Development of Biofuels in China

Technologies, Economics and Policies

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Abstract

China promulgated the Medium and Long-Term Development Plan for Renewable Energy in 2007, which included targets of 2010 and 2020 for various renewable energy technologies including biofuels. The 2010 biofuel targets were met and even surpassed except for non-grain fuel ethanol; however, there is debate on whether and how the country will be able to meet the 2020 biofuels target. This paper provides a resource and technological assessment of biofuel feedstocks, compares biofuel production costs from various feedstocks and technologies, and evaluates policies introduced in the country for the development of biofuels. The paper also

presents the projections on the production of biofuels under various policy scenarios. The study shows that China can potentially satisfy its non-grain fuel ethanol target by 2020 from the technology perspective. But it will probably fall far short of this target without additional fiscal incentives as production costs of non-grain feedstock based biofuels are expected to remain relatively high. By contrast, the 2020 target of biodiesel production has a high probability of being achieved because the target itself is relatively small. With additional support policies, it could develop even further.

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Development of Biofuels in China: Technologies, Economics and Policies

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1. Introduction

The total energy consumption of China surpassed 3.25 billion tons of coal equivalent (tce) in 2010, 37.7% higher than the 2005 level (NBS, 2011). This rapid increase in demand has placed significant pressure on energy supplies in China, especially that of oil. From 2002 to 2010, China's apparent oil consumption increased by 7.8% per year from 249 million tonnes to 455 million tonnes, with the overseas oil dependence ratio increasing to 55% in 2010 (CNPC Research Institute of Economics and Technology, 2011). It is projected that the domestic oil demand will increase to 650 ± 50 million tonnes by 2030 and 750 ± 50 million tonnes by 2050 (RGCMLDS, 2011a). Since the domestic production of crude oil production will, most likely, stabilize at around 200 million tonnes by 2020 (Tong, et al, 2009), the gap between domestic supply and demand provides development opportunities for alternative fuels, including biofuels.

China promulgated the Medium and Long-Term Development Plan for Renewable Energy in 2007, which included sub-targets of 2010 and 2020, broken down into various renewable energy technologies (Table 1).

Table 1: Renewable energy targets in the medium and long-term planning

Target	Unit	2010 Target	2020 Target
Percentage of renewable in energy consumption	%	10	15
Sub-targets			
Hydro power installation capacity	Million kilowatts	190	300
Biomass power installation capacity	Million kilowatts	5.5	30
Biomass briquette consumption	Million tonnes	1	50
Biogas for heat in rural areas	billion m ³	15 ^a	30 ^a
Non-grain fuel ethanol consumption	Million tonnes	2	10
Biodiesel consumption	Million tonnes	0.2	2
Wind power installation capacity	Million kilowatts	5	30
Solar PV power installation capacity	Million kilowatts	0.3	1.8
Solar water heater installation capacity	Million m ²	150	300

Note: The 2020 targets might increase to 500 GW (300 GW of hydropower, 150 GW of wind power, 30 GW of biomass power, and 20 GW of solar PV) from 362 GW mentioned in Table 1 (Martinot and Junfeng, 2010).

In 2010, the installed capacity of hydro power (213 million kilowatts), wind power (44 million kilowatts), biomass power (6.7 million kilowatts), solar PV power (0.8 million kilowatts) and solar water heater (168 million square meters), and the consumption of biomass briquette (2.5 million tonnes) have already surpassed the corresponding targets for 2010 (see Fig.1). And the consumption of biogas (14.26 billion m³) in rural area was almost achieving its targets for 2010. However, the only exception is the fuel ethanol. The realized fuel ethanol production in 2010 was only 1.86 million tonnes with only 0.37 million tonnes

using non-grain feedstocks.

Fig. 1. Achievement of 2010 targets for various renewable energies in China

Source: the 2005 data are from *Medium and Long-term Development Plan for Renewable Energy in China*; the 2010 data of solar PV power generation is from Shi et al. (2011), non-grain fuel ethanol is from Liu et al.(2011), and biogas consumption is from DSERE(2011); other data of 2010 are from Zhao et al.(2011).

There are numerous challenges facing the development of biofuels in China, including the potential impact of biofuels production on the grain security and agriculture development (Huang, et al., 2009; Huang, et al., 2010; Fu, et al., 2011), uncertainty of available land potential for biofuels development (Tian, et al., 2009), economic supply of feedstock (Zhang, et al., 2009) and potential ecological environment problems caused by large-scale cultivation of energy crops (Yan and Zhao, 2009). Much of the debate has now been focused on what the impact of meeting the 2020 targets. Some existing studies have analyzed this issue. For example, Shi, et al.(2010) projected that to meet the target of 15% non-fossil energy by 2020, set by the State Council, about 11 million tonnes of ethanol and 2 million tonnes biodiesel will be required. Qiu et al. (2011) argued that the target of 10 million tonnes of fuel ethanol by 2020 seems to be a prudent target, causing no major disturbances in China's food security. And the results of Wu et al. (2011) presented that the achievement of 2020 fuel ethanol target is necessary to keep the oil independent ratio lower than 60%.

The objective of the paper is to make an assessment of potential technology pathways and policies that might help achieve the 2020 targets. The paper is organized as follows. Section 2 presents current status of biofuels development in China, followed by discussions on potential technological pathways to meet the biofuels targets in 2020 regarding their respective resource potential, supply cost and challenges in Section 3. In Section 4, after the review of current policies and major barriers in China based on broader literature analysis, policy options needed to achieve the target are provided. Section 5 presents an overview of results from the biofuels projection scenarios, and provides insights into the comparison of results. Section 6 summarizes the results in this paper.

2. Current status of biofuels development in China

The development of biofuels in China has undergone three distinct stages, as illustrated in Figure 2. From 2002 to 2004 was the start-up period of biofuels. Five cities (Zhengzhou, Luoyang, Nanyang, Haerbin, and Zhaodong) were chosen to launch a Vehicle-use Ethanol Gasoline Pilot Testing Program. In 2004, the National Development and Reform Commission (NDRC) and seven other departments expanded the test areas of fuel ethanol to nine demonstration districts at the provincial and urban level. During the following three years, ethanol production grew rapidly; with 10% ethanol gasoline blends (E10) spreading to nine provinces that accounted for approximately 20% of national gasoline consumption by Dec. 2006. In Dec. 2006, the Chinese government declared to strengthen the entry regulation to avoid perceived negative impacts on food security and ecological systems. Since the regulation was put in place, the speed of biofuels expansion has slowed significantly and production increase came mainly from the capacity expansion of existing designated projects (Table 1).

Fig. 2 Biofuels production in China

Source: Chang, et al.2012.

The turning point in December 2006 on the existing policies can be explained from at least three aspects. First, the initial motivation of fuel ethanol was to utilize the aged-grain, but the inventory of aged-grain consumed rapidly and has been close to zero in 2006 (Shang, 2006). Second, international food prices started to spike since 2006. The international food price index is 101.37 in the January of 2006, while increase to 114.84 in December rapidly (IMF, 2011). Even the increase of major domestic grain prices in China, i.e., corn, wheat and rice, were not remarkably (Huang, et al., 2010), it's still a strong implication to the potential food insecurity. Third, there occurred a surge in applying for new production capacity, which would use fresh grain as feedstock thereby leading to fuel vs. food concerns in China.

As of 2010, there were only five fuel ethanol plants with a production value of 1.86 million

tonnes in China (4.81% and 8.41% of fuel ethanol productions in U.S. and Brazil by volume¹), including a 200,000 tonnes fuel ethanol project using cassava as feedstock. Two major oil companies - China National Petroleum Corporation (CNPC) and China Petrochemical Corporation (SINOPEC) - and a large agri-business company - China National Cereals, Oil & Foodstuffs Corp (COFCO) - have engaged in the production of fuel ethanol through stipulated investments, stock holdings and other mechanisms. SINOPEC, CNPC, and another major oil company – China National Offshore Oil Corp (CNOOC) - are also involved in the production of biodiesel (Table 2).

Table 2: Designated Biofuels producers in China

	Location	Initial Capacity Approved(1000 tonne)	Current Capacity (1000 tonne)	Supply region	Feedstock
Fengyuan	Bengbu, Anhui Prov.	320	440	Anhui , Shandong, Jiangsu, Hebei	Corn
Tianguan	Nanyang, Henan Prov.	300	500	Henan, Hebei, Hubei	Wheat, Cassava
COFCO Zhaodong(Former as Huarun)	Zhaodong, Heilongjiang Prov.	100	280	Heilongjiang	Corn
Jilin Fuel Alcohol	Jilin, Jilin Prov.	300	500	Jilin, Liaoning	Corn
Guangxi Bioenergy	Beihai, Guangxi Prov.	200	200	Guangxi	Cassava
CNOOC	Hainan Prov.	60 ^a	60	Hainan	Jatropha/waste oil ^b
CNPC	Nanchong, Jiangsu Prov.	60 ^c	-	-	Jatropha
SINOPEC	Guizhou Prov.	50 ^c	-	-	Jatropha

Note: a. The project has been completed in 2010, but production is suspended for modifications in 2011; b. Planned feedstock is jatropha, but according to authors' field survey, the current feedstock is waste oil due to the jatropha planting base is still under construction; c. The project has been approved by government, but hasn't initiated yet.

The biodiesel productions in China are now carried out mostly by private enterprises using waste oil as feedstocks. Total capacity is about 1.5 Million tonnes (Liu et al. 2011), and even 2 million tonnes (CRES, 2010). About 10 enterprises' capacity are higher than 100,000 tonnes, i.e., Zhuoyue (100,000 tonnes) in Fujian Province. And some companies adopted advanced technologies (i.e., biological enzyme catalysis process by River in Hunan province (20,000 tonnes)).

¹ Fuel ethanol productions in U.S. and Brazil are 49 and 28 billion liters respectively in 2010 according to REN21 (2011).

3. Potential technology options of biofuels

The Chinese government highly emphasized the non-grain (non-food oil) development path in various policy documents, i.e., the Medium and Long Term Renewable Energy Development Plan by NDRC, the Agricultural Bioenergy Development Plan (2007-2015) by the Ministry of Agriculture, and the Issues on Development and Promotion of Oil Plants by General Office of State Council. In this study, we discuss different technology options allowed under these plans. These options include: (i) fuel ethanol from non-grain starch and sugar crops, (ii) biodiesel from oil bearing trees, (iii) biodiesel from waste oils, and (iv) biofuels from cellulosic biomass (second-generation biofuels). For each technology, we first present resource potential followed by supply costs and key challenges.

3.1 Fuel ethanol from non-grain starch and sugar crops

Starch and sugar crops are currently the dominant feedstocks for the production of biofuels, and ethanol is by far the most important fuel derived from these crops. Corn-based ethanol accounts for more than 89% of fuel ethanol production in the United States (calculated based on RFA, 2011). The same is true for China, where the major feedstocks are by far corn and wheat with market share of more than 80%. However, as discussed above, no new projects based on these feedstocks are allowed; therefore, this paper focuses on alternative non-grain sugar and starch energy crops, involving cassava, sweet sorghum and sweet potato.

3.1.1 Resource potential

The available land resource for feedstock production is one of the major determinants of the development of biofuels. China has limited land resources but huge population. To meet the growing food demand and grain self-sufficiency rate target², the land management policies are very strict. Therefore, it is necessary to find available land for biofuels development, which compliances with current land management and food security policies. In line with the Land Administration Law, RGCREDs (2008) classifies marginal land into two parts: (i) unutilized land and (ii) part of low-productive arable land. Based on some preliminary researches on land suitability assessment, the marginal land available for three types of feedstocks is shown in Table 3. The total marginal land available for these feedstocks is 23.73 million hectare and corresponding potential for ethanol production could be 65.48~88.57 million tonnes. Although there might be high uncertainties on the yields, the available marginal land indicates that land supply would not be a barrier to meet China's biofuels targets in 2020. Note however that marginal lands do need water resources, fertilizers and so on. If these resources are provided, one might argue that the land can be used for production of food instead of biofuels, if food security is the primary concern of the country.

² Grain self-sufficient rate is defined as the ratio of domestic consumption and domestic productions of grains. According to the *National Framework for Medium- and Long-term Food Security*, grain self - sufficiency rate is required above 95% by 2020.

Table 3: Potential marginal lands available for non-grain sugar & starch energy crops

	Unit	Cassava	Sweet sorghum	Sweet potato
Current planting area	Million ha.	0.387 ^a	0.0033-0.0067 ^b	4.76 ^c
Current production	Million tonne	7.94 ^a	n.a. ^d	102.2 ^c
Current utilization		70% for starch & alcohol, etc. 30% for feed ^e	n.a. ^d	50% for feed 15% for industry processed 14% for food 6% for seed ^f
Unutilized land available	Million ha.	0.124 ^b	5.31 ^g	1.30 ^g
Low-productivity arable land available	Million ha.	7 ^h	7 ^h	3 ^h
Marginal land available	Million ha.	7.12	12.31	4.3
Land productivity of feedstock	Tonne /ha.	20.55 ^a	45-75 ^b (60)	21.47 ^c
Starch or sugar content	%	25	15	20
Assumed conversion efficiency	Tonne (ethanol)/tonne (feedstock)	0.14	0.625	0.112
Land productivity of ethanol	Tonne /ha.	2.88	2.81-4.69 (3.75)	2.4
Ethanol yield potential on unutilized land	Million tonne	0.36	14.93-24.91(19.93)	3.13
Ethanol yield potential on low-productivity arable land	Million tonne	20.14	19.69-32.81(26.25)	7.21
Ethanol yield potential on marginal land	Million tonne	20.5	34.63-57.72(46.18)	10.35

Notes: a. the 2008 value; data from Fang, et al (2010); b. Data from EB (2009); c. the 2008 value; data from DRST, et al. (2009) ; d. the value is not available; e. data from Tian et al.(2010); f. the 2008 value with other 15% of sweet potato was rotting; data from Jin et al. (2011); g. data from EB (2009), but because North China is suitable for both sweet sorghum and sweet potato, unused land here is assumed to be divided evenly between both crops; h. data from Shi (2011);

3.1.2 Supply cost

The production of ethanol from starch and sugar crops is a relative mature technology, widely employed at commercial scale. The economic viability of these processes largely depends upon the price of feedstocks as feedstock accounts for over 50% of the total cost (see Table 4). Although the production costs of fuel ethanol are higher, they have certain cost advantage

compared to gasoline, based on the wholesale pricing mechanism between fuel ethanol producers and gasoline wholesaler³.

Table 4: Typical cost and related assumptions by energy crop

Items	Unit	Cassava	Sweet sorghum	Sweet potato
Feedstock cost	Yuan/tonne (ethanol)	2,857-4,643	3,840-4,364	2,727-3,636
Assumed feedstock pricing mechanism		Market-based pricing ^a	Cost-based pricing ^b	Market-based pricing ^a
Assumed feedstock price	Yuan/tonne (feedstock)	400-650 ^c	240 ^d	300-400 ^e
Starch (sugar) content	%	25	10-16	20
Conversion efficiency	tonnes ethanol/tonne feedstock	0.14	0.055-0.0625	0.11
Non-feedstock cost^f	Yuan/tonne (ethanol)	2,160^g	1,609^h	2,160ⁱ
Conversion technology		Traditional fermentation	Advanced solid state fermentation (ASSF)	Traditional fermentation
Investment cost ^j	Yuan/tonne (ethanol)	4325 ^k	n.a.	4325 ⁱ
Ethanol total production cost	Yuan/tonne	5,017-6,802	5,444-5,968	4,887-5,796
Share of feedstock cost	%	56.95-68.25	70.54-73.12	55.8-62.74
Designated fuel ethanol wholesale price from January 1, 2008 to April 7, 2011	Yuan/tonne			
- Min		4,956 (January 15, 2009)		
- Average		6,238		
- Max		7,816 (April 7, 2011)		

Note: a. as mentioned in Table 2, there are other utilizations for cassava and sweet potato in China, therefore their assumed prices are equal to current average market prices, which are not only for energy use, but also for the use of food, feed, starch, and so on; b. as mentioned in Table 2, there is almost no sweet sorghum market in China, therefore, the pricing mechanism of sweet sorghum is cost-based pricing involving farmer's profit; c. Feedstock price is assumed to be the average value from 2007 to 2008, data from Sun et al (2008); d. data from Wei, et al. (2010); e. data from Cai et al (2011); f. non-feedstock cost includes capital costs, fuel costs, operation & maintenance costs, and auxiliary material costs; g. Data from EB (2008); h. data from Han et al. (2010); i. Costs assumed to be the same as those for cassava; j. Investment cost is for the conversion process only (excluding the investment cost to establish a planting base); k. Survey data based on the cassava project of Guangxi Bioenergy Company with total investment as 0.865 billion Yuan.

3.1.3 Challenges

Economic supply of feedstocks

Ensuring low and stable feedstock costs is one of the major challenges facing the development of starch- and sugar-based biofuels in China. Since crops used for biofuels

³ Wholesale price of fuel ethanol is the ex-factory price of 90# Gasoline multiplied with a factor as 0.911 before Mar.1st, 2011, and is the ex-factory price of 93# Gasoline multiplied with the factor of 0.911 after Mar.1st, 2011.

feedstocks (e.g., cassava and sweet sorghum) also follow market prices, production costs of biofuels are sensitive to the current market and future demand for these crops. A relatively mature cassava market currently exists in China as shown in Table 3. If domestic demand for cassava increases following the current trends, its price would put pressure on the production of cassava-based ethanol. Besides this demand side factor, supply of cassava would be also a concern as China depends on import for cassava supply. In 2001, China became the largest cassava importer in the world, by 2006, China's share of worldwide cassava (fresh or dry) imports reached its peak of 88.5%. Although the share decreased to 42.96% in 2008, China still remains as the largest cassava-importing country in the world (Zhan et al, 2010). One of the most important processed products of cassava, cassava starch, also relies heavily on import (Fig. 3). The higher dependence on imports might have discouraged Chinese farmers to plant domestically (Chai et al, 2009).

Fig.3 Imports of cassava and cassava starch

Source: the values of domestic Cassava Production are from Fang, et al (2010); the values of import cassava are from Zhan, et al.(2010); the cassava consumption is calculated by domestic cassava production plus cassava import; the values of starch are from DRST, et al. (2009).

In the case of sweet sorghum, domestic production is very limited due to lack of existing domestic market. Currently it is grown for the purpose of animal feed in Mongolia and alcohol in Hebei, Shandong, and Xinjiang provinces. Zeng et al. (2009) shows that plantation of sweet sorghum is very sensitive to perceived risk and comparative economic advantage. The storage and pretreatment of sweet sorghum also presents challenges. Sweet sorghum can be planted only once a year, and the traditional fermentation time is very long taking about 14 days (Li & Chan-Halbrendt, 2009). An increase in fermentation concentration and a decrease in fermentation time are necessary to lower the cost of producing ethanol from sweat sorghum (Li & Chan-Halbrendt, 2009).

Uncertainty of emission reduction of starch & sugar energy crops-based ethanol

Although biofuels are treated as “carbon neutral” under the Kyoto Protocol, their actual Greenhouse Gas (GHG) emissions are the subject of much debate. Recent life cycle analysis (LCA) studies in China indicated that fuel ethanol derived from sugar and starch energy crops have possibility to less sustainable than fossil fuels(Fig.4) due to large indirect consumption of coal during planting process. Sustainable regulations are required.

Fig.4. Fuel ethanol Well-to-Wheels (WTW) GHG emissions (CO₂ eq. g/km)

Notes: SI: Spart Ignition; DI: Direct Injection; DISI: Direct injection spark ignition; PISI: , FFV: Flexible Fuel Vehicle; DISI HEV: Hybrid Electric Vehicle

Source: based on analysis of three published Well-to-Wheels (WTW) studies in China; data from Zhang, Shen & Han, et al. (2008), Ou et al. (2009), and CATARC/GM(2007).

3.2 Biodiesel from waste oil

Waste oil from food oil is major feedstock of current biodiesel production in China.

3.2.1 Resource potential

The consumption of food oil was about 26.8 million tonnes in China in 2010 (Chang, et al.2012), and it is annually increasing due to population growth and income rise. It is estimated that 20%-30% of waste oil generated every year. And if 50% of them can be collected, the technical availability for biodiesel production is about 2.68 ~ 4.02 million tonnes (Guo, et al, 2010).

3.2.2 Supply cost

Although termed as ‘waste oil’, it has commercial value and find competitive applications in

feed industries, chilling oil in leather or rolling industry and even illegal refining for cooking oil. Therefore, waste oil takes market price and takes major share of biodiesel production costs (Table 5). The total supply cost is still higher than that of diesel in most cases. The relative high cost of this feedstock is also contributed by the lack of economic drivers and policy instruments for the construction of collection system.

Table 5: Typical cost and related assumptions of waste oil-to-biodiesel in China

Items	Unit	Waste oil
Feedstock cost	Yuan/tonne(biodiesel)	3,556-5,556
Assumed feedstock pricing mechanism		Market-based pricing
Assumed feedstock price	Yuan/tonne	3200-5000 ^a
Feedstock conversion efficiency	Tonne biodiesel / tonne feedstock	90%
Non-feedstock Cost	Yuan/tonne(biodiesel)	1444.4^a
Conversion technology		acid catalyzed process
Investment cost	Yuan/tonne(biodiesel)	3000 ^a
Total production cost		5,000-7,000
Share of feedstock cost	%	71.11-79.37
Designated biodiesel wholesale price from January 1, 2008 to April 7, 2011 ^b	Yuan/tonne	
- Min		4,425.2 (January 2009)
- Average		5,644.2
- Max		7,111.6 (April 2011)

Notes: a. Survey data of a project with 50,000 tonnes capacity by author in 2010; b. the designated diesel price multiplied by the fixed factor 0.92, which is the suggested factor by Hainan project based on the survey of authors.

3.2.3 Challenges

As mentioned in section 2, the current conversion capacity of waste oil-based biodiesel is more than 1.5 million tonnes in China, but most of them are not operated due to lack of collection system from the residential and commercial sectors (Liu et al.2011).

3.3 Biodiesel from oil-bearing trees

3.3.1 Resource potential

There are more than twenty species of oil-bearing tree species that can be used to produce biodiesel feedstock in China. Approximately one-fourth of these species are found in the northern part of the country, while the rest in the southern part, especially in the tropical and subtropical zones (Lv, et al. 2008). The main species include jatropha curcas, xanthoceras sorbifolia, Chinese pisache, varnish tree, sapium sebiferum, S. wilsoniana Sojak, idesia, sumac, euphorbia tirucalli and tung tree. The land productivities of typical oil-bearing trees are shown in Table 6. As in the case of non-grain sugar and starch energy crops, the marginal land available for oil-bearing trees should be in compliance with current land administration policies. It is estimated that, among the available forest barren lands, barren mountains, barren sand areas, and unutilized land resources, there are more than 36 million hectares that

can be available for oil bearing trees, of which more than 14 million hectares is from forest land alone (Table 7).

Table 6: Land productivities of oil-bearing trees

	Unit	Jatropha		Xanthoceras sorbifolia	Pistacia chinensis
Land productivity of feedstock	Tonne feedstock/ha.	1.5-3 ^a	6-9 ^b	1.5-5 ^c	7.5 ^d
Oil content	%	35-40	35-40	35-45	30-46
Assumed conversion efficiency	tonne (feedstock) / tonne (biodiesel)	3	3	3	3
Land productivity of biodiesel	tonne biodiesel/ha.	0.5-1	2-3	0.5-1.67	2.5
Total forest land area in 2009	Million ha.	30.38 ^e			
Total oil-bearing tree base by 2010	kha.	200 ^f			

Notes: a. 3-5 years after forestation in southwest area, source from Zhang, Lv & Lv, et al., 2008; b. 3-5 years after forestation in Hainan, source from Zhang, Lv & Lv, et al., 2008; c. 5 years after forestation, source from Zhang, Lv & Lv, et al., 2008; e. source from Xie, et al.2011 c. data from the newly 7th forest resource survey from 2004 to 2008 by State Forestry Administration (SFA, 2009); d. data from Wang (2011).

Table 7: Land resources distribution and potential for developing oil-bearing trees

Province	Main Oil Species	Area of Available Land	Available forest land	Biodiesel potential on marginal land	In which, potential on available forest land
Unit		Million ha.		Million tonne	
South China and Southwest	Jatropha, euphorbia tirucalli, etc.	2	1	1-4	0.5-2
North China, Central China and East China	Chinese pisache, tung tree, varnish tree, sapium sebiferum, Idesia, euphorbia tirucalli	4	3	2-8	1.5-6
Northwest, North of North China and west of Northeast	xanthoceras sorbifolia, Chinese pisache, robur	30	10	15-60	5-20
Total		36	14	18-72	7-32

Note: Calculated based on the assumed land productivity as 0.5-2 tonne biodiesel/ha.

Source: Lv, et al.2008

3.3.2 Supply cost

The supply cost of biodiesel produced from oil-bearing trees is relatively higher than that of diesel due to the high cost of feedstock (Table 8).

Table 8: Typical cost and related assumptions of jatropha-based biodiesel in China

Items	Unit	Jatropha
Feedstock cost	Yuan/tonne(ethanol)	3,000-6,000
Assumed feedstock pricing mechanism		Cost-based pricing ^a
Assumed feedstock price	Yuan/tonne(feedstock)	1,000-2,000 ^b
Assumed conversion efficiency	Tonne (feedstock) / tonne (biodiesel)	3
Non-feedstock Cost	Yuan/tonne(biodiesel)	2,000^c
Conversion technology		super critical fluid transesterification without catalyst
Investment cost	Yuan/tonne(biodiesel)	2,300-2,500 ^d
Total production cost		5,000-8,000
Share of feedstock cost	%	75
Designated biodiesel wholesale price from January 1, 2008 to April 7, 2011	Yuan/tonne	See Table 5

Note: a. there is no mature market for jatropha in China, while there are some jatropha planting contract between company and farmers with protect price range from 1000 to 2000; b. estimated by expert; c. data from field survey based on Hainan project; super critical fluid process is expensive on capital and operation costs compared with conventional acid/basic catalyzed process according to Hainan project; d. data from Wu et al.(2008).

3.3.3 Challenges

The feedstock cost again is one of the major challenges to the development of biodiesel. For example, jatropha has a gestation lag of 3-4 years and the amount of capital required is substantial (Pradip, et al 2010), particularly when it has be grown in marginal lands. Although about 0.2 million hectares of planting base have been built in China, only 40 tonnes of jatropha-derived oil has been produced so far (Wang, 2010). Farmers do not plant jatropha unless they see explicit return from it. According to the case study in Panzhihua, the capital cost of planting base is about 4500-6000 Yuan/ha. (Xin & Zhang, 2011). Due to high risk, the actual development of Jatropha industry in Panzhihua shows sharp contrast to initial expectation (Liu et al., 2010).

3.4 Second-generation biofuels

3.4.1 Resource potential

The cellulosic resource for 2nd generation biofuels includes agriculture and forest residues (Table 9).

Table 9: Cellulosic biomass in China

	Generation Potential Million tonnes		Current Utilization
	Current(2008/2009)	2020(estimated)	
Agriculture residues	650.55 ^a (2010)	679.22 ^b	15% for burning, 15% for returning to the field, 24% for fodder, 43% for fuel wood, 3% for industry use.
Forest residues	854.56 ^d (2010)	965.39 ^b	Part of bush residues was used to feed, fiber, etc.

Note: a. data from Chang, et al. 2012

3.4.2 Supply cost

The production cost of 2nd generation biofuels is full of uncertainties. Production cost for 2nd generation biofuels in the literatures range between USD 0.60/liter and 1.30/liter (4937.4 and 10697.7 Yuan /tonne⁴) (Ralph, et al, 2010). The pilot scale cost in China is about 7845 Yuan/tonne based on the techno-economic analysis of 300 tonnes project (Table 10). The supply cost is higher than that of gasoline, and lacks of comparative economic advantage. The feedstock cost is relative low, about 19.8% of total production cost. This is partly because the feedstock requirement of 300 tonne demonstration project is not very high. With the increase of production scale to deployment & commercialization stages, the feedstock price will inevitably increase due to long collection radius. Therefore, government subsidies are required.

3.4.3 Challenges

The technology uncertainty is the biggest challenges. Although the Chinese government has put lots of attention on technology R&D of 2nd generation biofuels, and it is expected that the 2nd generation biofuels will become commercially viable within 7~10 years, it will not play vital role on target achievement by 2020.

4. Policies needed to achieve 2020 targets

4.1 Screening of current policies on biofuels deployment relevant policy

A large number of policies, ranging from command and control instruments (i.e., standards, mandatory and entry regulation) and fiscal and economic measures (tax exemptions and subsidies) have been introduced in China to support the development of biofuels (see Appendix Table A). These policies are aimed at different stages of the biofuels chain can be summarized in Table 11, covering production of feedstock, and conversion of feedstock to biofuels and consumption of biofuels. For fuel ethanol, most of the policies were drafted before 2007 and applied to designated projects only. Since 2007, there are several preferential policies for biodiesel, especially for waste oil-based biodiesel.

⁴ Exchange rate is 6.5 Yuan/ USD; the density here used is 1266 l/tonne

Table 10: Techno-economic analysis of a pilot cellulosic ethanol project with capacity as 300 tonne in China

Cost category	Unit	Value	Assumptions/remarks
Feedstock Cost	Yuan/tonne	1,550^a	<p>① Corn straw price is 220 Yuan/tonne;</p> <p>② Transportation collection radius is about 8 km, and transportation & crush cost of corn Stover is 65-70 Yuan/tonne;</p> <p>② Main components of corn straw: Cellulosic: 37.2%; Hemicellulosic: 25.3%; Lingo: 18%</p> <p>④ Key indicators of conversion process: Corn straw saccharification rate: 51.6%; Ethanol concentration: 23g/L; Ethanol production rate: 18.1%</p>
Non-feedstock cost	Yuan/tonne	5,835	<p>① Conversion technology is dilute acid pretreatment and enzymatic saccharification and fermentation;</p> <p>② Enzyme cost is most expensive part, which accounting for 31.8% of unit total production cost.</p>
Total production cost	Yuan/tonne	7,845	
Share of feedstock cost	%	19.8%	
Investment cost	Yuan/tonne	8,700	
Designated fuel ethanol wholesale price	Yuan/tonne	See Table 3	

Source: Song, et al (2010)

Table 11: Synthesis of selected policies and measures for supporting biofuels during process chain

Process Chain	Measures	Fuel ethanol			Biodiesel		
		Corn/Wheat designated	Cassava designated	Non-designated starch-sugar energy crops	Oil-bearing trees/waste oil Designated	Non-designated oil-bearing trees	Waste oil
Feedstock	Subsidies						
	-Subsidies for aged-grain used	X					
	- Subsidies for energy crops planting		X	X	X	X	
Conversion	Tax Exemption or Refund						
	-Consumer Tax	X	X		X		X
	-Value added Tax	X	X		X		X
	-Income Tax				X		X
	Subsidies	X	X		X		
	Wholesale Price Guarantee	X	X		X		
Distribution	Mandate	X	X		X		
	Subsidies	X	X				
	Retail Price Guarantee	X	X		X		

4.2 Barriers and options for policy response

Comparing recent progress to the required growth for meeting the 2020 targets, it appears that there are additional policies needed on biofuels development. In this sector, an overview of major economic and non-economic barriers of biofuels development will be analyzed based on broad literature reviews and our own analysis in section 3 (Table 12). Then potential policy responses are provided. The method is similar as Klessmann, et al. (2011) used to evaluate the barriers and policy options of European Union.

Table 12: Barriers and policy responses to address these barriers

Barrier	Options for policy response
Economic and market barriers	
- Not cost-competitive under current market conditions	
High cost for non-grain sugar and starch fuel-based ethanol and oil-bearing trees-based biodiesel (Wang, Zhao, & Zhang, et al., 2010) <ul style="list-style-type: none">• Inefficient subsidies policies for energy crops planting (Wang, Zhao, & Zhang, et al., 2010);• Lack of support policies for non-grain-fuel ethanol conversion;	<ul style="list-style-type: none">• Increase subsidies to feedstock production, especially that of oil-bearing trees(Wang, Zhao, & Zhang, et al., 2010);• Financial support to build new demonstration projects of non-grain fuel ethanol(Wang, Zhao, & Zhang, et al., 2010);• Tax exemption for fuel ethanol derived from non-grain feedstocks(Wu, et al., 2010);• Increase subsidy or establish special subsidy fund for non-grain fuel ethanol development (Wu, et al., 2010; RGCMLDS,2011);• Encourage technology penetration of energy crops, and enhance the land productivity through scientific research(EBSDEC,2009);• Encourage international cooperation to introduce good species of energy and support their demonstration projects (EBSDEC,2009);
High feedstock cost for waste oil biodiesel <ul style="list-style-type: none">• Lack of recycling mechanism of waste oil	<ul style="list-style-type: none">• Build recycling mechanism of waste oil for biodiesel production(Ji & Wang, 2007; Chang, et al.2012)
High capital costs and production costs for 2 nd generation biofuels <ul style="list-style-type: none">• Lack of transparent support policies on 2nd generation biofuels (RGCREDS, 2008)	<ul style="list-style-type: none">• Financial support demonstration projects of 2nd generation biofuels (Wang, Zhao, & Zhang, et al., 2010; Qiu & Wang, 2010; Qiu & Huang.2010; Chang et al. 2012);• Provide higher subsidies to 2nd generation biofuels than that for existing grain-ethanol(Song, 2010);
- Limited access to finance	
Limited access to finance on non-grain sugar and starch fuel ethanol	<ul style="list-style-type: none">• Establish stable and long-term policy framework and targets to build trust in future markets (Chang, Zhang, Chai, 2008);• Set up venture capital fund for non-grain fuel ethanol (Wu, et al., 2009);• Set up industry development fund for 2nd generation biofuels (Song,2010)
Limited access to finance on oil-bearing trees biodiesel	
Limited access to finance on 2 nd generation biofuels (Chang, Zhang, Chai, 2008; Song,2010)	
Administrative and legal barriers	
Lack of strategy guideline and technology roadmap on biofuels development (Wang, Zhao, & Zhang, et al., 2010)	<ul style="list-style-type: none">• Specific planning on biofuels (RGCREDS, 2008; Wang, Zhao, & Zhang, et al., 2010; Wu et al. 2010, RGCMLDS,2011)
Lack of policies on access of newly added biofuels (Wang, Zhao, & Zhang, et al., 2010) <ul style="list-style-type: none">• Lack of transparent approvment procedure for	<ul style="list-style-type: none">• Clarify approvment indicators or guidelines for non-grain fuel ethanol projects;• Clarify policies on access to the distribution system

non-grain sugar & starch fuel ethanol projects (Wang, Zhao, & Zhang, et al., 2010) ; • Lack of transparent access policy for biodiesel;	for non-grain fuel ethanol and biodiesel(Wang, Zhao, & Zhang, et al., 2010); • Permit more competitor in the processing and retailing sectors(Li & Chan-Halbrendt,2009);
Lack of standard and regulations for sustainable production of biofuels (i.e., what kinds of marginal land is available for energy crops from the sustainable perspectives) (Wang, Zhao, & Zhang, et al., 2010)	• Set standard and regulations on sustainable production of biofuels (Wang, Zhao, & Zhang, et al., 2010); • Integrate the environmental and social performance of biofuels with economic and non-economic incentives;
Information and acceptance barriers	
Lack of knowledge on environmental and social externality of biofuels (RGCREDS, 2008; Wang, Zhao, & Zhang, et al., 2010; Chang, et al.2012) • Potential impact of biofuels production on the grain security and agriculture development(Huang, et al. 2010, Fu, et al. 2011) • Potential ecological environment problems caused by large-scale cultivation of energy crops (EBSDEC, 2009)	• Further improve Life cycle analysis methodology for biofuels (Wang, Zhao, & Zhang, et al., 2010; IEA,2012; Chang, et al., 2012);
Lack of resource assessment (i.e., quantity and distribution of marginal land in China for energy crops) (Wang, Zhao, & Zhang, et al., 2010)	• Further improvement of method on resource assessment; Carrying out resource assessment, especially in resource rich provinces; (EBSDEC, 2009; Wang, Zhao, & Zhang, et al., 2010)

Each technology faces respectively the different barriers, but supply cost is one of the major barriers faced by all pathways, especially that of feedstock cost. Non-grain fuel ethanol attracts more concerns to address their economic barriers as policies suggested shown in table 12. Second-generation biofuels are projected as the most promising pathway in medium- and long-term. Several countries have preferential provisions that encourage the use of second-generation biofuels (e.g. specific policy target in the United States). Policy support for second-generation biofuels in China focused mainly on research and development (R&D), while there are almost no specific policies for deployment of second-generation biofuels in China. It is necessary to shift gradually from R&D to market deployment policies.

Non-economic barriers still exist in China, like administration. Most of existing policies related to fuel ethanol are aimed at grain based ethanol (i.e., corn or wheat). Without central government permission, new fuel ethanol companies have no access to the biofuels industry, no financial subsidies, tax exemptions and bank credits support, even no access to the distribution channel. Despite the existence of the entry regulation, there are still no transparency indicators or guidelines on what kind of starch and sugar energy crops should be designated.

Considering the uncertain impacts of large scale biofuels production on climate security, as

discussed in section 3.1.3, introduction of sustainability criteria might be needed to ensure that Chinese biofuels industry help reduce GHG emissions. The U.S. Renewable Fuel Standard (RFS) and the EU Directives both placed efforts on measures to ensure that renewable fuel is indeed reducing GHG emissions and to require minimal lifecycle GHG threshold compared to equivalent fossil fuel consumption (Sorda, et al. 2010).

Another non-economic barrier is information. More science-based analysis to provide knowledge and increase acceptance to public is necessary.

5. A review of the biofuels projection and its implications

An overview of existing literatures regarding biofuels projections in the medium- and long-term is presented here. A comparison of these studies including scenario designs and key assumptions is shown in the Appendix Table B. To show the role of policies, these scenarios are grouped as Reference Storyline (RSL) and Policy Storyline (PSL). RSL includes scenarios designed as business as usual scenarios or current policy scenarios which are following current policies; and PSL includes scenarios with additional policies on energy conservation or that address climate change modeled. Figure 5 summarizes the key results of these studies.

The scenario projections cluster relatively during the near-term (by 2020) rather than long-term (by 2050) (Table 13). The minimum value of 2020 biofuels projection is 4 Mtoe from the Current Policy Scenario (CPS) of IEA (2011a), while the maximum value is 29.8 Mtoe from Active Scenario (AS) of RGCMLDS (2011)⁵. In order to meet the proposed sub-targets of fuel ethanol and biodiesel, a minimum 8.18 Mtoe should be produced given the heat value of fuel ethanol as 0.6377 toe/tonne and biodiesel as 0.903 tone/tonne.

⁵ Not all data are available for each time points for comparison. Liner Interpolation was carried out to provide data that are not explicitly specified in these literatures.

Fig.5. Review of biofuels projections

Table 13: Comparison of biofuels projection from reviewed studies

	Units	2015	2020	2025	2030	2035	2040	2045	2050
RSL									
Max	Mtoe	8.89	16.26	28.58	40.90	48.18	55.45	62.73	70.00
Min	Mtoe	2.52	4.00	6.50	9.00	12.00	15.04	16.72	18.24
PSL									
Max	Mtoe	15.66	29.80	58.55	87.30	100.73	114.15	127.58	153.58
Min	Mtoe	2.00	5.00	8.00	12.00	16.00	35.14	42.11	49.08

As to the sub-targets of fuel ethanol and biodiesel, almost all scenarios provide optimistic projections on biodiesel, while great difference on fuel ethanol projections by 2020 (Table 14). The minimum projection is from M1 scenario of Chang et al. (2012), which assumed a most pessimistic development of fuel ethanol by 2020. The maximum projection is from Most Optimistic Scenario (MOS) of Li & Chan-Halbrendt (2009), which is identified as the most optimization scenario by the authors.

A Bundle of additional policies were modeled to show the effectiveness to trigger biofuels development in the following years by 2020. These policies include less regulation coupled with sustainable guidelines(MOS from Li & Chan-Halbrendt (2009); L1&L2 from Chang, et al.(2012)); speeding up of technology development (M2 & L2 from Chang et al. (2012); BA from Zhang, et al. (2012); MS & AS from RGCMLDS (2011); MOS from Li & Chan-Halbrendt (2009)); increasing renewable energy share binding target (NPS from IEA(2011a); AS from RGCMLDS (2011)); energy security (Qiao, et al., 2010); and climate change addressing (450 Scenario from IEA(2009), NPS and 450 Scenario from IEA(2010), NPS and 450 Scenario from IEA(2011a), AS from RGCMLDS (2011)). Notwithstanding the modeling methodological difference, all scenarios demonstrate the perspective of biofuels development by adopting different policy options.

Table 14: Comparison of fuel ethanol and biodiesel projections in 2020 under reviewed scenarios.

Storyline	Target	Scenario comparison				
		Max	Min	Average	Variance	Standard Deviation
Fuel ethanol						
Unit	Mtoe	Mtoe	Mtoe	Mtoe	-	-
RSL	6.38	12.00	2.44	5.81	18.80	4.34
PSL	6.38	32.00	3.48	10.72	69.17	8.32
All Scenarios	6.38	32.00	2.44	9.08	55.58	7.46
Biodiesel						
Unit	Mtoe	Mtoe	Mtoe	Mtoe	-	-
RSL	1.81	3.00	1.80	2.64	0.32	0.56
PSL	1.81	13.55	2.80	6.59	14.27	3.78
All Scenarios	1.81	13.55	1.80	5.15	12.64	3.56

(a) Fuel ethanol

(b) Biodiesel

Fig.6 Review of fuel ethanol and biodiesel projections in 2020

6. Conclusions

China set a target of meeting 10% of its energy supply by 2010 and 15% by 2020 through renewable energy sources including hydropower, biomass, wind and solar. While most renewable energy technologies have reached or even surpassed the 2010 targets, the non-grain fuel ethanol is lagging behind meeting its target of 2 million tonnes for 2010 and

10 million tonnes for 2020. This study shows that a number of non-grain feedstocks such as cassava, sweet sorghum and sweet potato grown in low productive arable lands or marginal lands have enough potential to meet ethanol targets in 2020. The costs of ethanol production from these feedstocks vary from 4,887 Yuan/tonne to 6,802 Yuan/tonne. Which are comparable to existing wholesale prices of ethanol in China. However, should these lands be used for biofuels is not an easy question to answer as these lands could be utilized to produce grains to meet china's self-sufficiency target on grain supply. On other hand, cellulosic feedstocks, such as agricultural and forest residues have a much higher technical potential of supplying ethanol, but their costs are much higher as compared to those non-grain crops mentioned above. In the case of biodiesel, the target set for 2020 is 2 million tonnes. Alternative feedstocks, such as waste oil and oil fruit bearing non-edible shrubs (e.g., jatropha), each would have more technical capacity to meet the targets. Again, production costs are the major barriers as costs of biodiesel produced from these feedstocks would be higher compared to diesel price in China. Various policy measures, particularly, financial incentives, such as direct subsidies to non-grain sugar and starch based ethanol and cellulosic ethanol, building up recycling system to reduce the feedstock cost of waste oil-based biodiesel, and increasing subsidies to oil-bearing shrubs would be needed to overcome the costs barriers to biofuels in China.

This study also reviews several studies that projects production of biofuels for China. Due to differences on underlying assumptions and structures of models used, the projections vary widely across the studies. Nevertheless, most studies predict that China could not meet its biofuel targets in the business as usual scenarios. However, with the introduction of additional policy interventions, the country would meet those targets.

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Appendix

Table A

Relevant policy and measures during the process chain

Process	Policies	Scope
Fuel ethanol derived from sugar and starch crops		
Feedstock	Subsidies for aged-grain as feedstock	Designated projects only
	Subsidies of 180 Yuan per mu (2700 Yuan per ha.) on unused land.	Non-grain sugar & starch energy crops
Conversion	For designated grain-ethanol producers, exercise tax is exempted before Oct. 1, 2011. From Oct. 1, 2011, the levy of exercise tax on fuel ethanol using grain as feedstocks will be restored with tax rate as 5%. The tax rate will reduced to 1% from Oct.1, 2011 to Dec. 31, 2011, 2% in 2012, 3% in 2013 and 4% in 2015. From Jan.1, 2015, 5% will be restored.	Designated projects only
	For designated grain-based ethanol producers, value-added tax is refund before Oct. 1, 2011. From Oct, 1, 2011 to Dec. 31, 2011, the tax refund proportion is 80%. It will decrease to 60% in 2012, 40% in 2013 and 20% in 2014. From Jan. 1, 2014, the refund policy will be canceled.	Designated projects only
	Specific subsidies to offset production cost.	Designated projects only
	Entry regulation: Construction of newly fuel ethanol projects must be approved by state government.	
	Reward fund for scale up production of non-grain bioenergy and biochemistry	Hasn't implemented.
Distribution	Fuel blending standards	
	Regional mandatory blends as 10% in pilot areas	Designated projects only
	Wholesale price of fuel ethanol is the ex-factory price of 90# Gasoline multiplied with a factor as 0.911 before Mar.1 st , 2011, and is the ex-factory price of 93# Gasoline multiplied with the factor of 0.911 after Mar.1 st , 2011.	Designated projects only
	Retail price of ethanol gasoline is the same as that of gasoline.	Designated projects only
Biodiesel derived from oil-bearing trees		
Feedstock	Subsidies of 200 Yuan per mu (3000 Yuan per ha.) on unused land are given.	Oil-bearing trees
	Target on major commercial forest land(incl. energy plants) of total forest land	
	Check Method of Forest Energy Planting Base.	
	Guideline of Sustainable Planting of Energy Forest and the Guideline of Sustainable Planting of Jatropha.	
Conversion	Reward fund for scale up production of non-grain bioenergy and biochemistry	Hasn't implemented.

Distribution	Fuel blending standards	
	Regional mandatory blends as 5% in pilot area	Designated projects in Hainan province only.
Biodiesel derived from waste oil		
Conversion	Value-added tax is refund.	Biodiesel used waste oil as feedstock.
	Income tax is relieved by 10%.	Biodiesel company used waste oil as feedstock.
	Consumption tax is exempted.	Biodiesel used waste oil as feedstock.
Distribution	Fuel blending standards	
Second generation biofuels		
Feedstock	Agricultural residues and forestry residues utilization are encouraged.	
Conversion	Reward fund for scale up production of non-grain bioenergy and biochemistry	Hasn't implemented.

Source: Chang et al. 2012

Table B

List of scenarios reviewed

Reference	Name of Scenario	Storyline	Scenario description			Scope		
			General definition	Technological development assumed	Selected policies modeled	Supply vs.Demand	Transportation biofuels incl.	Transportation modes incl.
Chang,etal.2012	M1	RSL	It is designed that government will maintain the existing policy scenarios, and wait for the success of 2 nd generation technology innovation conservatively.	The 2 nd generation biofuels technology will begin to be commercially deployed by 2025.	Few special RDD&D support for 1.5 and 2 nd generation biofuels, waiting for the deployment of 2 nd generation in the world; Strict land use policy with upper limitations of unused land utilization ratio as 20%, and forbidding newly added arable land for biofuels.	Supply	Fuel ethanol, Biodiesel	Road
	M2	RSL	It is designed that government will take a more active policy of sustainable development in China, increase the R&D investment to second-generation technology, and strengthen the supervision and management on biofuels development, especially that of 1 st biofuels.	The 2 nd generation biofuels technology will begin to be commercially deployed by 2025.	Encouragement of investment aid for biofuels projects especially that of 1.5 and 2 nd generation biofuels; medium strict land use policy with upper limitations of unused land utilization ratio as 50%. Strong support will be given to the projects which in line with the requirements of sustainable development.	Supply	Fuel ethanol, Biodiesel	Road

	L1	PSL	It is designed that government will maintain the existing policy scenarios, and wait for the success of second-generation technology innovation.	The 2 nd generation biofuels technology will begin to be commercially deployed by 2015.	Few special RDD&D support for 1 st generation biofuels, waiting for the deployment of second-generation in the world; Strict land use policy with upper limitations of unused land utilization ratio as 20%, and forbidding newly added arable land for biofuels.	Supply	Fuel ethanol, Biodiesel	Road
	L2	PSL	It is designed that government will take a more active policy of sustainable development, increase the R&D investment to 2 nd generation technology, and strengthen the supervision and management on biofuels development, especially that of 1 st generation biofuels.	The 2 nd generation biofuels technology will begin to be commercially deployed by 2015.	Encouragement of investment aid for biofuels projects especially that of 2 nd generation biofuels, medium strict land use policy with upper limitations of unused land utilization ratio as 50%. Strong support will be given to the projects which in line with the requirements of sustainable development.	Supply	Fuel ethanol, Biodiesel	Road
IEA,2011a	New Policy Scenario(NPS)	PSL	The scenario incorporates the broad policy commitments and plans that have been announced by countries around the world to tackle energy insecurity, climate change and local pollution, other pressing energy-related challenges, even where the specific measures to implement these commitments have yet to be announced.	Not explicitly specified.	A 40% reduction in carbon intensity compared with 2005 by 2020; CO ₂ pricing from 2020; a 15% share of non-fossil energy in total energy supply by 2020; Increased biofuels blending;	Demand	Fuel ethanol, Biodiesel, Aviation biofuels	Road, Aviation
	Current Policies Scenario(CPS)	RSL	The CPS embodies the effects of those government policies and measures that were enacted or adopted by mid-2011.	Advanced biofuels, including those from ligno-cellulosic feedstock, are assumed to reach commercialization, by around 2025 in the CPS.	Implementation of measures in 12 th Five-Year Plan, including 17% cut in CO ₂ intensity by 2015; Ethanol blending mandates 10% in selected provinces.	Demand	Fuel ethanol, Biodiesel, Aviation biofuels	Road, Aviation

	450 Scenario	PSL	The 450 scenario sets out an energy pathway that is consistent with a 50% chance of meeting the goal of limiting the increase in average global temperature to two degrees Celsius, compared with pre-industrial levels.	Advanced biofuels, including those from ligno-cellulosic feedstock, are assumed to reach commercialization, by around 2015 in the 450 Scenario.	A 45% reduction in carbon intensity compared with 2005 by 2020; higher CO ₂ pricing; enhanced support for renewable. Support for the use of aviation biofuels. Enhanced support for alternative fuels.	Demand	Fuel ethanol, Biodiesel, Aviation biofuels	Road, Aviation
IEA,2011b	Roadmap based on Blue Map Scenario(BMS) in ETP(2010)	PSL	It sets out cost effective strategies for reducing greenhouse gas emissions by half by 2050.	It anticipates the installation of the first commercial-scale advanced biofuels plants within the next decade, followed by rapid growth of advanced biofuels production after 2020.	<ul style="list-style-type: none"> • Governments create a stable, long-term policy framework; • Governments ensure sustained funding and support mechanisms ; • Governments continue to develop internationally agreed sustainability criteria; • Governments link financial support schemes to the sustainable performance of biofuels 	Demand	Biomethane, Biojet, Biodiesel, Fuel ethanol	Road, Aviation & Shipping
Li & Chan-Ha lbrendt,2009	Most Likely Scenario(MLS)	RSL	Not explicitly specified.	Not explicitly specified.	Less regulation coupled with sustainable guidelines.	Supply	Fuel ethanol using non-grain sugar or starch crops	Road
	Most Optimistic Scenario(MOS)	PSL	Not explicitly specified.	Not explicitly specified.	Less regulation coupled with sustainable guidelines.	Supply	Fuel ethanol using non-grain sugar or starch crops	Road

Li & Wang 2012.		PSL	According to the land occupation feature of feedstock, the potential of CO ₂ emission reduction by developing ethanol is evaluated.	Not explicitly specified.	Not explicitly specified.	Supply	Fuel ethanol using non-grain sugar or starch crops	Road
Qiao.et al.2010	Low	PSL	Forecasting of biofuels development considering energy security pressure in the medium- and long-term (2030, 2050)	Not explicitly specified.	Second generation biofuels will be priority in government support policy.	Supply	Fuel ethanol, Biodiesel	Road
	High	PSL						
RGCML EDS2011	Active Scenario(AS)	PSL	A strong policy driven scenario assumed that government will be in the face of serious pressure of environment conservation and climate change addressing.	Large scale, low cost biomass feedstock production and collection system will be early realized. Cellulosic ethanol and F-T diesel will achieve fundamental breakthrough early.	Increase financial support to development and deployment of biofuels; Increase the share requirement of renewable energy;	Supply	Fuel ethanol, Biodiesel, Biomethane	Road
	Medium Scenario(MS)	PSL	A balance development scenario considering resource potential, environmental constraints and social cost comprehensively.	Large scale, low cost biomass feedstock production and collection system will be realized rapidly. Cellulosic ethanol and F-T diesel will achieve fundamental breakthrough rapidly.	Not explicitly specified.	Supply	Fuel ethanol, Biodiesel, Biomethane	Road
	Routine Scenario(RS)	RSL	A relative conservative scenario without considering climate change pressure.	Renewable energy will development gradually.	Not explicitly specified.	Supply	Fuel ethanol, Biodiesel, Biomethane	Road

Zhang, et al.2012	RS	RSL	Government hasn't explicit target for medium- and long-term automotive energy. No additional policies for innovation of vehicle technologies and fuel technologies will be released. The current technology and market conditions will continue.	Second generation biofuels will not have fundamental breakthrough before 2025. The cost of 2 nd generation biofuels will decrease sharply after 2035.	Not explicitly specified.	Supply	Fuel ethanol, Biodiesel	Road
	Biofuel Acceleration (BA)	PSL	In 2025, second generation biofuels will enter into rapid development phase.	In 2025, second generation biofuels will enter into rapid development phase.	Not explicitly specified.	Supply	Fuel ethanol, Biodiesel	Road
Zhao, et al.2010		PSL	Non-grain fuel ethanol potential was calculated based on quantity of available marginal land, land productivity of energy crops and conversion efficiency of fuel ethanol.	The land productivities of marginal weed, saline and alkali land are limited. Even if improved seed and cultural technique introduced, potential increased output is also limited.	Not explicitly specified.	Supply	Fuel ethanol using non-grain sugar or starch crops	Road