion process as well as new enzyme products. In October 2006, the first batch of ethanol was produced and a threefold cost reduction over the 2007 figure was achieved. According to predictions, this decrease will continue in the future. In China, at least three pilot plants have been established for second-generation fuel ethanol production (Table 8.10).

Thermochemical Process

The commonly used thermochemical methods include biomass gasification and synthesis and direct biomass liquefaction. The principle of biomass gasification and

Table 8.11 Comparison of biochemical and thermochemical pathways

Process	Biofuel yield (L/dry tonne)	Energy content (MJ/tonne)	Energy yield (GJ/tonne)
Biochemical			
Enzymatic hydrolysis ethanol	121.3–330.8	23.3	2.5–6.9
Thermochemical			
Syngas to F-T diesel	82.7–220.5	32.9	2.9–7.6
Syngas to ethanol	132.3–176.41	23.3	2.8–3.7

Data source: IEA (2008)
Note: 1 ton = 0.907 tonne

synthesis is to produce high-quality fuel ethanol, ether, and hydrocarbons by such processes as F-T synthesis following biomass gasification. The diesel production process of gasification followed by F-T synthesis has been industrialized though mainly using fossil feedstock. The process with biomass feedstock is still under development. The German firm CHOREN utilizes such biomass as wood and crop straw to produce synthetic diesel, and it has developed a biomass gasification process called Carbon V. The company has been devoted to research and development of this process since its establishment in 1990. In 1998, a demonstration project was set up, and in 2007 a commercial plant with an annual output of 15,000 tonnes was built. At present, CHOREN is planning a plant with an annual capacity of 200,000 tonnes Biomass to Liquid (BTL). The main product, Sunfuel, has excellent performance, and it can be used in current diesel engines by being blended with conventional diesel at any ratio.

Biomass synthetic fuels have suffered from high costs in recent years. The cost of F-T diesel is 27 % higher than that of lignocellulosic bioethanol. And the future development of biomass synthetic fuels is a matter of dispute. However, some studies have shown that the process for F-T diesel will be commercialized within 10 years—before that of lignocellulosic ethanol. However, this will require breakthroughs to be achieved with key technologies for biomass pyrolysis and liquefaction (Table 8.11).

The IEA (2008) made estimates about the cost of biofuels and concluded that the production costs of both cellulosic ethanol and synthetic biodiesel would be greatly reduced after 2010 and reach a stable level by 2030 with an optimistic estimate of technological development. Adopting a pessimistic estimate, the IEA forecasts that the production cost would slowly fall to between $0.65 and $0.7/L of gasoline equivalent by 2050 (Table 8.12).

Hybrid Process

In addition to the biochemical process, more efficient energy-conversion technologies have been explored internationally, such as the biogasification-fermentation process. This technology represents leading-edge development in the production of

Table 8.12 Projected costs of second-generation biofuels

		Cost/RMB/tonne[a]		
Second-generation biofuel	Assumption	2010	2020	2030
Cellulosic ethanol[b] (biochemical)	Optimistic estimate	6,806	5,105	4,934
	Pessimistic estimate	6,806	5,955	5,785
BTL[c]	Optimistic estimate	10,000	6,500	6,000
	Pessimistic estimate	10,000	8,000	7,800

Source: IEA (2008)

Notes:

[a] US$1 = RMB1

[b] 1 L cellulosic bioethanol equals 0.84 L oil equivalent

[c] 1 L BTL equals 1 L oil equivalent

liquid biofuels. Preliminary research and evaluation results point to good economic efficiency. Coskata, an American company, has established a biogasification-fermentation process demonstration plant in Madison, Pennsylvania.

8.3.2.2 Policies for Second-Generation Biofuels

It is crucial to support the development of renewable and new-energy technologies by means of definite policies at different stages of technological development. China has been promoting first-generation biofuels since 2001 in such ways as supporting R&D, enforcing pilot operation, and providing subsidies. However, policies for second-generation biofuel production are still under discussion or initial preparation except with respect to R&D (Fig. 8.13).

8.3.2.3 Future Progress with Second-Generation Biofuels

Progress needs to be made to utilize biomass resources more extensively, promote the conversion efficiency of biomass resources, and address the conflict between demand for biomass resources and sustainable development. The Research Group of Biomass Resource Strategy of the Chinese Academy of Sciences (2009) believes that the development of second-generation biofuels should follow the trajectory indicated in Fig. 8.14.

8.3.3 Algae

Algae is a promising feedstock that features low input but high output, with production per unit area 30 times higher than with land resources. Algae do not compete for land with grains and can be grown rapidly in the natural medium of seawater. The use of algae to produce such biofuels as biodiesel and pyrolysis fuel oil by means of cell engineering and biochemical technology has become an

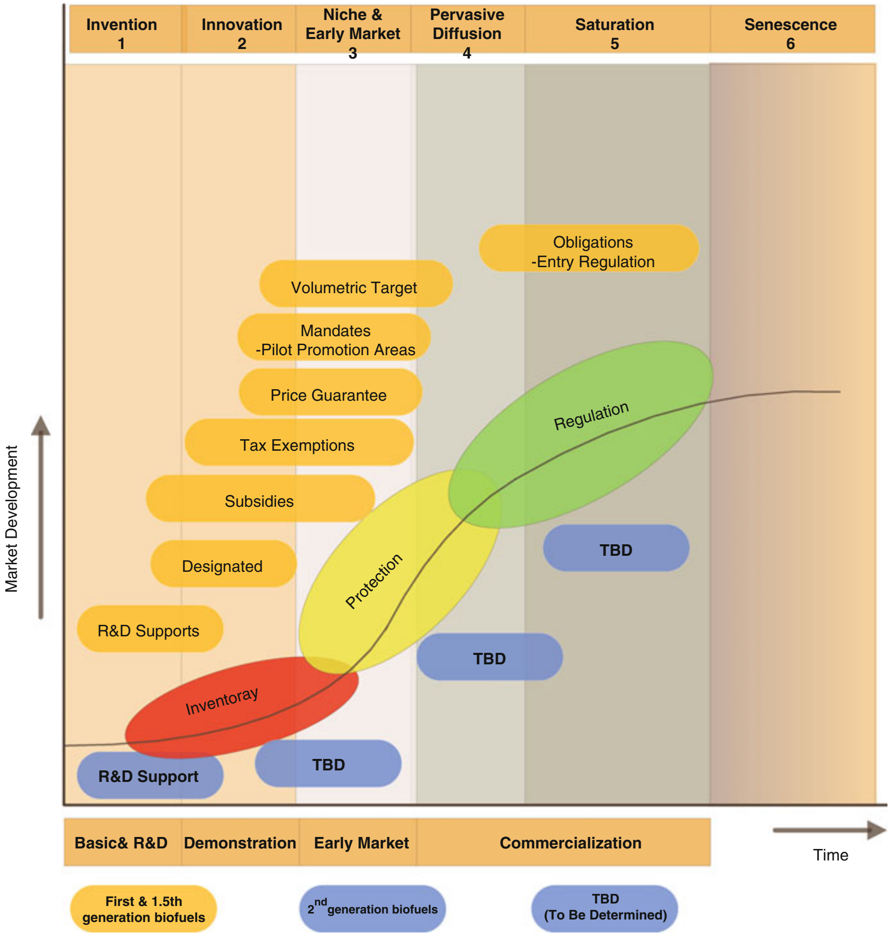


Fig. 8.13 Review of policies relating to second-generation biofuels (Adapted from Ros et al. (2006) and Bauen et al. (2009))

area of keen interest. ENN Group has started R&D in this area in China. A carbon sequestration bioenergy project has been initiated using microalgae in Daqi, Inner Mongolia.

8.4 Biofuel Development Scenario

8.4.1 Pathway Options

To investigate the specific situation in China by means of a development scenario, 18 pathways were selected by the author. The pathways included 1.5-generation

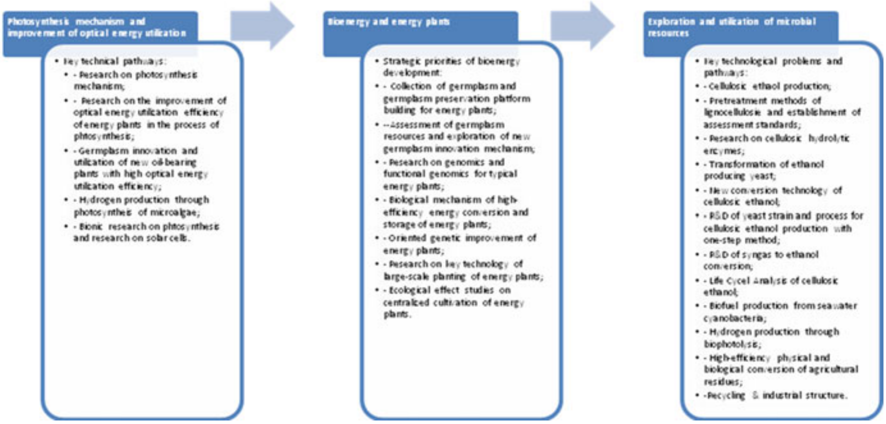


Fig. 8.14 Technical pathways for the future development of biofuels (*Source*: summarized by the author based on the Research Group of Biomass Resource Strategy of the Chinese Academy of Sciences 2009)

non-grain biofuel production from cassava, sweet sorghum, and *Jatropha curcas*, and second-generation biofuel production using broader biomass resources, e.g., agroforestry residues as feedstocks (Table 8.13).

8.4.2 Scenario Setting

8.4.2.1 Technology Development Scenario

Second-generation biofuels have been determined as one of the most promising alternative transport fuels; it is believed that they will represent an important breakthrough in addressing energy security and environmental protection while using low resources input. However, there are many uncertainties with these biofuels. Many research institutes around the world have advanced different visions regarding the success of second-generation biofuels, and the differences in the time frame for deployment vary from 10 to 20 years. As evident in Table 8.14, with the ACT and BLUE scenarios, the IEA (2008) has projected that second-generation technology will be deployed by 2012 and 2015, respectively, and commercialized by 2030 and 2035. The OPEC Fund for International Development and the International Institute for Applied System Analysis (OFID/IIASA 2009) has adopted the assumption of scenario WEO-V2/TAR-V2, whereby second-generation conversion technologies will be deployed after 2030. Therefore, two scenarios of second-generation biofuels are chosen in the present study—a slow and a fast development scenario.

Table 8.13 Biofuel pathways

No.	Resource	Feedstock	Conversion technology	Fuel product
1	Arable land	Corn/wheat	Fermentation	Fuel ethanol
2	Marginal land	Cassava	Fermentation	Fuel ethanol
3	Marginal land	Sweet sorghum	Fermentation	Fuel ethanol
4	Marginal land	Sweet potato	Fermentation	Fuel ethanol
5	Industry/service industry	Waste oil	Transesterification	Biodiesel
6	Marginal land	*Jatropha curcas*	Transesterification	Biodiesel
7	Marginal land	*Pistacia chinensis*/ *Xanthoceras sorbifolia*	Transesterification	Biodiesel
8	Agriculture	Primary agricultural residues	Hydrolysis and fermentation	Cellulosic ethanol
9	Manufacturing	Secondary agricultural residues	Hydrolysis and fermentation	Cellulosic ethanol
10	Forestry	Primary forestry residues	Hydrolysis and fermentation	Cellulosic ethanol
11	Manufacturing	Secondary forestry residues	Hydrolysis and fermentation	Cellulosic ethanol
12	Agriculture	Primary agricultural residues	Gasification and synthesis	Synthetic biodiesel
13	Manufacturing	Secondary agricultural residues	Gasification and synthesis	Synthetic biodiesel
14	Forestry	Primary agricultural residues	Gasification and synthesis	Synthetic biodiesel
15	Manufacturing	Secondary forestry residues	Gasification and synthesis	Synthetic biodiesel
16	Urban	Municipal solid waste	Gasification and synthesis	Synthetic biodiesel
17	Marginal land	Energy crops	Hydrolysis and fermentation	Cellulosic ethanol
18	Marginal land	Energy crops	Gasification and synthesis	Synthetic biodiesel

8.4.2.2 Policy Scenario

Policy support will strongly influence the development of future energy demand as China faces rigid limitations regarding land availability for the further expansion of energy crops. Two options considered here have the following characteristics: (1) The first option is to maintain the existing policy scenario and await the success of second-generation technology innovations. This is similar to the second type of biofuel policy scenario, called Moratorium, which was developed by the Food and Agriculture Organization of the United Nations (2008). That scenario advocates a 5-year moratorium for the sustainable development of biofuel technology, experience accumulation, and preventing a potentially negative impact on the environment, social community, and human rights; (2) The second option is to adopt a more active

Table 8.14 Review of the outlook for second-generation biofuels

Reference	Scenario	Description
IEA (2008)	ACT	Bring global CO_2 emissions back to current levels by 2050 (485 ppm), deployment begins by 2015, full commercialization by 2035
	BLUE	Reduce CO_2 emissions by 50 % by 2050 (450 ppm), deployment begins by 2012, full commercialization by 2030
	WEO-V1/TAR-V1	Become commercially available after 2015; deployment is gradual
OFID/IIASA (2009)	WEO-V2/TAR-V2	Owing to delayed arrival of second-generation conversion technologies, all biofuel production until 2030 is based on first-generation feedstock
	TAR-V3	Accelerated development of second-generation conversion technologies permits rapid deployment; 33 and 50 % of biofuels used in developed countries are second generation in 2020 and 2030, respectively

policy for sustainable development, increase R&D investment for second-generation technology, promote the formulation of standards for biofuel energy efficiency and greenhouse gas (GHG) emissions, and strictly supervise management of the biofuel industry. This option involves giving strong support to projects in line with the requirements of sustainable development and promoting the smooth transition from first- to second-generation technology.

In accordance with the above technology and policy information, four scenarios were designed (Table 8.15).

8.4.3 Cost and Technology Diffusion

8.4.3.1 Cost Calculation Method

The cost calculation method for various biofuel pathways is divided into different stages along the supply chain as follows:

$$C_{qj} = \sum_{p=1}^{n} (\mathrm{CAPEX}_{pqj} + \mathrm{FO\,\&\,}M_{pqj} + \mathrm{VO\,\&\,}M_{pqj}) \tag{8.4}$$

where q is the biofuel pathway, j is the year, C_{qj} is the average cost of biofuel pathway q in the year j, p is the stage of the biofuel pathway up to n, CAPEX_{pqj} is the average unit capital cost, FO & M_{pqj} is the average unit fixed operation and maintenance (O&M) cost, and VO & M_{pqj} is the average unit variable O&M cost. The flow chart of the biofuel system is shown in Fig. 8.15.

Table 8.15 Scenario description for developing biofuels in China

	Abbr.	Scenario	Description
Slow development of second-generation biofuels	M1	Moratorium 1	Technology outlook: second-generation biofuel technology is deployed commercially by 2025. Policy option: little special R&D support for 1.5- and second-generation biofuels; awaiting the global deployment of second-generation technology; strict land-use policy with the upper limit of unused land utilization proportion as 20 %; prohibited use of newly added arable land for biofuels.
	L1	Moderate development 1	Technology outlook: second-generation biofuels technology is deployed commercially by 2025. Policy option: encourage investment in biofuel projects, especially for 1.5- and second-generation biofuels; formulation of standards for biofuel energy efficiency and GHG emissions; strict management of the industry; permitted utilization of marginal agroforestry land for biofuel production; moderate land-use policy with upper limit of unused land utilization proportion as 50 %.
Fast development of second-generation biofuels	M2	Moratorium 2	Technology outlook: second-generation biofuel technology is deployed commercially by 2015. Policy option: little special R&D support for 1.5-generation biofuels, awaiting the global deployment of second-generation technology; strict land-use policy with upper limits of unused land utilization proportion as 20 %, prohibited use of newly added arable land for biofuels.
	L2	Moderate development 2	Technology outlook: second-generation biofuel technology is deployed commercially by 2015. Policy option: encourage investment in biofuel projects, especially for 1.5- and second-generation biofuels; formulation of standards for biofuel energy efficiency and GHG emissions; strictly supervise management of the industry; permitted utilization of marginal agroforestry land for biofuel production; moderate land-use policy with upper limits of unused land utilization proportion as 50 %.

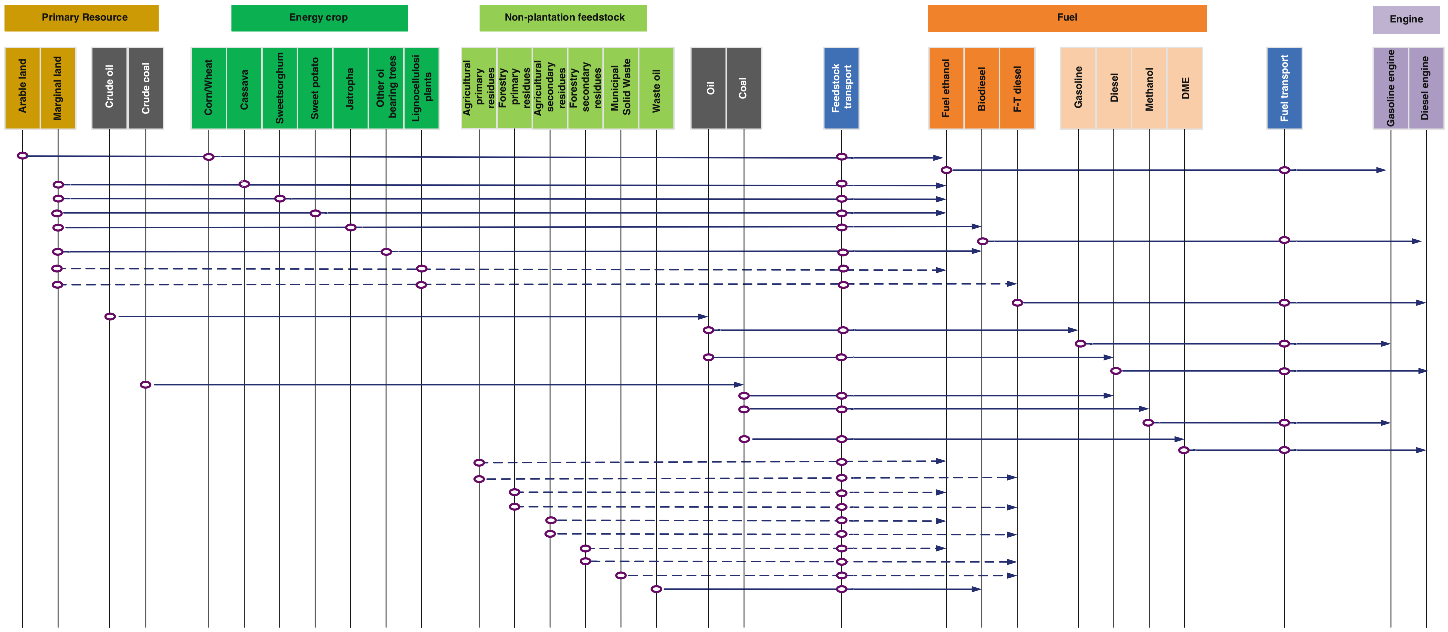


Fig. 8.15 Flow chart for biofuels (the fossil fuel pathway is included for reference). *Notes*: *Solid lines* indicate that the technology is at the stage of promotion or early commercialization; *dotted lines* denote that the technology is at the R&D or demonstration stage

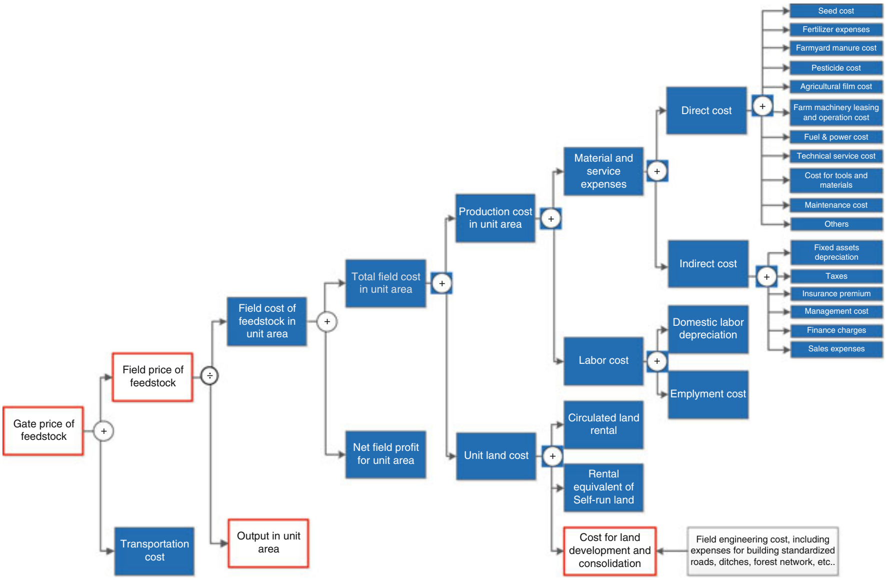


Fig. 8.16 Cost accounting system for agricultural products in China

8.4.3.2 Cost Assumption of Various Biofuel Pathways

The 1.5-generation non-grain technology has the following features: (1) Feedstock cost accounts for a large proportion of the total cost, (2) long-term cost reduction mainly relies on improving the conversion efficiency and decreasing the conversion cost, and (3) there is little potential for unit cost reduction. In terms of the cost accounting system of China's agricultural products, the major cost of energy plants derives from materials and services, labor, and land resources. In addition, for energy plants growing on marginal land, the cost of land exploitation and development also has to be considered (Fig. 8.16). With China's food crops, the main cost involves material and services, followed by labor. The land cost is relatively low. From 1978 to 2009, the average land cost underwent a 50-fold increase from RMB 2.23/μ to RMB 114.6/μ (Fig. 8.17). In the long term, there is great potential for increasing the cost of land for food crop cultivation, though currently it is relatively low. The land cost will be relatively high for biofuel development in China.

The cost reduction with second-generation biofuels depends on technological innovation in the near term and on economies of scale and technology learning in the long term, as shown in Fig. 8.18.

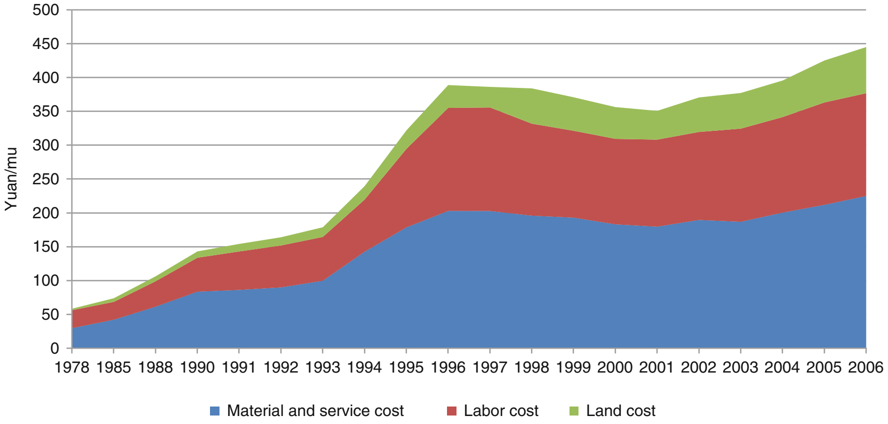


Fig. 8.17 Historical costs for China's food crops (*Source*: Department of Pricing of National Development and Reform Commission 2004, 2010)

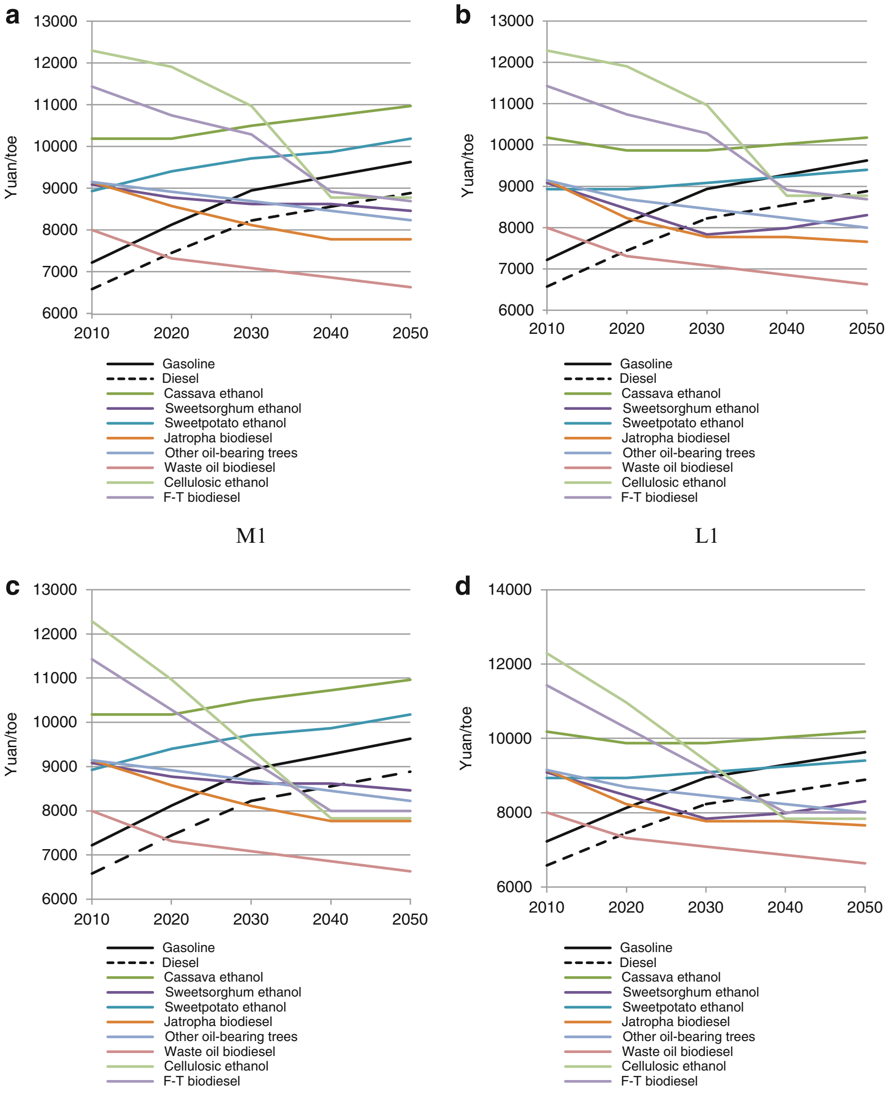
8.4.4 Constraints

Regarding the long-term prospect for biofuels, four kinds of constraints need to be considered: those relating to balancing energy flow, capacity, dynamic technical change, and the environment (Fig. 8.19).

8.4.5 Analysis and Evaluation of Development Potential of Biofuels in China

8.4.5.1 Automotive Energy Alternative

As evident in Fig. 8.20, biofuel production will continue to grow in China up to 2050, with the actual supply capacity then being about 32.4–79.7 mtoe. The oil substitution effect is lowest in the M1 scenario; the yield differs from that in L2 by 47.31 million tonnes in 2050. Owing to strict regulation, industrial development of biofuels lacks incentives in the M1 and M2 scenarios. The yield of fuel ethanol in 2020 in M1 and M2 is only 3.82 million tonnes and 4.17 million tonnes, respectively. That cannot achieve the expected target of 10 million tonnes as determined in the Medium- and Long-Term Development Plan for Renewable Energy (2007). In all four scenarios, the yield of biodiesel exceeds three million tonnes, which



M1 L1

M2 L2

Fig. 8.18 Costs of biofuels

surpasses the identified target of two million tonnes. In the near term, the growth of biofuel production depends largely on the diffusion of cultivation technology of 1.5-generation energy crops, reduction in feedstock cost, and related industry policies. In the medium term, it depends largely on innovation breakthrough with

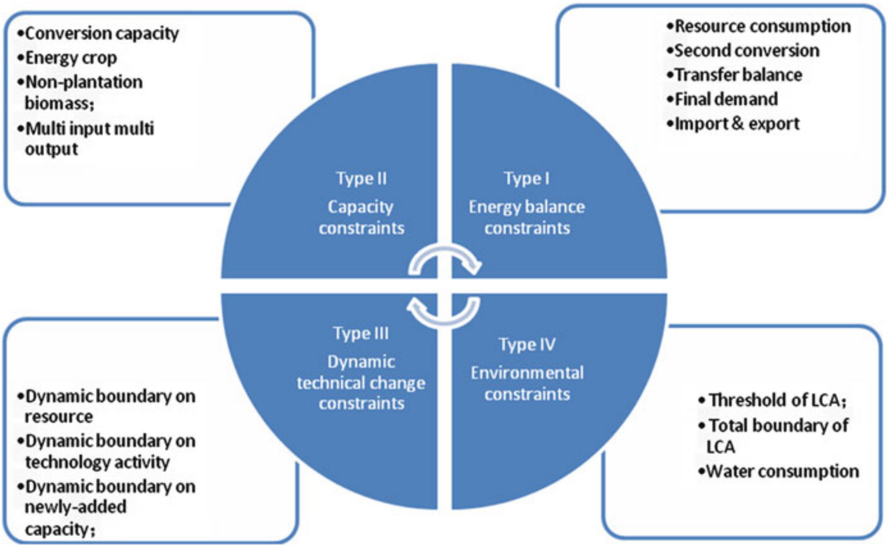


Fig. 8.19 Constraints on biofuel development

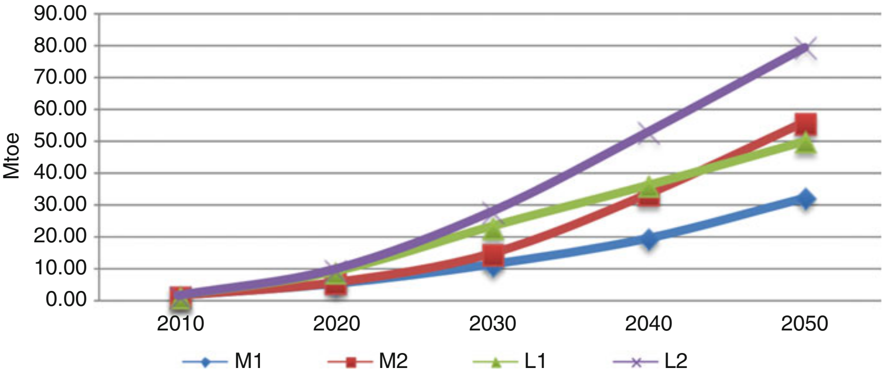


Fig. 8.20 Scenario projections for biofuels

second-generation biofuels. And in the long term, it depends on the biomass resource potential and market potential.

Owing to high compatibility with the existing transport infrastructure and high market demand, the demand and production of biodiesel will continue to rise. It will account for over 50 % after 2030 (Fig. 8.21).

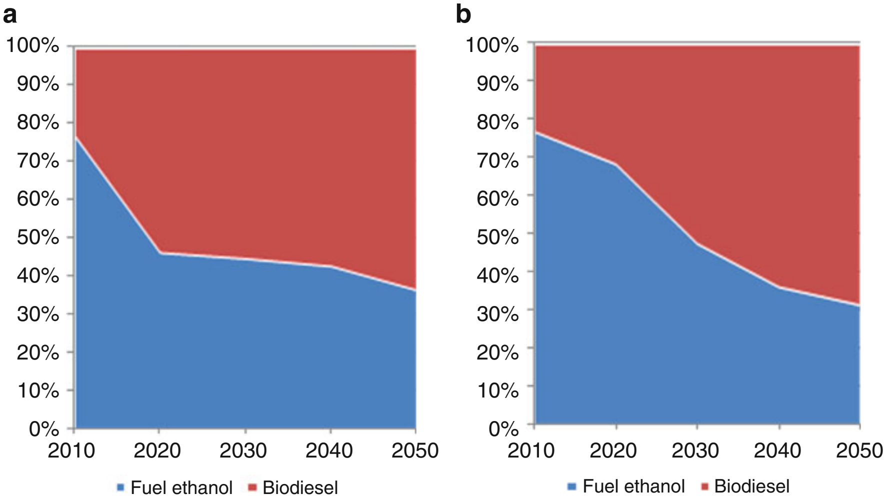


Fig. 8.21 Proportions of fuel ethanol (including cellulose ethanol) and biodiesel (including F-T synthetic diesel) in the (**a**) M1 and (**b**) L2 scenarios (based on energy value)

8.4.5.2 Second-Generation Biofuels

The difference in production under the various scenarios is great; however, the proportion of second-generation biofuels displays a significant upward trend in each scenario. By 2050, the production in three of the four scenarios is greater than 50 % (Figs. 8.22 and 8.23).

8.4.5.3 Feedstock Portfolio

The feedstock portfolio under the various scenarios is different. Biofuels derived from starch and sugar crops will decrease, those derived from oil-bearing trees will account for a large proportion in the medium term, and biofuels derived from agricultural and forestry residues will play an important role after 2030. Biofuels obtained from cellulosic energy crops will gradually increase after 2030 (Fig. 8.24).

Fig. 8.22 Production of second-generation biofuels

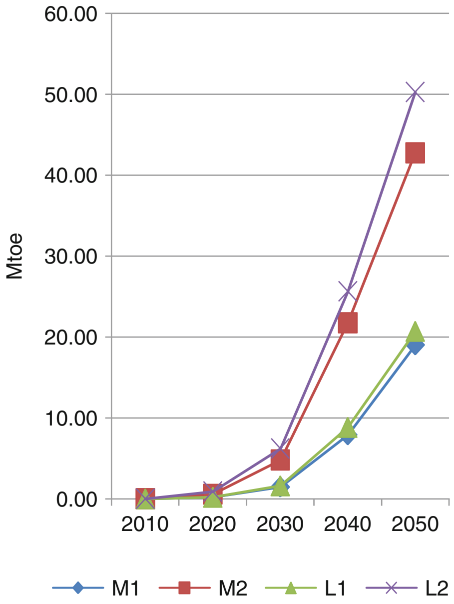
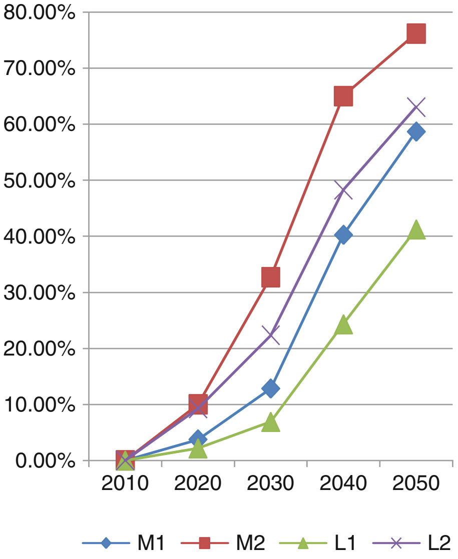


Fig. 8.23 Proportion of second-generation biofuels



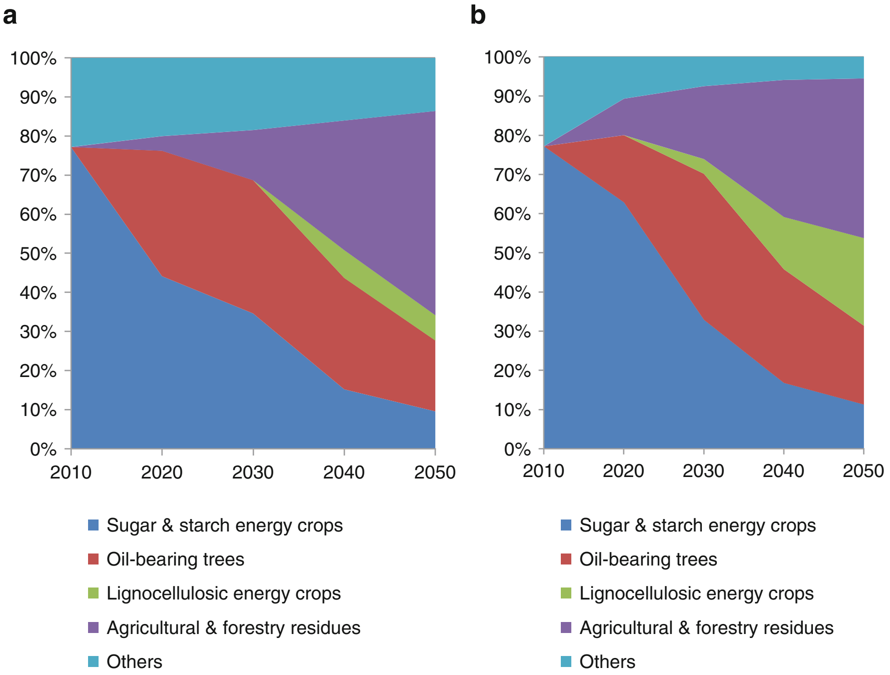


Fig. 8.24 Feedstock portfolio under scenarios (**a**) M1 and (**b**) L2

8.5 Conclusions

8.5.1 Major Conclusions

8.5.1.1 Biofuel Production Will Amount to 32.4–79.7 mtoe by 2050

The scenario analysis shows that biofuel production will continue to grow in China up to 2050, and the actual supply capacity will be about 32.4–79.7 mtoe by 2050. In the near term, the growth of biofuel production depends largely on the diffusion of cultivation technology of 1.5-generation energy crops, reduction in the feedstock cost, and related industry policies. In the medium term, it depends largely on innovation breakthroughs with second-generation biofuels. In the long term, it depends on the biomass resource potential and market potential.

8.5.1.2 Resource Potential

The collectable volume of agricultural and forestry residues will be 1.187 billion tonnes in 2050. Of that, about 535–772 million tonnes can be used for energy production, and about 210–446 million tonnes can be used for liquid biofuel production considering many other uses of biomass. The resource potential of energy crops in 2050 in China amounts to 17.29 EJ based on the direct equivalent method of calculation.

8.5.1.3 Fuel, Technology, and Feedstock Portfolios

Fuel portfolio: Owing to high compatibility with the existing transport infrastructure and high market demand, biodiesel will continue to rise. After 2030, it will consume over 50 % of total biofuel production.

Technology portfolio: The radical technological changes required for 1.5-generation non-grain ethanol and biodiesel fuel are almost impossible to achieve. However, incremental innovation will contribute to cost reduction, such as increased energy crop yield, increased conversion efficiency, and comprehensive utilization of wastewater and solids. China does not have any cost advantage with several mature-market energy crops, such as cassava; growing energy crops, such as sweet sorghum and *Jatropha curcas*, on marginal land will add to land development costs. Therefore, feedstock cost will continue to be a problem for the large-scale development of 1.5-generation biofuels in China over the next 10–20 years, during which time second-generation biofuels are expected to become a revolutionary innovation. The 1.5-generation non-grain biofuel technology will play an expedient role in the long term, and its overall trend will become stable after 2030 as its growth rate slows down. This technology will make a contribution mainly in the period from 2020 to 2040. Second-generation technology will grow during the period from 2020 to 2030, and it is expected that second-generation biofuels will serve as important long-term alternatives.

Feedstock portfolio: The feedstock portfolios are different under the various scenarios. Biofuels derived from starch and sugar crops will decrease; those derived from oil-bearing trees will assume a large proportion in the medium term and those derived from agricultural and forestry residues will play an important role after 2030. Biofuels derived from cellulosic energy crops will gradually become prominent after 2030.

8.5.1.4 Technology R&D and Industrial Policy

China’s cautious biofuel policies would appear to be appropriate for the short term. However, it is expected that more supportive policies will be implemented to promote the long-term development of liquid biofuels.

8.5.2 Suggestions

1. Since they are of strategic significance, priority should be given to the future development of second-generation biofuels. It is imperative that China lends greater support to R&D of second-generation technology. Technical support should be extended to cover demonstration projects with scales of over 1,000 or even 10,000 tonnes. Demonstration and subsidy policies urgently need to be formulated and implemented in accordance with China's technology development status.
2. China has a large potential for developing biodiesel. Since biodiesel production from waste oil is quite mature, both technologically and industrially, it is critical that a well-organized recovery management system for waste oil be established. Owing to the important role it will play in the medium term and its rich feedstock resources, there has to be greater policy support for biodiesel derived from oil-bearing trees. An upward adjustment can be made to the biodiesel development target for 2020, and guidance and incentives can promote the utilization of biodiesel in automobiles.
3. Three types of energy crops—non-grain energy crops, oil-bearing trees, and lignocellulose energy crops—will become important in, respectively, the short, medium, and long term. R&D efforts into biofuel production from non-grain energy crops have been conducted over a number of years, and it is now necessary to implement policy support for demonstration and expansion projects. Breeding and cultivating technology for oil-bearing energy plants is not at an advanced state of development. Over the next 10–15 years, therefore, accumulated experience in technological and industrial development needs to lead to the establishment of a sound feedstock cultivation system. Lignocellulosic energy crops will become important in the middle and long term; accordingly, it is suggested that appropriate plans be made in advance and pilot projects promoted.
4. It is suggested that the priority be given to biofuel production using waste oil and agroforestry residues as feedstock. This is less controversial in terms of sustainability and is more compatible with existing industrial and environmental policies.
5. Greater efforts need to be made into analyzing the macro- and microlevel impact of biofuels. At the macrolevel, it is necessary to explore the economic and environmental capacity of biofuel development under various scenarios. It is essential to determine an appropriate boundary between biofuel development and land use. The interaction among biofuel development, energy substitution, and reducing GHG emissions likewise demands investigation. Coupling studies need to be conducted on the complex interaction of energy, economy, the environment, and land use. At the microlevel, it is necessary to promote life-cycle analyses of energy consumption and carbon emissions with biofuel production to facilitate the formulation of sustainable development standards for liquid biofuels.

Appendices

Appendix 8.1 Related Parameters in Estimating Non-plantation Resources

Parameter	Unit	2010	2020	2030	2040	2050
Food	10,000 tonnes	53,830	56,202[a]	58,439[a]	59,572[a]	59,703[a]
Forestry	10,000 ha	19,545.22[b]	22,080[c]	23,040[d]	24,000[d]	24,960[c]
Comprehensive coefficient of agricultural residues	tonnes/tonnes	1.04	1.04	1.04	1.04	1.04
Comprehensive coefficient of forestry residues	tonnes/ha	2.49	2.49	2.49	2.49	2.49
Biomass power capacity using agricultural and forestry residues as feedstock[e]	10 MW	232.00	1,769.00	2,193.00	2,628.00	3,083.00
Biomass briquettes	10,000 tonnes	280.00	5,000.00	8,000.00	8,000.00	8,000.00
Centralized supply of biomass gas	10^3 m^3	456,250.00	4,562,500.00	8,668,750.00	12,775,000.00	6,881,250.00

Notes:

[a] Data from Institute of Agricultural Economics and Development of CAAS (2007)

[b] Seventh Forest Resources Inventory Data.

[c] According to the Action Plan to Address Climate Change of the National Forestry Administration, three-phased target should be achieved: national forest coverage of 20 % by 2010; national forest coverage increasing to 23 % by 2020; stability of forest coverage above 26 % by 2050

[d] Linear interpolation between 2020 and 2050

[e] Including direct fired power generation, gasification, and power generation and IGCC (Integrated gasification combined cycle). Bagasse-fired power generation is not included in the power capacity for 2010

Appendix 8.2 Overview of Studies on China's Marginal Land Resources

Type of marginal land	Area	Overview of study results
Land suitable for agricultural use in the category of unused land	702[a](304.36–2,136)	Research Group of China Renewable Energy Strategy (2008) concluded that land suitable for forestation in the category of unused land was 7.344 million hm^2, based on Survey and Evaluation of Arable Land Reserve Resources (Wen and Tang 2005) According to Xie et al. (2007), Marginal Land I includes arable land reserve resources as well as barren hills and wasteland with a slope of less than 15°, accounting for 30 % of the total area, i.e., 21.36 million hm^2 The Editorial Board of Sustainable Development of Energy Crops in the People's Republic of China (2009) used the data of arable land reserve resources released by the Ministry of Land and Resources as the basis for its studies. The board did not think it appropriate to reclaim sparsely wooded land and shrubbery for crop cultivation owing to the existing national policy on converting farmland to forest. Further, in terms of ecological protection, it was not desirable to reclaim marshland and reed land for agricultural purposes. Therefore, the potential of arable land reserve resources was 7.02 million hm^2, with arable marsh and reed land being excluded Zhang et al. (2010) concluded that the land potential for sweet sorghum cultivation in the category of unused land was only 786,000 hm^2, considering such factors as climate, soil, terrain, and land utilization. In this context, 3.0436 million hm^2 was taken as the minimum value of land suitable for agricultural use, which was based on a compromise between the above two research results of the Editorial Board of Sustainable Development of Energy Crops in the People's Republic of China (2009) The latest survey result released by the Ministry of Land and Resources in 2011 indicates that the total area of China's continuous arable land reserve resources amounted to 7.3439 hm^2.
Land suitable for forestation in the category of unused land	3,736.06[a] (3,736.06 – 10,000)	According to Lv (2008), roughly 100 million hm^2 of marginal land is unsuitable for agricultural use in China, including moderate and mildly saline-alkaline land, arid and semiarid sandy land, mine and oilfield reclamation land. The potential area in the category of unused land that can be exploited for growing oil-bearing plants amounts to about 24 million hm^2

		The lower value of the land area suitable for forestation in the category of unused land equals the area of usable but unused land (Wen and Tang 2005) minus the area of arable land reserves (Wen and Tang 2005) minus the area of land suitable for forestation in the category of forest land (State Forestry Administration 2009) = 8,874 − 734.4 − 4,403.54 = 3,736.06 (10,000 hm^2)
Land suitable for growing energy crops in the category of wooded land[b] (including oil-bearing plant forest and land suitable for forestation[c]; the potential of firewood forest and shrubbery is estimated based on residues)	4,824.14[a] (4,296.3–6,047)	Based on the 2005 Report on China's Forest Resources, the Research Group of China Renewable Energy Strategy (2008) concluded that the area of oil-bearing trees in China was about 3.43 million hm^2 and that the land area suitable for forestation was 57.04 million hm^2, which amounts to 60.47 million hm^2 According to Xie et al. (2007), the land mainly consists of barren hills and wasteland with a slope of 15°–25°, cutover land (2.51 million hm^2), burnt land (600,000 hm^2), and sandy land suitable for planting xerophytic shrubbery energy crops (7.003 million hm^2), which amounts to a total of up to 42.963 million hm^2 According to the Report on Forest Resources in China—Seventh Inventory of National Forest Resources released by the State Forestry Administration—the land suitable for forestation in the category of wooded land was 44.0354 hm^2. Zhang and Lv (2008) concluded that the area of woody oil-bearing forest was 4.206 hm^2. The total is 448.2414 hm^2 Lv (2008) concluded that the normal land area for oil-bearing plants was about 36 million hm^2, among which 12 million hm^2 was in the category of land suitable for forestation
Land suitable for growing energy plants in the category of arable land (mainly including non-grain land with middle and low production in the category of nonbasic farmland)	2,000[a] (0–2,091)	Based on empirical estimates by the Research Group of China Renewable Energy Strategy (2008), 40 % of 50.24 million hm^2 (20 million hm^2) of low-production arable land in China could be used as marginal land to cultivate biomass feedstock Shi (2011) verified the above figures by referring to the Investigation and Assessment of Quality Classification of National Arable Land released by the Ministry of Land and Resources in 2009. That classified the national arable land into 15 levels, with the first level being the best and 15th level the poorest. The last three levels of arable land are naturally poor with low and unstable production; they cover an area of 20.91 hm^2

(continued)

Appendix 8.2 (continued)

Type of marginal land	Area	Overview of study results
Unclassified wasteland for energy crops	2,680	According to the Interim Regulations on the Subsidy for Bioenergy and biochemical Feedstock promulgated by the Ministry of Finance in 2007, feedstock bases had to meet the requirement of not occupying arable land or unused land that had been planned for agricultural purposes. From the perspective of conservation, growing energy plants on any arable land was likewise prohibited. The Ministry of Agriculture carried out a project called Investigation and Assessment of Marginal Land Resources Suitable for Planting Energy Crop Resources with the support of all levels of rural energy management departments. The investigation covered wasteland for energy crops and winter fallow land suitable for growing energy crops. Wasteland for energy crops refers to natural grassland, sparsely wooded land, shrubbery, and unused land suitable for growing energy crops. Results showed that the total area of marginal land suitable for growing energy crops was 34.2 million hm^2, including 26.8 million ha of wasteland and 7.4 million ha of winter fallow field (Kou et al. 2008). Shi (2011) also arrived at the figure of 26.8 million hm^2
Total	11,262.2[a] (8,336.72–20,274)	

Notes:

[a] This value is adopted in this chapter

[b] The definition of "wooded land" comes from the Regulations for the Implementation of Forestry Law of the Peoples' Republic of China, which consists of arbor forest with a crown density above 0.2, bamboo forest, shrubbery, and sparse woodland as well as land suitable for forestry planned by county-level or higher governments, i.e., barren hills and area suitable for forestry, sandy wasteland suitable for forestry, and others

[c] According to Major Technical Regulations on Planning, Design, and Inventory of Forest Resources issued by the State Forestry Administration in 2003, land suitable for forestation consists of barren hills and wasteland, sandy bare land, and others. Barren hills and wasteland suitable for forestation mainly includes barren hills, desolated beaches, and deserted ditches that have been listed in the category of wooded land by county-level or higher governments and that do not meet the standards of forest land, sparse wood land, shrubbery, and afforestation land. Sandy bare land suitable for forestation mainly includes fixed and migratory sandy land (sand dunes) and desertified land that can grow trees and has been listed in the category of wooded land by county-level or higher governments and that fails to meet the standards of forest land, sparse wood land, shrubbery, and afforestation land

Appendix 8.3 Relevant Policy and Measures During the Process Chain

Biofuels	Process	Policies	Source	Application
Sugar and starch energy crops for fuel ethanol	Feedstock	Subsidies for aged grain as feedstock	NDRC et al. Expanding Vehicle-Use Ethanol Gasoline Trial Promotion Schedule and Detailed Rules for Implementation (2004)	Designated projects only
		Subsidies of RMB 180 per *mu* on unused land	MOF. Interim measures on financial subsidies to production bases of feedstock for the bioenergy and biochemical industry (2007)	
	Conversion	Consumption tax is exempted	NDRC et al. (2004)	Designated projects only
		Value-added tax is refunded	NDRC et al. (2004)	Designated projects only
		Specific subsidies to offset extra cost	NDRC et al. (2004)	Designated projects only
		Entry regulation	NDRC. Announcement regarding greater management of bioethanol projects and promoting healthy development of the ethanol industry (2006)	
		Incentive funds for scaling up production of non-grain bioenergy and biochemical processes	MOF. Interim measures on incentive funds for the bioenergy and biochemistry industry (2007)	Has not been implemented
	Distribution	Standards	National standards of Denatured Fuel Ethanol (GB18350-2001) Ethanol Gasoline For Motor Vehicles (GB 18351-2001)	
		Regional mandatory mixture of 10 % in pilot areas	NDRC et al. (2004)	Designated projects only
		Settlement prices of denatured fuel ethanol between producers and distributors guaranteed	NDRC et al. (2004)	Designated projects only

(continued)

Appendix 8.3 (continued)

Biofuels	Process	Policies	Source	Application
		Retail price of ethanol gasoline is the same as that of gasoline.	NDRC et al. (2004)	Designated projects only
Oil-bearing trees for biodiesel	Feedstock	Subsidies of RMB 200 per *mu* on unused land	MOF. Interim measures on financial subsidies to production bases of feedstock for the bioenergy and biochemical industry (2007)	
			SFA. Check Methods of Forest Energy Planting Base 2009	
		Anticipated ratio target for major commercial forest among total forest land	SC. National Plan for Conservation and Utilization of Forest Land (2010–2020) (2010)	
		Sustainable guidelines	SFA. Guideline of Sustainable Planting of Energy Forest and the Guideline of Sustainable Planting of *Jatropha* (2011)	
	Conversion	Incentive funds for scaling up production of non-grain bioenergy and biochemical processes	MOF. Interim measures on incentive funds for the bioenergy and biochemical industry (2007)	Has not been implemented
	Distribution	Standards	Biodiesel Blend Stock for Diesel Engine Fuels (BD100) (GB/T20828-2007)	
			Biodiesel fuel blend (B5) (GB/T 25199-2010)	
		Regional mandatory mixture of 5 % in pilot areas	HPPGO. Work program on biodiesel deployment in Hainan Province (2009)	Designated projects in Hainan Province only
Waste oil to biodiesel	Feedstock	Collection	MEP, MHURD, and NDRC. Notice on improving the collection of municipal waste (2010)	
	Conversion	Value-added tax refunded	MOF et al. Notes on value-added tax policies related to comprehensive utilization of resources (2008)	
		Income tax relief of 10 %	MOF. Notes on list of income tax relief preferential policies for comprehensive utilization of resources (2008)	

		Consumption tax exempted	MOF & SAT. Notes on consumption tax exemption for biodiesel using waste oil as feedstock (2010)	
	Distribution	Standards	Biodiesel Blend Stock for diesel engine fuels (BD100) (GB/T20828-2007)	
			Biodiesel fuel blend (B5) (GB/T 25199-2010)	
Second-generation biofuels	Feedstock	Utilization of agricultural residues and forestry residues encouraged	SC & NDRC. Adjustment list of industry structure 2011 (2011)	
	Conversion	Reward fund for scale up production of non-grain bioenergy and biochemistry	MOF. Interim measures on reward fund for bioenergy and biochemistry (2007)	Has not been implemented

Notes: *HPPGO* Hainan Provincial People's Government Office, *MEP* Ministry of Environment Protection, *MHURD* Ministry of Housing and Urban–rural Development, *MOF* Ministry of Finance, *NRDC* National Reform and Development Commission, *SAT* State Administration of Taxation, *SC* State Council, *SFA* State Forestry Administration

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