GREATER MEKONG SUBREGION
ECONOMIC COOPERATION PROGRAM

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BIOFUELS

AND RURAL RENEWABLE ENERGY

THE PEOPLE'S REPUBLIC OF CHINA

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THE PEOPLE'S REPUBLIC OF CHINA

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Abbreviations

Chinagro	–	Decision Support System for Sustainable Agricultural Development in the People's Republic of China
mt	–	million ton
mtce	–	million tons of coal equivalent
NDRC	–	National Development and Reform Commission
PRC	–	the People's Republic of China
R&D	–	research and development
WTO	–	World Trade Organization

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Introduction

Background of the Study

The economy of the People's Republic of China (PRC) has grown remarkably since economic reforms were initiated in 1978. Although the growth pattern has been cyclical, the country's economy grew so fast after 1980 that it outperformed almost all other countries in Asia. The average annual growth rate of gross domestic product (GDP) reached nearly 10% in the three decades since the reforms. Real GDP in 2006 was about 12 times that in 1978.[1]

Rapid economic growth led to a rapid rise in demand for energy, which also raised concerns about national energy security. The nation's record on greenhouse gas emission is also becoming a concern, not only in the PRC, but also in the rest of the world. In 2006, 350 million tons (mt) of oil were imported, accounting for about 48% of total oil demand (footnote 1). Given the energy security concerns, the search for alternative sources of energy has become a top government priority. Biofuel, with its reputation for being relatively carbon neutral, has been the focus of much government attention.

The PRC is now the third largest biofuel producer in the world after the United States and Brazil.[2] In 2007, the country's bioethanol production reached 1.35 mt. Maize is the primary feedstock. Biodiesel, on the other hand, is still in its infancy, not only because the PRC has been relatively late to venture into biodiesel, but also because of the limited supply of feedstock and the relatively high cost of constructing large-scale plants.

The development of biofuel to provide additional energy to meet rising domestic demand entails a lot of questions and issues that need to be analyzed and assessed. For example, what are the likely trends in biofuel production in the future, considering the country's limited potential land for feedstock production? Bearing in mind cost effectiveness and the potential uncertainty of feedstock supply, which feedstock or feedstocks should be produced in larger amounts? Where are the promising areas in the country that can be developed for feedstock production? What are the implications of using different feedstocks? Will a biofuel program provide opportunities to strengthen the agriculture sector, improve food security, and reduce poverty; or will it lead to more risks for the rural population, especially the landless? What kinds of policies and institutional arrangements should be adopted for the sustainable development of the country's biofuel industry? These questions have gone largely unanswered.

Scope and Objectives of the Study

The goals of this project are to better understand biofuel development in the PRC; assess the implications of the biofuel program on food prices, crop diversification, land-use patterns, and farm restructuring; and derive policy implications for the future development of biofuels in the country.

To achieve these goals, several activities were undertaken, including national policy dialogue and workshops, literature review, and preliminary impact assessments.

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1 National Bureau of Statistics. 2007. *China Statistical Yearbook*. Beijing: China Statistics Press.

2 Chew, C. 2006. *Current Status of New and Renewable Energies in China*: *Introduction of Fuel Ethanol*. Report to the Institute of Energy Economics. Japan.

Energy Market Outlook in the People's Republic of China

Energy Supply and Demand

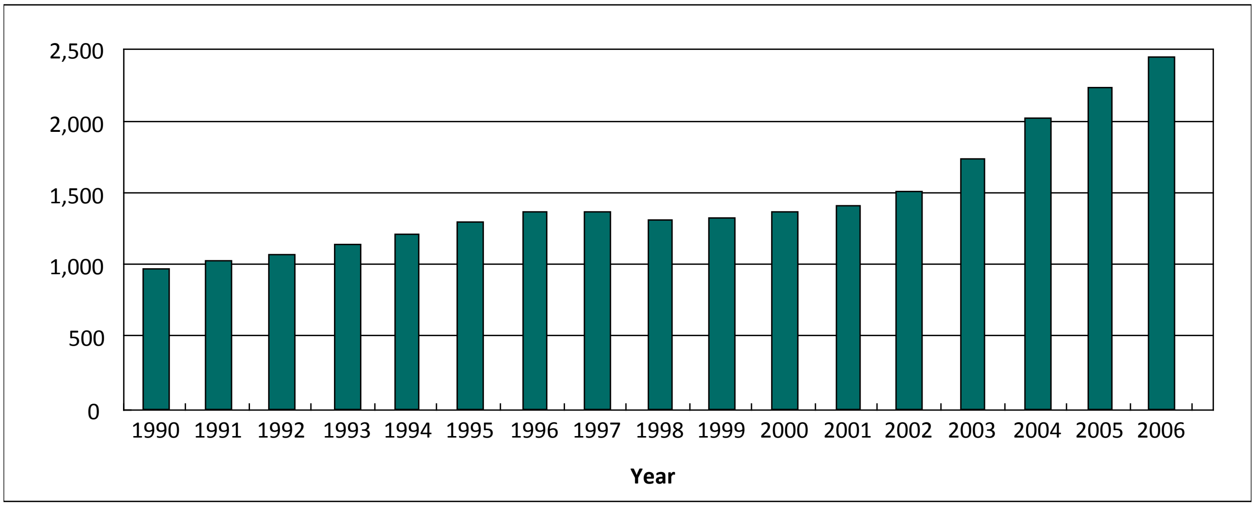
Energy demand

With the rapid development of the economy, the demand for energy in the People's Republic of China (PRC) has also increased at a fast rate over the last 20 years. Total energy consumption has more than doubled from 987 million tons of coal equivalent (mtce) in 1990 to 2,463 mtce in 2006 (Figure 1 and Appendix 1 Table A1). The rapid rise in energy demand since 2000 has led to increasing concerns about the country's energy security.

The most rapid rise in demand comes from industrial expansion. In 2006, industry consumed 1,751 mtce, accounting for about 71% of total energy consumption (Figure 2). Urban and rural households consumed 254 mtce, which accounted for 10.3% of total demand, while transport and communications consumed 186 mtce, or 7.6% of total demand, making it the third biggest energy user. The energy demand of other sectors, including agriculture, construction, and wholesale and retail, only accounted for 11.1% of total demand.

Energy demand in the transport sector (mainly gasoline) recorded the highest growth rate between 1978 and 2008. In 1980, the number of automobiles was less than 1.8 million. In 2005, the number reached 31.6 million.[3] Gasoline used in transport increased accordingly, from less than 4 mt in 1980 to 48.5 mt in 2005. The rise in demand for gasoline is expected to continue considering that the annual growth rate of automobiles accelerated by 9.0% in 1995–2000 and 14.5% in 2000–2005.[4]

Figure 1: Total Energy Demand in the People's Republic of China, 1990–2006
(million tons of coal equivalent)



Source: *Statistical Yearbook of China.* 2007.

[3] National Bureau of Statistics. 2006. *China Statistical Yearbook.* Beijing: China Statistics Press.

[4] National Bureau of Statistics. 2006 and 1986. *China Statistical Yearbook.* Beijing: China Statistics Press.

Energy supply in the People's Republic of China

Energy production in the country has also increased rapidly. Total energy production more than doubled from 1,039 mtce in 1990 to 2,211 mtce in 2006 (Figure 3). However, the growth in the rate of demand has been higher than the growth in the rate of supply. This has reversed the PRC's trade position as a net energy exporter in 1990 to a net importer in 1991.

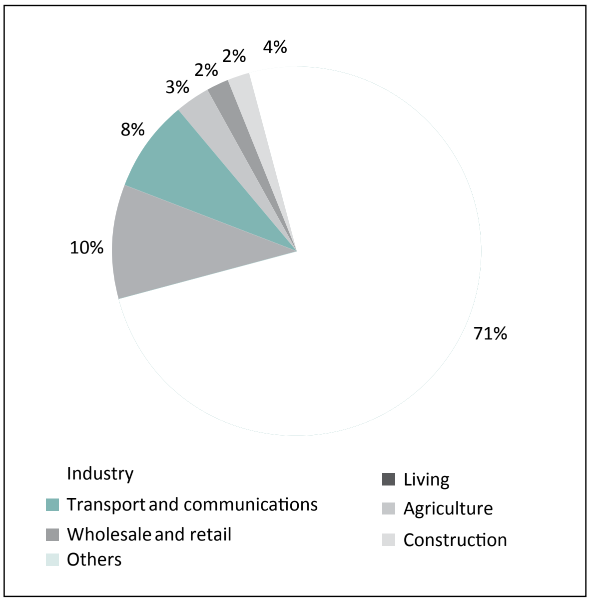
Of the different sources of energy supply, the share of coal increased from 70.3% in 1990 to 76.7% in 2006. Over the same period, the share of natural gas increased from 2.9% to 3.5%, and that of other energy sources, including hydropower, nuclear, and wind, increased from 3.1% to 7.1% (Figure 4). Although the overall supply of energy produced from oil increased, its share of the total energy supply dropped from 23.7% in 1990 to 11.9% in 2006.

International Trade in Energy Produced by the People's Republic of China

Energy exports expanded particularly rapidly after 2001 (Figure 5). Both oil (including crude and refined oil) and coal are imported; however, crude oil imports increased much faster during 2004–2009, while coal imports declined (Figure 6). This is mainly due to the rapid increase in oil demand from the transport and communications sector.

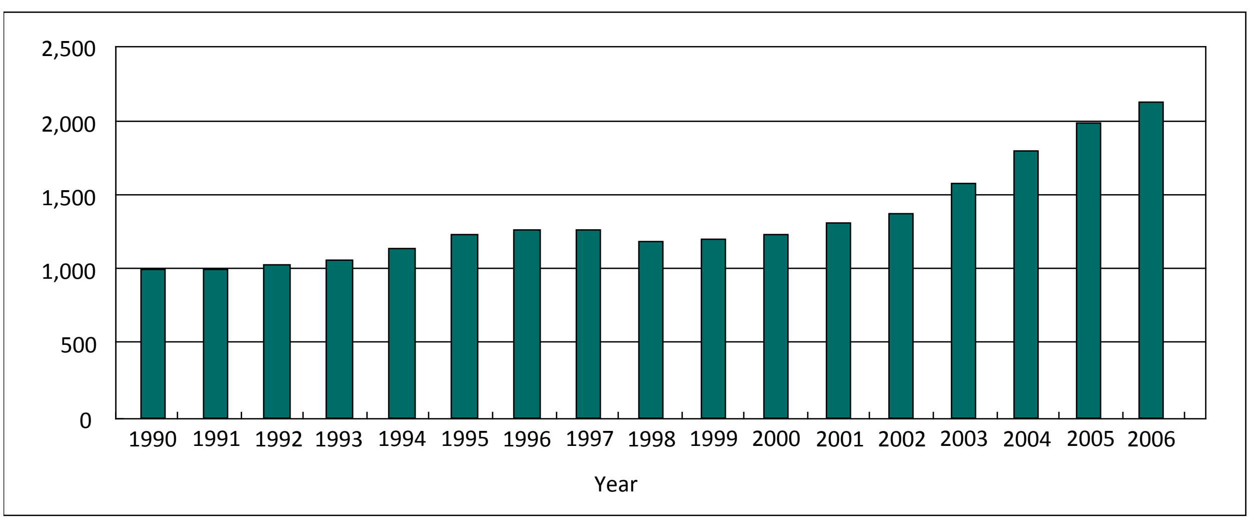
Since early 1993, the PRC had been a net importer of oil (Appendix 1 Table A2). In 1994, it imported

Figure 2: Share of Energy Demand by Sector in the People's Republic of China, 2006 (%)



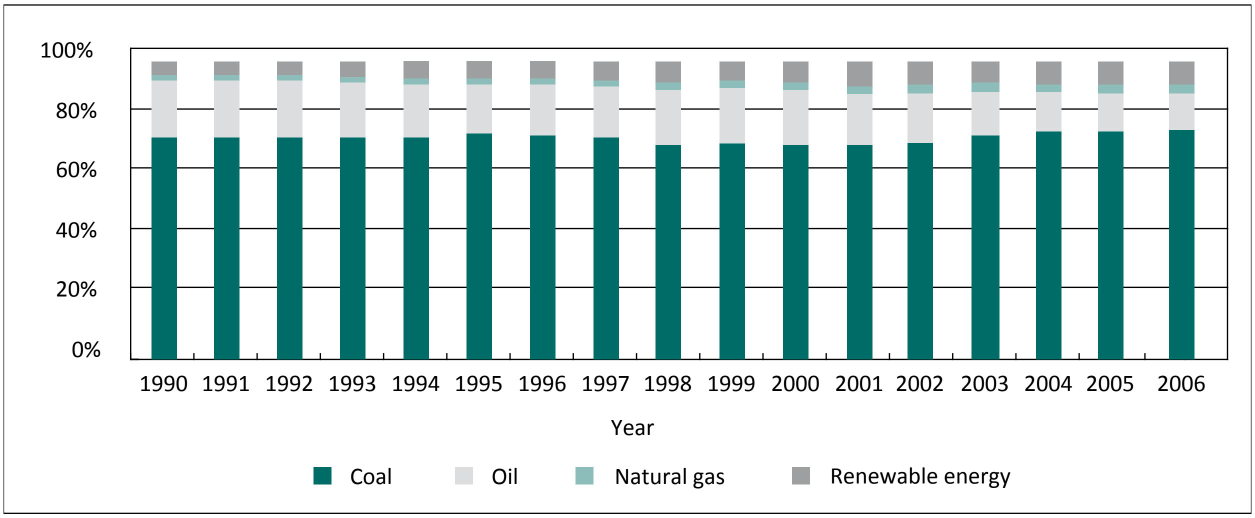
Source: *Statistical Yearbook of China*. 2007.

Figure 3: Total Energy Production in the People's Republic of China, 1990–2006 (million tons of coal equivalent)



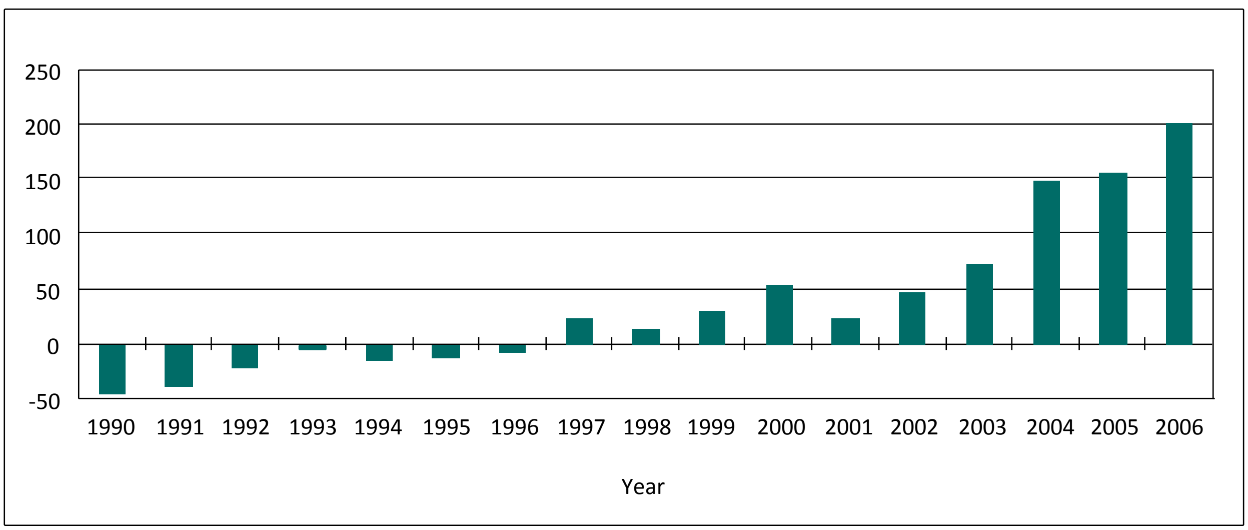
Source: *Statistical Yearbook of China*. 1991–2007.

Figure 4: Shares of Energy Production in the People's Republic of China, 1990–2006 (%)



Source*: Statistical Yearbook of China*. 1991–2007.

Figure 5: Net Energy Imports of the People's Republic of China, 1990–2006
(million tons of coal equivalent)



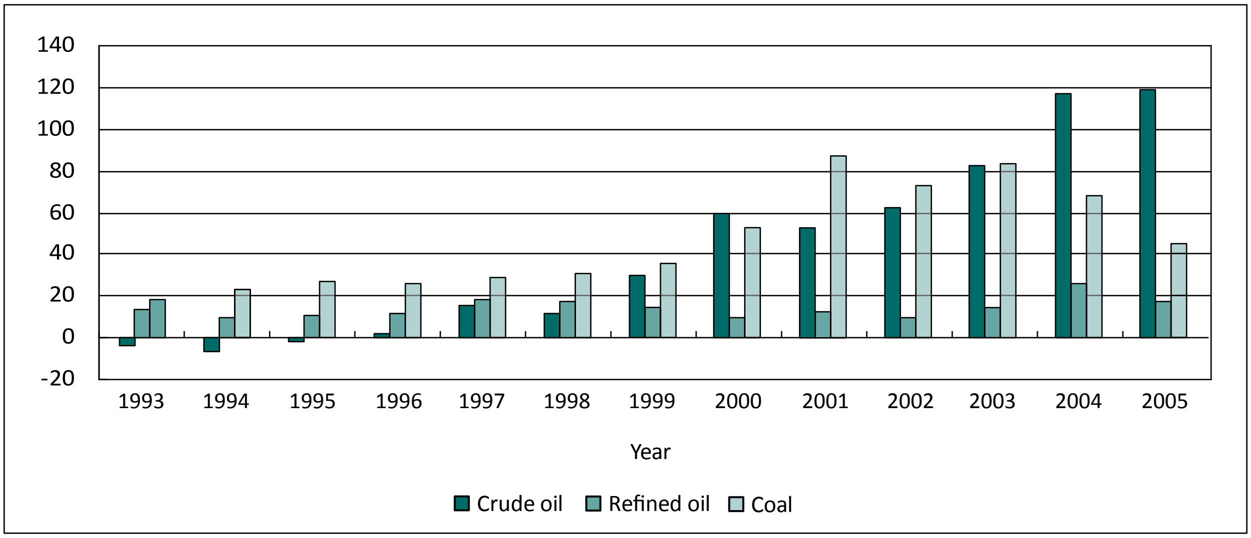
Source: *China Energy Statistical Yearbook*. 2007. *China Statistical Press*. Beijing.

2.9 mt of oil, which accounted for 1.9% of total oil demand. With the expansion of the economy, the volume of imported oil and dependence on the international oil market had increased. In 2006, the PRC imported 162.9 mt of oil, which accounted for 47% of its total oil demand.

Rapid economic growth will continue to increase the demand for oil. Almost every major economic modeling team in the world has projected that strong economic growth in the country will continue at about 8% until the mid-2010s and will range between 6% and 7% annually between 2010 and 2020.[5] The size of the

[5] Although the economic downturn that began in 2008 may have negative impacts on the economy of the PRC, it is not expected to have significant impacts on the country's long-term economic development.

Figure 6: Net Import of Crude Oil, Refined Oil, and Coal in the People's Republic of China, 1993–2005 (million tons)



Source: *Statistical Yearbook of China*. 2007.

PRC's economy means that such rapid growth is likely to have profound implications for its national energy demand and for the global energy market, especially for oil. Several studies show that the country's oil imports will continue to increase.[6] A 2005 study by the International Energy Agency showed that the PRC's oil imports will increase to 77% by 2020 and to 80% by 2030. A 2006 study by Wei et al. showed that by 2020, under every scenario and considering the growth of the PRC's population and economy, more than 50% of its oil demand will have to be met through imports.[7] The Ministry of Commerce projects that by 2020, the country will import 265 mt of oil, representing about 57.6% of its total oil demand (Table 1). The above studies show that the PRC will become a big oil importing country after 2010 and will have to search for alternative energy resources, including biofuels, to power its growth.

[6] Wei Yiming, Fan Ying, Han Zhiyong, and Wu Gan. 2006. *China Energy Report 2006.* Beijing: China Science Press; International Energy Agency (IEA) World Energy Outlook 2005. Paris; Ministry of Commerce of the PRC. 2006.

[7] Wei Yiming, Fan Ying, Han Zhiyong, and Wu Gan. 2006. *China Energy Report 2006.* Beijing: China Science Press.

Table 1: Oil Demand, Production, Net Import, and Projections for 2010, 2015, and 2020, People's Republic of China
(10,000 tons)

Year	Demand	Production	Net Import	Import/Total Demand (%)
1994	150	147	3	1.9
1995	157	149	8	5.4
1996	172	159	14	8.1
1997	196	162	34	17.0
1998	189	160	29	15.4
1999	204	160	44	21.5
2000	233	163	70	30.0
2003	267	170	97	36.4
2004	318	175	144	45.1
2005	318	181	136	42.9
2006	347	184	163	47.0
2010	363	185	178	49.0
2015	375	186	189	50.4
2020	460	195	265	57.6

Source: Ministry of Commerce. 2007.

Renewable Energy Development in the People's Republic of China

The People's Republic of China (PRC) has made substantial improvements in biomass energy use over the last 20 years in an attempt to mitigate potential energy security problems. By the end of 2007, biogas was in use by more than 26 million households, the annual production capacity of bioethanol reached 1.33 mt, and a pilot power plant using crop residues was in operation.[8]

Biogas

The PRC has invested heavily in the biogas industry. In the 10th Five-Year Plan period 2000–2005, CNY3.4 billion ($0.4 billion) was invested in the construction of biogas facilities in rural areas, benefiting more than 3.74 million rural households. Most of the biogas facilities use livestock manure and crop residues as feedstock. By the end of 2007, annual biogas production was 1.02 billion cubic meters and 26.50 million rural households were using biogas. The country also invested in medium- and large-scale biogas production plants that use agricultural wastes. By the end of 2007, the total number of biogas plants reached 26,600, with an annual production of 350 million cubic meters.[9] Two types of biogas plants currently in use are the household-based methane digester system and the village-based methane digester system. These systems use animal waste and crop residues to produce a clean, convenient form of energy for use by rural households.

Investment in biogas technology has also increased. The government started promoting biogas technology in the 1970s, but the most significant support for the development of the technology occurred after 2000. Currently, the development and adoption of biogas technology is part of the PRC's "new socialist countryside development" program. The Ministry of Agriculture cooperates actively with academic institutions on biogas research.

Biomass

Energy generation from biomass has developed steadily. Biomass power generation technology in the PRC can be divided into direct combustion power generation, co-combustion power generation, gasification power generation, and biogas power generation. By the end of 2005, the total capacity of biomass power generation reached 2,000 megawatts (MW). Molasses-based power generation reached 1,700 MW of the total; waste-based power generation capacity reached 200 MW; and other crop by-products and residue-based power generation capacity, including rice husks and crop by-products, reached about 100 MW.[10]

Biodiesel

Biodiesel production is also promoted, although total production remains small. By the end of 2007, about 10 biodiesel plants were operating in the country. Most of them use industrial waste oil and waste cooking oil as feedstock. The annual production capacity for most of these plants is less than 0.2 mt. Unlike bioethanol, biodiesel is not used in the transport sector. Most of it is used as fuel for factories or construction machinery. Biodiesel production needs a stable supply of lipid or vegetable oil as feedstock, but there is a shortage of these oils in the country. In 2007, the PRC imported more than 30 mt of vegetable oil. However, it can not afford to rely on imported vegetable oil for biodiesel production. Given

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8 National Statistical Bureau. 2007. *China Statistical Yearbook*. Beijing: China Statistics Press.

9 Chinese Academy of Agricultural Engineering. 2007. *Bioenergy Development in China*. Internal report. Beijing.

10 Kou, Jianping. 2007. *Current Status and Prospective of China's Biomass Energy Development*. Conference of Biomass Energy and China's Agricultural Trade. Beijing.

the domestic supply constraints, there are plans to develop forest-based biodiesel, using for example, jatropha seeds.

Bioethanol

The PRC is the third largest bioethanol producer in the world—after the United States and Brazil—with a production of 1.33 mt in 2007. Four large-scale bioethanol plants in Heilongjiang, Jilin, Henan, and Anhui provinces were constructed in 2001. They mainly use maize as feedstock. Their combined annual production capacity is approximately 1.5 mt. In 2007, another bioethanol company was established in Guangxi Zhuang Autonomous Region. It uses cassava as feedstock. Annual production capacity is 0.2 mt. Table 2 shows the distribution of the country's five bioethanol plants and their feedstock demands in 2007.

Table 2: Distribution and Feedstock Use of Bioethanol Plants in the People's Republic of China, 2007
('000 tons/year)

Location	Yield ('000 tons/year)	Feedstock	Feedstock demand ('000 tons/year)
Jilin	600	Maize	1,820
Heilongjiang	100	Maize	330
Henan	300	Wheat and maize	900
Anhui	320	Maize	960
Guangxi*	200	Cassava	1,440

* Operation of the cassava-based bioethanol plant in Guangxi was scheduled to start in early 2008; hence, yield and feedstock demand were estimated based on its production capacity.

Source: Chinese Academy of Agricultural Engineering. 2007.

National Policies, Targets, and a Model for Agribusiness

Major Policies and Targets for Biofuel Production

To facilitate bioethanol production and marketing, the government has set up a series of supporting policies since the late 1990s. In the initial years, substantial support was given through investment in research and development (R&D), especially for biofuel technology development. The First Five-Year Plan for Bioethanol and the Special Development Plan for Denatured Fuel Ethanol and Bioethanol Gasoline for Automobiles in the 10th Five-Year Plan (2001–2005) were announced in early 2001. The main goal was to experiment with bioethanol production, marketing, and support measures. To achieve this goal, two policy documents—the Pilot Testing Program of Bioethanol Gasoline for Automobiles and the Detail Regulations for Implementing the Pilot Testing Program of Bioethanol Gasoline for Automobiles—were jointly issued by the National Development and Reform Commission (NDRC) and seven other ministries in early 2002. At the same time, national standards for denatured fuel ethanol and bioethanol gasoline for automobiles were formulated and implemented. The marketing of a bioethanol and gasoline blend with 10% ethanol (E10) for the automobile sector was initiated in 2003 in three cities in Henan Province and in two cities in Heilongjiang Province.

The two policy documents provided the following major support policies during the pilot testing of the program:

(i) The 5% consumption tax on all bioethanol under the E10 program was waived for all bioethanol plants.

(ii) The value-added tax (normally 17%) on bioethanol production was refunded at the end of each year.

(iii) All bioethanol plants received subsidized "old grain" (grains reserved in national stocks that are not suitable for human consumption) for feedstock. This subsidy was jointly provided by the central and local governments.

(iv) The government offered a subsidy to ensure a minimum profit for the bioethanol plants. This meant that if, despite the other support mechanisms, any bioethanol plant were to record a loss in production and marketing, it would receive a subsidy equal to the gap between marketing revenues and production costs plus a reasonable profit that the firm could have obtained from an alternative investment. This subsidy is estimated for each plant at the end of each year.

Besides the four support policies, the government also ensured that there were markets for the bioethanol produced by these state-owned plants. Bioethanol produced by private plants was not allowed to enter the market.

The pilot testing program was expanded in 2004. New policy guidelines were issued replacing those issued in early 2002. The new policies proposed the expansion of bioethanol production in the four state-owned plants. Annual bioethanol use in automobiles was targeted at 1.02 mt in 2004. Five provinces and 27 cities in another four provinces were selected to participate in the expanded testing phase. The new policy guidelines also ensured that most supporting policies implemented in the first pilot testing program would continue into the second pilot testing phase, with the exception of the measure that ensured a minimal level of profit. In the second phase, to encourage technological innovation and provide incentives for improving the efficiency of bioethanol production, a fixed amount of subsidy was provided to all bioethanol plants. This fixed subsidy was computed based on the average production cost of biofuels per ton from all biofuel plants, rather than the specific production cost of each plant.

In 2005, the People's Republic of China (PRC) issued the Renewable Energy Law, which has been in effect since 1 January 2006. This law makes clear that the country will forcefully push the development of renewable energy, including biofuels. In June 2007, under the Renewable Energy Law guidelines, the NDRC formulated the Middle- and Long-Term Development Plan of Renewable Energy. This plan aims to increase annual bioethanol production to 4 mt in 2010 and 10 mt by 2020.

The newly drafted 11th Five-Year Plan is accompanied by a set of support policies that will be implemented jointly by the NDRC, the Ministry of Finance, and several other ministries. The new support policies are similar to those implemented in the second pilot testing phase, but with two revisions:

(i) The previous fixed profit/loss subsidies are replaced by a "flexible subsidy for loss." Recognizing the existence of oil market price fluctuations, a risk fund has been established to smooth the shocks from oil price changes. The subsidy level is flexible as it is linked to gasoline market prices.

(ii) A new subsidy will be granted to firms that develop a new production base of feedstock not currently produced in the existing cultivated land area. This policy is in response to recent increasing concerns regarding trade-off between food (grain) security and energy security.

The global food price inflation of 2007 and 2008 caught the attention of policy makers. Food prices in the country increased by 40% in 2007 over those of 2006. In response to rising concerns over the trade-off of food, feed, and fuel, the government issued a regulation on the use of feedstock for biofuel production in September 2007. The policy stated that "biofuel must not compete with grain over land, it must not compete with the food that consumers demand, it must not compete with feed for livestock, and it must not inflict harm on the environment."[11] In addition, to reduce the stress on national food security, the government prohibited the use of any other grains for biofuel production in the future, except in the four existing maize and wheat bioethanol plants. These four plants were also prohibited from expanding any capacity for using cereals as a feedstock to produce bioethanol. Instead, the government is encouraging the use of sweet sorghum, cassava, sweet potato, and cellulose as major feedstocks.

While there is a clear intention to continue to improve the country's food security, it is unclear whether these policies can really ease the pressure on food security and, at the same time, help the PRC further develop and strengthen its biofuel industry. The success of the policies depends on whether the non-grain feedstocks will eventually compete with grains for the use of land if the demand for biofuels continues to expand.

The Biofuel Agribusiness Model in the People's Republic of China

In the PRC, biofuel is produced exclusively by state-owned companies. Private companies have not yet entered the government-controlled bioethanol and biodiesel marketing system. Almost all energy oil markets are controlled by two large state-owned companies—Sinopec and PetroChina. The farmers' involvement in the industry extends only to the provision of feedstocks. Farmers either sell the feedstocks directly to biofuel companies, or—more commonly—to national or local grain companies, most of which are controlled by national or local state grain bureaus.

Agribusiness Arrangement for Bioethanol

A bioethanol and fuel oil blend (E10) was used in the transport sector in the 5 provinces of Heilongjiang, Jilin, Liaoning, Anhui, and Henan, and in 27 cities in 4 other provinces. These are the cities of Xuzhou, Lianyungang, Huai'an, Yancheng, and Suqian in Jiangsu Province; Jinan, Zaozhuang, Jining, Tai'an, Linyi, Liaocheng, and Heze in Shandong Province; Wuhan, Xiangfan, Jingmen, Suizhou, Xiaogan, Shiyan, Yichang, Huangshi, and E'zhou in Hubei Province; and Shijiazhuang, Baoding, Xingtai, Handan, Cangzhou, and Hengshui in Hebei Province.

[11] NDRC. 2007. *Medium- and Long-Term Development Plan for China's Renewable Energy*. Beijing.

Because the arrangement for current bioethanol production is similar across major firms, a bioethanol company in Jilin Province is used to illustrate the agribusiness arrangement for bioethanol in the country.

The Jilin Fuel Alcohol Company is the largest ethanol production facility in the PRC. It is located in an industrial complex in the north of the country near Jilin City in Jilin Province. It was established in 2001 as a joint venture between PetroChina, Cofoco, and the Jilin Food Company. Ethanol production started in 2003. By the end of 2007, the plant's annual capacity was 500,000 tons (t), but actual production was only 380,000 t in 2006 and 450,000 t in 2007. The company plans to expand production. Unlike most ethanol plants in the United States , the Jilin facility has its own power station and water treatment facility. The plant has 430 employees, of which 10% are managerial staff. The facility uses the improved dry milling process to produce ethanol (Table 4). Maize is milled prior to fermentation, and the oil is extracted from the germ. Maize oil is sold for human consumption on both the domestic and international markets. The milling and fermentation equipment were developed in the PRC; the ethanol extraction equipment was imported from Australia. It is estimated that the Jilin bioethanol plant generates about 10 t of wastewater and uses the energy equivalent of 600 kilograms (kg) of standard coal (4,885 kilowatt-hour)[12] to produce 1 t of ethanol.

After fermentation and distillation, the distiller's grains are dried to a moisture content of 10%. The average protein content of the dried distiller's grain is 28%. This grain can be sold as feed for CNY200–CNY300/t ($25–$40/t) less than the price of maize. All the ethanol produced by the Jilin facility goes to PetroChina, and the dried distiller's grain is sold on the domestic and international markets.

Ethanol is shipped by rail to blenders, where it is stored until it is blended with gasoline just prior to delivery to retail outlets. In 2003 a blending station was built by PetroChina in Changchun. Its unloading dock is capable of pumping ethanol from 48 railway cars at a time to fill its two 500-cubic meter holding tanks. The station has a total blending capacity of 1.5 mt/year. Ethanol blends in the PRC are 10%, and the octane ratings are 90, 93, and 97. The blending station uses roughly 120–130 t/day of ethanol. PetroChina has 20 ethanol blending stations in Jilin Province.

All the maize used in the Jilin plant is sourced from Jilin Province. About 70%–80% of the maize is purchased from grain traders at market prices; thus, farmers are indirectly involved in the biofuel production system. The remaining maize is purchased from farm households, typically at a somewhat lower price. The plant uses both old maize (usually 2 years old) and new maize. All maize is tested for moisture and starch content at purchase, and premiums or discounts are paid based on quality.

Agribusiness Arrangement for Biodiesel

Although there were about 10 biodiesel plants operating in 2007, the total production of biodiesel was only about 0.1 mt. Since biodiesel production is very limited, there is no national standard for biodiesel yet. Most of the biodiesel was used in the local transport sector and in some industries as a substitute for diesel fuel.

The government has not yet approved any biodiesel company for commercial production. The agribusiness arrangement for biodiesel in the country is currently unclear. According to NDRC regulations, if a company wants to invest in biodiesel production, it must have a sufficient feedstock production base or bases of its own, and the land used must be marginal. In early 2007, Sinopec and Cofoco signed a contract with the National Forestry Administration to develop two jatropha production bases in Yunnan and Sichuan provinces with a total land area of about 600,000 mu (40,000 hectares [ha]). The land was contracted from local farmers, the state, or collectively owned farms (mainly in the forest sector). The company paid land rent and made a commitment to hire local farmers to cultivate jatropha. Biodiesel will be purchased by Sinopec or PetroChina under a price fixed by the government, as is the case with bioethanol.

[12] One standard ton coal equivalent is 29.31 gigajoule (low heat) or 8,141 kilowatt-hour.

Biofuel Resource Potentials and Priorities

Potential Feedstocks

With about two decades of experience in promoting bioethanol programs, the People's Republic of China (PRC) has moved from the initial preparation stage in the 1980s and 1990s to testing and demonstration stage since 2001. In the mid-1980s, the national biofuel R&D program was launched. Investment was mainly through national R&D programs such as the National High Technology Research and Development Program (also known as the 863 Plan).

Maize and Wheat

In the testing and demonstration stage, the PRC continues to use first-generation technology to convert grain into bioethanol. The feedstock is saccharified and fermented before being converted into ethanol. Prior to 2005, three large plants using maize to produce bioethanol were established in three major maize-producing provinces—Heilongjiang, Jilin, and Anhui. To reduce the costs of reserving and disposing of rotting wheat, a fourth ethanol plant was built in 2003 in Henan Province using wheat as feedstock.

However, after 2004, the old grain had been used up. Faced with the prospect of limited supply, experiments began on the use of other non-grain crops to produce ethanol.[13] Due to growing concerns over the impact of biofuel expansion on food security, in 2007 the government prohibited the use of grain for the future expansion of biofuel production. The use of these feedstocks must be considered carefully in the light of competing uses, particularly livestock feed. Conservation agriculture[14] technologies should be seriously considered and the environmental effects of using reserved lands for feedstock production should be evaluated. The PRC has recently indicated that it will focus on cellulosic sources for ethanol production in the future (footnote 11). However, research into these second-generation technologies is still at the planning stage.

Sweet Sorghum

Sweet sorghum is also considered as an alternative feedstock to maize and wheat. The PRC has launched research and pilot production activities on the use of sweet sorghum as a feedstock for bioethanol production, especially its cultivation on alkaline and saline lands. Although sweet sorghum production is currently limited, it is likely that production will be increased at least in the short run to make it one of the principal feedstocks for bioethanol production.

Sweet sorghum is an annual crop and is a variety of ordinary grain sorghum. In 2006, total production of sorghum—a very minor crop compared to rice, maize, and wheat—amounted to 2,098,000 t (Table 3). Most of the sorghum produced was used to produce alcohol. Sweet sorghum has a high tolerance to drought and waterlogging, and can be planted on saline–alkali soils. Most of the country, from the southernmost to the northernmost parts, is suitable for sweet sorghum production. The most suitable areas are in the northeast, north, northwest, and some areas of the Huanghuai River Delta. Areas of the northeast include Heilongjiang, Jilin, Liaoning, and Inner Mongolia provinces; the regions of northern PRC include Beijing, Tianjin, Shanxi, Hebei, Shandong, Henan, and Hubei provinces; the northwestern regions include the southern part of Shanxi Province, all of Ningxia Province, Qinghai, Gansu, and the southern part of Xinjiang Province; and the Huanghuai River Delta includes the provinces of Jiangsu and Anhui.

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[13] Ministry of Agriculture. 2007. *China Agriculture Yearbook*, 1985–2007. Beijing: China Agriculture Press.

[14] Conservation agriculture aims to achieve sustainable and profitable agriculture and to improve farmers' livelihood by applying the three principles of minimal soil disturbance, permanent soil cover, and crop rotations.

Table 3: Feedstock Production in the People's Republic of China Yunnan Province, and Guangxi Zhuang Autonomous Region, 2006

	People's Republic of China			Yunnan			Guangxi		
Feedstock	Area ('000 ha)	Yield (kg/ha)	Production ('000 tons)	Area ('000 ha)	Yield (kg/ha)	Production ('000 tons)	Area ('000 ha)	Yield (kg/ha)	Production ('000 tons)
Maize	26,970.8	5,394	145,485	1,183.3	3,821	4,521	515	3,845	1,980
Wheat	22,961.6	4,550	104,464	980.7	6,230	6,220	121.6	5,806	706
Sorghum	566.4	3,704	2,098	2.3	2,174	5	2.8	2,143	6
Cassava[a]	438	20,000	8,760	60	20,000	1,200	260	19,500	5,070
Sweet potato[b]	4,475	19,500	87,262.5	22.5	20,000	450	—	—	—
Sugarcane	1,495.4	66,727	99,783,667	287.2	58,452	167,872,610	838.4	70,668	592,483,430
Rapeseed	6,887.9	1,837	12,649,312	169.3	1,865	3,156,620	57	1,091	621,640
Jatropha[c]	—	—	—	40	—	—	—	—	—

— = data not available, ha = hectare, kg = kilogram.

[a] Data for cassava is from 2005. There is no official cassava data for Yunnan and Guangxi; figures were estimated by the authors based on various reports.

[b] No official data on sweet potato production in the People's Republic of China; data were calculated based on the total tuber crop minus potato and cassava.

[c] Jatropha plantation is located only in Yunnan Province. Since most jatropha crops were on the total planted only after 2005, seed production had not begun.

Source: Ministry of Agriculture. 2007.

Sweet sorghum has a high energy content, high photosynthetic efficiency, and high biomass production capacity. Its growth period is 110–150 days, thus, it can be harvested twice a year in high-temperature locations. In addition, sweet sorghum is a crop with one of the highest biomass outputs, with a grain yield of 14–27 kg/ha; its yield of fresh stem can reach about 200–300 kg/ha. The stem of sweet sorghum has a high sugar content, which can be used for bioethanol production through simple fermentation. At present, sweet sorghum is still not a major crop in the PRC and its cultivation is highly dispersed, mainly in the northern part of the country.

Cassava

Because of its high yield and high conversion rate to ethanol, cassava is a potential alternative feedstock for bioethanol. In 2006, the Central Government of the PRC approved a cassava-based bioethanol plant in Guangxi Zhuang Autonomous Region with a targeted annual bioethanol production capacity of 200,000 t.

Cassava, a perennial sub-shrub, is one of the three largest tuber crops in the world (the other two are potato and sweet potato).[15] Cassava has high tolerance to drought and poor soil. It is suitable for planting in low-latitude tropical areas with an annual average temperature of 25–29°C and annual average precipitation of 1,000–1,500 millimeters.

The characteristics that make cassava a suitable feedstock for bioethanol production are:

(i) High rate of utilization of light, heat, and water resources. Biomass production per unit area is higher than most other crops. Fresh cassava yield is about 90 t/ha, and its dry matter accounts for about 42% of total fresh product. Therefore, on a per hectare basis, cassava can produce 38 t of dry matter, or about 30 t of starch.

(ii) High tolerance to drought and poor soil. It can be planted on barren land where other grain crops do not thrive.

[15] Wang, W., J. Ye, K. Li, and W. Zhu. 2006. Impact of Cassava Fuel Ethanol Production and the Core Technology for its Industry Development. *Chinese Journal of Tropical Agriculture.* 26 (4). pp. 44–49.

(iii) High starch content. In general, the starch content of fresh cassava is 26%–34%, which is higher than that of sweet potato and potato.

In 2006, Guangxi Zhuang Autonomous Region produced 5.07 mt of cassava, and its cultivation area and production both accounted for more than 70% of the national total for the crop (Table 3). Other cassava-producing provinces are Hainan, Guangdong, Fujian, Yunnan, Guizhou, and Sichuan, which accounted for 30%. In 2005, total area planted to cassava reached about 600,000 ha, with a total output of 11 mt. Currently, cassava is mainly used for starch and bioethanol production.

Sweet Potato

Sweet potatoes are grown in most provinces. In 2006, the area planted to sweet potato amounted to 4.5 million ha, with total output of 87.3 mt (Table 3). Major sweet potato-producing provinces include Sichuan, Henan, Chongqing, Shandong, Guangdong, and Hebei. Their combined total output accounted for more than 60% of the country's total sweet potato production. Sweet potato is mainly used for processed food, feed, and feedstock for ethanol production. It also has a high biomass yield. The average yield of fresh sweet potato is 0.13–0.33 t/ha, and the starch content of fresh sweet potato is about 18%–30%. Using current technology, about 8 t of fresh sweet potato can produce 1 t of ethanol.

Rapeseed

Rapeseed is the fifth largest crop in the country, in terms of production area, after rice, maize, wheat, and soybean. The production area of rapeseed surpassed 6.9 million ha in 2006, and the total rapeseed output reached 12.6 billion t in 2006 (Table 3). Rapeseed is cultivated in 27 provinces. Only Beijing, Tianjing, Liaoning, and Hainan do not cultivate the crop. Major rapeseed-producing provinces include Hubei, Anhui, Jiangsu, Sichuan, and Hunan, whose sown area and output both accounted for more than 80% of the country's total. Since mid-2007, the government has prohibited the use of grain crops, including rapeseed, for biofuel production. Although the country has some potential areas (mostly winter fallow lands in southern PRC) for rapeseed production, the possibility of using rapeseed for biodiesel in the future is very low, given that about 70% of the country's vegetable oil consumption needs to be imported.

Jatropha

Jatropha is a small tree or shrub belonging to the *Euphorbiaceae* family. It is widely cultivated in tropical and subtropical regions and is mainly found in the hot, dry valleys of the southwest of the country. It has high potential as a biodiesel feedstock production because of its adaptability to diverse growing conditions, especially drought-prone areas where it has shown not only a high survival rate but also a high seed yield. Jatropha can typically grow at an altitude of 600–1,400 meters above sea level. Provincial governments in the southwest have plans to increase the area of jatropha by more than 1 million ha in the next decade.[16] Due to its natural advantage for growing jatropha, and the availability of land, Yunnan Province—one of two provinces of the PRC located in the Greater Mekong Subregion—aims to build the largest biodiesel base in the country. By the end of 2006, the jatropha area reached about 40,000 ha. However, since most of the jatropha crop was planted after 2005, by 2008 no seeds had been produced. Based on the development plan for biodiesel feedstock plantations in Yunnan Province, the area under jatropha cultivation in 2006 was 1 million mu (66,700 ha), and will be increased to 4 million mu (270,000 ha) by the end of 2010, and to 10 million mu (670,000 ha) by the end of 2015.[17]

Limitations and Risks

There are several potential limitations and risks to the use of these feedstocks for biofuel production. The seasonal crop production and storage of some feedstocks for daily ethanol production presents logistical problems. Sweet sorghum, for example, must be used soon after harvest in order to ferment the stalks while their sugar and moisture content is high. If stored wet, the stalks will begin to ferment in

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[16] Weyerhaeuser, H. T. Tennigkeit, Y. Su, and F. Kahrl. 2007. *Biofuels in China: An Analysis of the Opportunities and Challenges of Jatropha Curcas in Southwest China*. International Center for Research in Agroforestry (ICRAF) Working Paper No. 53.

[17] State Forestry Administration. 2007. *Development of Production Base of China's Bioforestry under 11th Five-Year Planning*. Beijing; State Forestry Administration, 2007. *Planning for China's Bio-Forestry Development*: 2020. Beijing.

an uncontrolled manner, potentially rendering them useless for ethanol production.

Practical difficulties associated with transporting feedstock from the field to the ethanol plant can also be critical. Most feedstocks are bulky and difficult to ship over long distances. This is a significant barrier, given that a large share of the PRC's marginal croplands lies in remote and mountainous locations. Thus, it may only be feasible to locate ethanol plants near crop production areas. For ethanol production from sweet sorghum, there is a suggestion to locate small-scale (5,000 t/year) fermentation plants in villages or towns near crop production areas. These fermentation plants would produce low-quality ethanol from sweet sorghum stalks, and ethanol produced would be transported to a large distillery in a less remote location.

The availability of ample supplies of some feedstocks is questionable considering the limited land and water resources and the potential negative impact on the environment. For example, northern PRC is a major area of maize production, which also faces water shortages. Cultivation and processing of sugarcane has the potential to create serious environmental problems if it is not correctly managed.

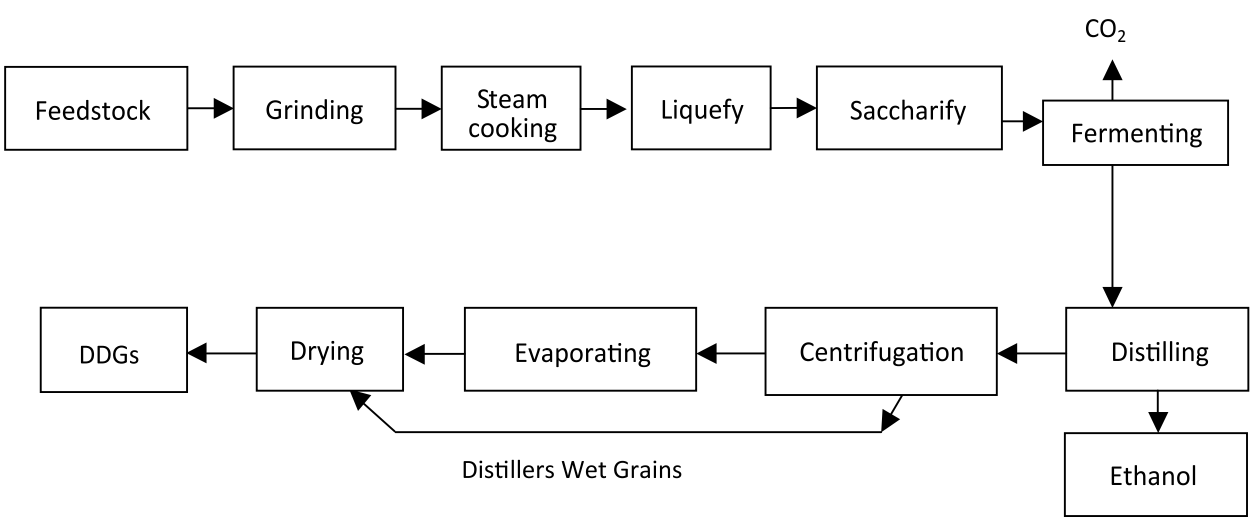
Uncertainty about the details of government policies toward ethanol production has kept some researchers and industry participants on hold, waiting for clear direction from the government. For example, 10 companies reportedly have been encouraged to develop sweet sorghum ethanol production facilities, and current production by these companies is roughly 50,000 t. However, none of this production is allowed to enter the fuel market system because access is tightly controlled by the government.

Biofuel Processing Technologies and Cost Analysis on the Use of Different Feedstocks

Biofuel Processing Technologies

Fuel ethanol is produced by fermenting sugar or starch. Generally, bioethanol processing technology can be divided into wet fermentation and dry fermentation. These processes are similar for all grain-based feedstocks. The difference is that in wet fermentation, after the feedstock has been steam-cooked, water is added to transform it into a liquid (Figure 7). In dry fermentation, yeast is mixed directly into the cooled steam-cooked feedstock, and then fermented (Figure 8). Recent improvements in these technologies are referred to as "improved dry milling technology" and "improved wet milling technology." The differences between these four technologies are shown in Table 4. At present, the wet ferment

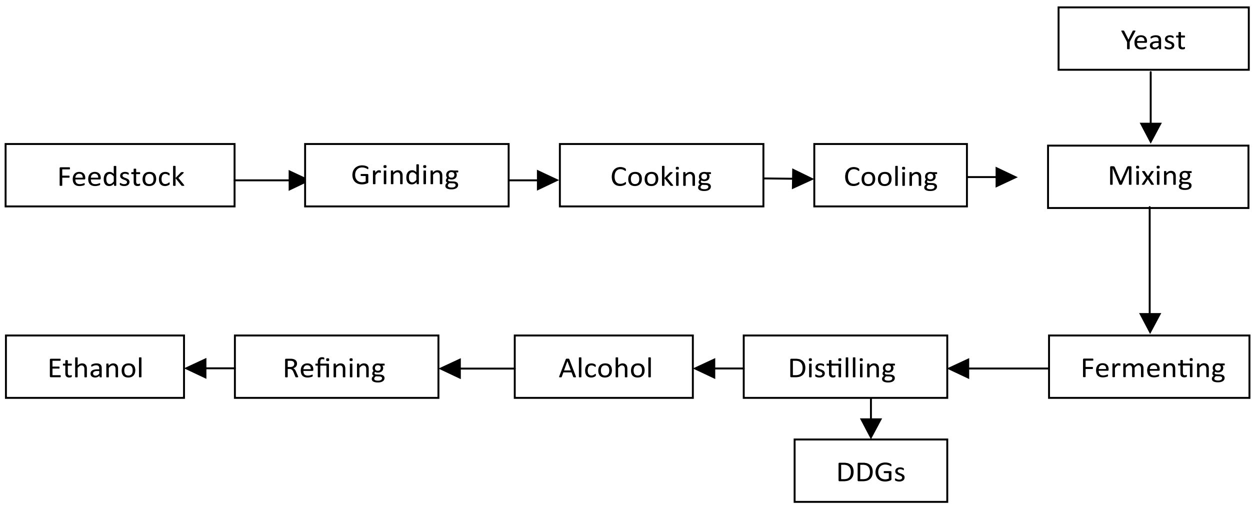
Figure 7: Bioethanol Production Process: Wet Fermentation



CO_2 = Carbon dioxide, DDGs = dried distiller's grains.

Source: Chinese Academy of Agricultural Engineering. 2007.

Figure 8: Bioethanol Production Process: Dry Fermentation



DDGs = dried distiller's grains.

Source: Chinese Academy of Agricultural Engineering. 2007.

Table 4: Comparison of Wet and Dry Maize Bioethanol Processing Technology

Item	Dry Milling	Improved Dry Milling	Wet Milling	Improved Wet Milling
Process	Maize is dry-ground, then added to water to form a mash. The mash is liquefied, saccharified, and fermented. After distillation and dehydration, 99% ethanol is separated from the alcohol–water solution.	After dry-grinding, maize germ is removed and maize oil is extracted from the germ. The starch is liquefied, saccharified, and fermented. With distillation and dehydration, 99% ethanol is separated from the alcohol–water solution.	After wet-grinding, all non-starch components are extracted to produce CO_2. Only the starch is liquefied, saccharified, and fermented. With distillation and dehydration, 99% ethanol is separated from the alcohol–water solution.	After wet-grinding, only maize germ is removed and maize oil is extracted from the germ. Starch is liquefied, saccharified, and fermented. With distillation and dehydration, 99% ethanol is separated from the alcohol–water solution.
Steeping	None	12 hours at room temperature	36–48 hours at 50°C	6–12 hours at 65°C
Maize oil (%)	None	1.5%–2.1%	3%	3%
By-products	DDGs, CO_2	DDGs without oil, CO_2, maize oil	DDGs without oil, CO_2, maize oil, germ cake, maize protein flour, CO_2	DDGs without oil , maize oil, CO_2
Investment*	1	1.1–1.2	1.8–2	1.3–1.4
Energy demand	Very low	Low	Very high	High

°C = degrees Celsius (centigrade), CO_2 = carbon dioxide, DDGs = dried distiller's grains.
*The investment in dry-milling technology was standardized as 1.

Source: Yue Guojun, Wu Guoging, and Hao Xiaoming. 2007. The Status Quo and Prospects of Fuel Ethanol Process in Technology in China. *Progress in Chemistry*. 19 (7). 1,084-1090.

process is widely used in the United States but most bioethanol companies in the PRC use improved dry milling processing technology, which can increase the efficiency of maize utilization.[18]

The PRC has made progress in selecting and breeding non-grain energy crops and in developing bioethanol production techniques using non-grain feedstocks.[19] For example, hybrid sweet sorghum has been successfully bred, and an industrial demonstration base has been established for cassava varieties with yields in excess of 45 t/ha. Some new biofuel-driven and multi-purpose sugarcane varieties have been cultivated. In addition, research into cellulose-based ethanol using second generation technology has begun, and a pilot production line with an annual capacity of 600 t has been set up at the Anhui Fengyuan bioethanol plant.

The PRC's biodiesel production capacity has reached more than 100,000 t/year, using rapeseed oil and waste cooking oil as the main feedstocks. Since 2000, rapeseed and sunflower have been cultivated, achieving up to 51.6% oil content. The potential of forest-based energy crops—such as jatropha seed and Chinese pistachio—and the appropriate production technologies to crush and extract oil from their seeds are also being studied.

Cost and Productivity of Different Feedstocks

Current feedstock production and biofuel processing technologies show large variations in productivity (Table 5). On average, 1 ha of land can produce 19.5 t of fresh cassava, 24.2 t of sweet potato, 60.0 t of sweet sorghum, 64.0 t of fresh sugarcane, 5.3 t of maize, or 4.3 t of wheat (Table 5). Using the current bioethanol production and processing technology, 1 ha of land can produce 2.9 t of ethanol from cassava, 3.9 t of ethanol from sweet sorghum, 4.8 t of ethanol from sugarcane, or 1.9 t of ethanol from maize. This shows that land productivity is highest if sugarcane is used to produce bioethanol.

However, when cost of production is taken into account, cassava, sweet sorghum, and sweet potato are the most viable crops for feedstock production under current technology and feedstock prices (Table 5). Feedstock accounts for about 60% of the total production cost of biofuel. Using the feedstock price of 2006, analysis shows that cassava-based bioethanol production is estimated to have the lowest feedstock costs—about CNY2,400/t ($354)—followed by sweet sorghum, sweet potato, sugarcane, maize, and wheat (Table 5). However, it should be noted that although cassava, sweet sorghum, and sweet potato

Table 5: Current Yields and Prices of Feedstock Crops and Costs of Ethanol Production in the People's Republic of China

Crop	**Yield** (t/ha)	**Market Price** (CNY/t)	**Feedstock to Produce 1 ton of Ethanol** (t/t)	**Ethanol Production per ha** (t/ha)	**Feedstock Cost per ton of Ethanol** (CNY/t)
Cassava	19.5	320	7.5	2.9	2,400
Sweet potato	24.2	380	8.0	3.0	3,034
Sweet sorghum	60.0	200	15.3	3.9	2,994
Sugarcane	64.0	274	13.3	4.8	3,646
Maize	5.3	1,400	2.8	1.9	3,955
Wheat	4.3	1,500	3.1	1.4	4,591

CNY = yuan, ha = hectare, t = ton.

Source: Chinese Academy of Agricultural Engineering. 2007.

[18] International Energy Agency (IEA). 2008. *Energy Technology Perspectives*. Paris: IEA.

[19] Wang Gehua. 2006. *Liquid Biofuels for Transportation: Chinese Potential and Implications for Sustainable Agriculture and Energy in the 21st Century*. Report. Beijing.

are relatively cheaper feedstocks, their prices will rise with the future expansion of ethanol production based on these crops. Careful study is needed to investigate the impact of ethanol production on the prices of various crops under different feedstock scenarios.

Since the costs of using maize and wheat as feedstock are high, large government subsidies are required to produce ethanol. If feedstock accounts for 60% of the cost of ethanol production, Table 5 suggests that it could cost as much as CNY5,600/t to produce maize-based ethanol, and CNY7,650/t for wheat-based ethanol. The government requires bioethanol plants to sell their fuel ethanol to an appointed oil company, such as Sinopec or PetroChina, at a price of 0.91 of the price of 90% gasoline (about $0.82/liter). The gap between the sale price and production cost will be covered by government subsidy. In August 2005, the Ministry of Finance issued a document that set the subsidy level of bioethanol at CNY1,883/t in 2005; CNY1,628/t in 2006; CNY1,373/t in 2007; and CNY1,373/t in 2009.

Potential for Biofuel Production in the People's Republic of China

Potential Marginal Arable Land

With the expansion of global biofuel production, national and world food prices rose rapidly during 2007–2008, triggering food security concerns. In July 2007, the government prohibited the use of grain (maize and wheat) for biofuel production to reduce pressure on food security, and instead promoted the use of sweet sorghum, cassava, sweet potato, and other non-grain crops as major feedstocks. The policy also emphasized that these non-grain feedstocks should only be produced on marginal lands. While these policies are well-intentioned, many people doubt that they can be implemented effectively. Success depends on the availability of agricultural resources, especially marginal lands, for the production of the non-grain feedstocks.

The People's Republic of China (PRC) has very limited potential marginal arable land, and most of it is fragmented. According to the 2003–2004 survey by the Ministry of Land and Resources,[20] the area of large-scale (not fragmented) potential arable land was only 7.3 million ha, which accounted for 8.28% of total reserved land.[21] The following discussion focuses on the two types of potential marginal arable land suitable for the cultivation of energy crops: reclaimable arable land and arable land.

Reclaimable arable land includes grassland, saline land, mudflats, and other reclaimable land, such as swampland, reed beds, and other unused land. Swampland and reed beds are important wetland resources and provide a habitat for wild birds and other animals. From the perspective of ecology and environmental protection, swampland and reed beds should not be used for feedstock production, even though they may have huge development potential. They should therefore be excluded from the area of reclaimable arable land.

To study the regional distribution of reclaimable arable land, the land data of eight regions were reviewed. They are northeast PRC, north PRC, the Loess Plateau, Inner Mongolia and Xinjiang, the middle and lower reaches of the Yangtze River, south PRC, southwest PRC, and the Qingzhan Plateau. The provinces included in each region are shown in Table 6. Reclaimable arable land is shown in Table 7, and the distribution of suitable arable lands for energy crop production is presented in Table 8.

A recent study by the Chinese Academy of Agricultural Engineering determined the distribution by region of arable lands suitable for energy crop production.[22] Taking into consideration environmental protection, the dynamics of arable land and urbanization, and the compatibility of energy crops and technology improvement for feedstock production, the study estimated that 20% of reclaimable arable land (Table 7) is considered suitable for energy crop production in 2012, and 50% will be considered suitable in 2020. Based on this assumption, they estimated that about 1.29 million ha could be used for energy crop production in 2012, and 3.22 million ha could be used in 2020 (Table 8).

Table 8 also shows the arable lands suitable for energy crop production in 2012 and 2020 in each region. The large areas of marginal land in Inner Mongolia and Xinjiang that are suitable for feedstock production account for more than 50% of total suitable arable lands for energy crop production in the country. These two provinces have the highest development

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20 Ministry of Land and Resources. 2004. *Report on China's Reserved Land Resources*. Beijing.

21 Reserved land is land with potential to be converted into arable land, but is not used currently, such as reclaimable grassland, saline land, and mudflats.

22 Chinese Academy of Agricultural Engineering. 2007. *Bioenergy Development in China*. Internal report. Beijing.

Table 6: Regions and Provinces with Reclaimable Arable Land

Region	Provinces
Northeast	Liaoning, Jilin, Heilongjiang
North	Beijing, Tianjin, Hebei, Shandong, Henan
Loess Plateau	Shanxi, Shaanxi, Gansu
Inner Mongolia and Xinjiang	Inner Mongolia, Ningxia, Xinjiang
Middle and lower Yangtze River	Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan
South	Fujian, Guangdong, Hainan, Guangxi Zhuang Autonomous Region
Southwest	Chongqing, Sichuan, Guizhou, Yunnan
Qingzhan Plateau	Tibet, Qinghai

Source: Chinese Academy of Agricultural Engineering. 2007.

Table 7: Distribution of Potential Reclaimable Arable Land ('000 hectares)

Region	Reclaimable Grassland	Reclaimable Saline Areas	Reclaimable Mudflat	Other Reclaimable	Total
Northeast	214.6	142.0	62.5	9.7	**428.8**
North	190.2	141.2	124.5	47.5	**503.4**
Loess Plateau	47.9	12.0	2.9	17.6	**80.4**
Inner Mongolia and Xinjiang	1,933.7	341.1	28.1	1,360.8	**3,663.7**
Middle and lower Yangtze River	336.4	5.4	227.6	62.2	**631.6**
South	62.1	0.4	51.1	6.4	**120.0**
Southwest	237.1	0.2	22.5	35.2	**295.0**
Qingzhan Plateau	162.6	49.9	2.3	12.5	**227.3**
Total	**3,615.8**	**800.5**	**547.2**	**1,710.6**	**6,674.3**

Source: Ministry of Land and Resources. 2004.

Table 8: Distribution of Suitable Arable Lands for Energy Crops ('000 hectares)

Region	Energy Crop	2012	2020
Northeast	Sweet sorghum	86	214
North	Sweet sorghum, sweet potato	101	252
Loess Plateau	Sweet sorghum, sweet potato	161	402
Inner Mongolia and Xinjiang	Sweet sorghum	733	1,832
Middle and lower Yangtze River	Cassava, sweet sorghum	126	316
South	Cassava	24	60
Southwest	Cassava	59	148
Qingzhan Plateau*	None	0	0
Total		**1,290**	**3,220**

*Note: Since temperatures in Qinzhang Plateau are low, and given the vulnerability of its environment, marginal lands in this area are not suitable for feedstock production. For the plateau areas, no suitable arable lands for energy crop are estimated.

Sources: Ministry of Land and Resources. 2004; and Chinese Academy of Agricultural Engineering. 2007.

potential, followed by the Loess Plateau (12.5%), the middle and lower reaches of the Yangtze River (9.8%), and north PRC (7.8%). Because of low temperatures, less of the available marginal land can be used in north PRC despite its vast territory and sparse population. Land resources in southwest PRC account for 4.6% of the suitable arable land for energy crop production, and south PRC has the lowest area, accounting for only 1.9% of the national total (footnote 22).

Estimates of the area of arable land suitable for ethanol energy crops indicate a low potential for large-scale expansion of the biofuel industry. Even if all suitable arable land could be reclaimed and used for the production of energy crops in 2020, it would account for only 2.5% of the current land area of 130.04 million ha. It is important to note that bringing this land into production would require substantial investment, and the large spatial distribution of these areas would present a great challenge to the transport of feedstocks for processing.

The Ministry of Agriculture estimated that there were 7.4 million ha of winter fallow lands in the provinces of Yunnan, Hunan, Sichuan, Guizhou, Hubei, Jiangxi, and Guangdong. Assuming that half of this land could be reclaimed for energy crop cultivation, the potential land area for additional rapeseed production could reach 3.7 million ha. However, caution should be exercised when interpreting this estimate as the assumption did not consider the high cost and other difficulties involved in reclaiming those lands.

Production Potential for Bioethanol

The production potential for bioethanol can be estimated from the suitable arable land area, the yield of energy crops, and the conversion rate of feedstocks to bioethanol. Due to the low quality of reclaimable marginal land and the likely improvement of crop production technology, it is assumed that future crop yields on marginal land will be slightly lower than yields on current cultivated land. It is further assumed that producing 1 t of bioethanol requires 7 t of cassava, 16 t of sweet sorghum, or 8 t of sweet potato. Based on these assumptions, it is estimated that the PRC could produce a maximum of 5 mt of ethanol by 2012 from 1.29 million ha of marginal land planted to cassava, sweet sorghum, and sweet potato. If this trend continues, ethanol production could reach 12 mt by 2020, assuming 3.32 million ha of marginal land is used for cassava, sweet sorghum, and sweet potato production. These production potentials are based on optimistic estimates and do not consider the many constraints, such as water resources, soil quality and its suitability for these feedstock crops, cost-effectiveness (i.e., the cost of planting on reclaimed marginal lands in terms of the expense of reclamation), and the logistical difficulties of collecting and transporting the feedstock to the biofuel plants.

Production Potential for Biodiesel

In 2007, the yield of rapeseed in the PRC reached 2.25 t/ha, with an average oil content of about 30% (footnote 22). Based on European experience of rapeseed and biodiesel production, the estimates of the Chinese Academy of Agricultural Engineering indicate that rapeseed yields in the PRC could increase to about 3 t/ha, average oil content could increase to about 50% in the next 15 years, and 3.7 million ha of winter fallow lands could be used to grow rapeseed (footnote 27). It is estimated that 12 mt of rapeseed can be produced, which will result in a potential biodiesel production of about 6 mt/year.[23]

However, the authors' estimate is much lower. The rapeseed yield is assumed to be only 2.5 t/ha and oil content in 2020 is assumed to be 40%, as many winter follow lands may not be suitable for rapeseed production. It is further assumed that only 2 million ha of the current winter fallow lands could be brought into rapeseed production in the future. Given these assumptions, the authors estimate that the PRC may be able to produce 4–5 mt of biodiesel by 2020.

Besides using rapeseed to produce biodiesel, the country is pursuing tree-based biodiesel development.

[23] It is assumed that with, the improvement of breeding technology, the oil content of rapeseed can reach 50% in the near future.

In 2005, the State Forestry Administration of the PRC issued the Program of China's Energy Development Plan and the 11th Five-Year Program of Energy Tree Production Base Development. Based on these programs, between 2006 and 2010, 830,000 ha will be planted to energy trees—mainly jatropha. By 2020, the area will increase to 13.3 million ha, which can produce 6 mt of biodiesel each year.[24]

[24] The production potential of jatropha-based biodiesel is only based on the data from Yunnan province. Other provinces such as Sichuan, Guangxi, and Guizhou, and Guangxi Zhuang Autonomous Region, are also starting to plan for the production of biodiesel. Since there is no official data from other provinces, the production potential of other provinces is not included in this report.

Potential Impact of Biofuel Development on Agriculture in the People's Republic of China

This section analyzes the potential impact of biofuel development in the People's Republic of China (PRC) on agricultural and rural development. The main analytical tool used is a multiregional equilibrium model for the analysis of sustainable agricultural development in the PRC. After a brief introduction of the model, the assumptions used in the design of the scenarios are discussed, and the preliminary results are presented.

The Decision Support System for Sustainable Agricultural Development in the People's Republic of China (Chinagro) was used for this analysis. Chinagro is a 17-commodity, 8-region general equilibrium welfare model.[25] It consists of six income groups per region, with production represented at county level. For each country, the model includes 28 outputs and a range of 14 farm types involved in cropping and livestock production. The 28 outputs include most of the country's agricultural products, including rice, maize, wheat, sugarcane, oil crops, pork, and poultry. The 14 farm types include categories for rainfed, irrigated, and traditional cropping, as well as intensified livestock production—separately for ruminants and nonruminants. Appendix 2 provides a detailed explanation of the model.

Based on the plan for bioethanol expansion in the 11th Five-Year Plan and the Medium- and Long-Term Plan, it is assumed that an annual production of 10 mt of bioethanol will be reached by 2020. Following previous practice, bioethanol firms will be located in the main production regions of the feedstock crops. However, interregional trade in these crops and in bioethanol are permitted in the model to accommodate changes in specialization patterns induced by the scenarios.

Bioethanol production is examined using the following four alternative scenarios:[26]

- Scenario 1 (S1): All 10 mt of bioethanol will be produced using maize as feedstock.
- Scenario 2 (S2): All 10 mt of bioethanol will be produced using sugarcane as feedstock.
- Scenario 3 (S3): All 10 mt of bioethanol will be produced using cassava as feedstock.
- Scenario 4 (S4): A mixed feedstock scenario assumes that 5 mt of bioethanol will be produced using maize as feedstock and that sugarcane and cassava will each produce 2.5 mt of bioethanol.

Results from the above alternative scenarios are compared with the results obtained from the baseline scenario (S0), which serves as a reference and has no biofuel production.

To simplify the analysis and derive policy implications, a number of trade-related assumptions were made. For example, after the baseline simulation, it was found that all three crops (maize, sugarcane, and cassava) would be imported in 2020. To explore the potential impact of ethanol production without additional demand being satisfied through imports, import quotas equal to the import levels under the baseline scenario were imposed for all the scenarios; for example, 20 mt for maize, 2.2 mt for sugar, and 5.5 mt for grain-equivalent cassava. The same import constraints were applied in the mixed feedstock scenario, S4. Export quotas were also imposed on

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[25] Keyzer, M.A., and W. van Veen. 2006. *Towards a Spatially and Socially Explicit Agricultural Policy Analysis for China: Specification of the Chinagro models.* A working paper. Amsterdam: Center for World Food Studies.

[26] Wheat does not appear to be a viable or sustainable feedstock for bioethanol production, therefore the use of wheat as an ethanol feedstock is not analyzed in this study. Despite the PRC's recently stated policy regarding maize, maize is included in the study due to its continued prevalence as a feedstock, both in the PRC and in other parts of the world.

commodities for which the country will be a net exporter in 2020 under the baseline scenario. For example, rice exports were set at 4,383,000 t and vegetables at 7,807,000 t.

The imposition of import quotas does not conform to World Trade Organization (WTO) regulations; however, at this stage of the investigation, it is useful to identify the extent to which the PRC is able to satisfy its own biofuel demand. Allowing for unrestricted imports would inevitably lead to significant increases in world prices. Hence, the present implementation can be interpreted as an extreme case, in which the world market would already be fully committed and have zero supply elasticity.

Impact on Agricultural Prices

The impact of bioethanol development on agricultural commodity prices under the different scenarios is presented in Table 9. Under S1, the maize price in 2020 is projected to be 74.3% higher than that of the baseline scenario for the same year. The extent to which other crop prices change depends on the nature of substitution between those commodities and maize. For example, under S1, national wheat prices increased by 9.2%, while sugar prices increased by only 4.4%. Price increases for maize and other crops will also increase the cost of livestock production. Under S1, pork prices will increase by 9.7%.

Results of the sugarcane scenario (S2) suggest that a bioethanol program based on sugarcane is not a good choice for the PRC. Compared with results of the baseline scenario for 2020, sugarcane prices are projected to increase nearly 4 times that year (Table 9). Thus, the use of sugarcane as a primary feedstock is not likely to occur due to at least two factors:

- The level of prices projected implies an extremely high level of government subsidy required to maintain its bioethanol program.
- This high price would lead to an obvious violation of WTO regulations. If the government does not impose a high import tariff on sugar, most of the extra sugarcane demand would have to be satisfied through imports—something that may not be feasible as sugarcane (as opposed to sugar) is not a highly traded commodity.

Table 9: Impact of Bioethanol Development on Prices of Agricultural Commodities in 2020, Compared with Baseline Results (%)

Commodity	S1	S2	S3	S4
Rice	4.2	11.8	4.7	8.0
Wheat	9.2	9.0	7.5	8.6
Maize	74.3	9.2	10.1	42.2
Tuber crops	4.6	11.6	98.8	23.3
Vegetable oil	5.4	9.2	2.8	5.1
Sugar	4.4	394.1	5.1	78.6
Fruit	6.6	5.9	4.6	6.2
Vegetables	13.1	11.1	7.1	12.1
Beef and mutton	3.3	3.1	3.2	3.2
Pork	9.7	4.9	5.3	8.0
Poultry	9.8	4.8	6.0	8.0
Dairy	5.8	3.1	3.5	4.7
Eggs	10.5	4.2	4.2	8.1

S = scenario.

Source: Center for Chinese Agricultural Policy, Chinese Academy of Sciences.

Using tuber crops as the primary feedstock (S3) for bioethanol production can also lead to higher prices for all agricultural commodities. Compared with baseline results for 2020, tuber crop prices would be 98.8% higher.

As expected, the impact of the mixed scenario (S4) on each of the feedstock prices are much less than in the previous three scenarios (Table 9). Under S4, three crops (maize, sugarcane, and cassava) are simultaneously used as feedstock for bioethanol production, and the demand pressure on any single crop is consequently eased. Simulation results show that, compared with the results of the baseline scenario for 2020, the price of maize would be 42.2% higher, sugarcane 78.6% higher, and tuber crops 23.3% higher. Thus, even under the mixed scenario, a bioethanol program with a target production of 10 mt would create significant incentives for farmers to produce these crops if prices are allowed to rise through market forces as demand increases.

Impact on Agricultural Production

The projected increase in prices of the three major feedstocks examined would trigger significant increases in the production of these commodities. Table 10 shows the percentage change in the production of commodities under the different scenarios, compared with baseline results for 2020.

Under S1, maize production would increase by 20.8% over the baseline. This would come from yield increases and from area expansion as the land area for other crops is planted to maize instead. Under S2, sugarcane production is projected to increase by 154.3%. This would occur primarily in south PRC, where agroclimatic conditions are suitable for sugarcane production. Under S3, tuber crop production would be 43.9% higher compared with the baseline results. Under the mixed scenario (S4), the production of maize would increase by 9.7%, sugarcane by 26.6%, and tuber crops by 6.5% in 2020

Table 10: Impact of Bioethanol Development on Production of Agricultural Commodities in the People's Republic of China in 2020 Compared with Baseline Results (%)

Commodity	S1	S2	S3	S4
Rice	(0.4)	(1.8)	(0.7)	(0.9)
Wheat	(1.3)	(1.0)	(1.1)	(1.1)
Maize	20.8	(1.4)	(1.2)	9.7
Tuber crops	(3.4)	(0.6)	43.9	6.5
Vegetable oil	(3.0)	(0.8)	(2.2)	(2.1)
Sugar	(1.8)	154.3	(1.9)	26.6
Fruit	(1.4)	(1.4)	(1.0)	(1.3)
Vegetables	(2.0)	(2.0)	(1.4)	(2.0)
Beef and mutton	(0.5)	(0.8)	(0.7)	(0.6)
Pork	(2.6)	(1.0)	(0.8)	(1.8)
Poultry	(2.3)	(0.9)	(0.7)	(1.5)
Dairy	(2.6)	(1.0)	(0.7)	(1.7)
Eggs	(3.0)	(0.9)	(0.8)	(1.9)

( ) = negative number, S = scenario.

Source: Center for Chinese Agricultural Policy, Chinese Academy of Sciences.

compared with the baseline, resulting in decreased production of other crops because tuber crops would require more land and other agricultural resources. Compared with baseline results, livestock production would also decline because of the increase in input costs and the scarcity of resources for agricultural production.

Impact on Farm Value Added in Different Regions

Because there are significant substitution effects among commodities and between regions, the changes in net output value, or farm value added, due to the impact of alternative bioethanol programs were also estimated in aggregate. Table 11 shows that different bioethanol programs have significant equity implications for farmers in different regions of the country.

Comparing the results from all four scenarios, farmers would benefit from the development of bioethanol, with farm value added increasing by 3.2%–8.1% under the different scenarios (Table 11). However, the impact varies significantly among regions and between types of farmers. Under all four scenarios, farmers in the crop sector would gain, while those in the livestock sector would lose. From a regional perspective, Tibet would be affected negatively, but only minimally, under all scenarios since this region is not suitable for feedstock production, and its livestock sector would suffer from the increase in feed prices.[32] Farm value added in most of the other regions (except south PRC under S1) would increase due to bioethanol expansion.

Table 11: Impact of Bioethanol Development on Farm Value Added in the Different Regions in 2020, Compared with Baseline Results (%)

	S1			S2			S3			S4		
Region	Crop Sector	Livestock Sector	Total	Crop Sector	Livestock Sector	Total	Crop Sector	Livestock Sector	Total	Crop Sector	Livestock Sector	Total
North	15.8	(9.3)	5.5	2.2	(0.3)	1.2	12.5	(2.3)	9.7	11.9	(5.2)	**4.9**
Northeast	34.2	(7.9)	13.6	11.5	(0.8)	5.5	13.2	(1.8)	8.7	21.8	(4.4)	**9.0**
East	3.8	(1.3)	2.4	2.4	(0.1)	1.5	7.4	(0.8)	8.0	4.1	(0.3)	**2.6**
Central	2.8	(1.8)	1.3	6.7	(0.3)	3.7	6.6	(1.0)	6.5	4.0	(0.5)	**2.1**
South	1.7	(3.7)	(0.5)	31.6	(1.8)	18.3	6.5	(1.3)	6.6	8.2	(2.2)	**4.1**
Southwest	8.2	(14.3)	0	12.3	(0.7)	7.6	10.5	(2.1)	9.4	8.8	(7.9)	**2.7**
Tibet	2.7	(6.0)	(3.3)	1.3	(0.8)	(0.2)	1.7	(2.1)	(0.5)	3.4	(3.0)	**(1.1)**
Northwest	15.9	(4.1)	7.7	15.2	(1.5)	8.3	9.9	(2.1)	8.2	13.0	(2.5)	**6.6**
National	**9.3**	**(6.1)**	**3.2**	**11.7**	**(0.7)**	**6.7**	**9.6**	**(1.6)**	**8.1**	**10.2**	**(3.4)**	**4.1**

( ) = negative number, S = scenario.

Source: Center for Chinese Agricultural Policy, Chinese Academy of Sciences.

[27] The impact of biofuel development on the livestock sector needs further investigation. In this preliminary analysis, biofuel by-products (e.g., dried distiller's grains and stalks) that can be used as feeds for the livestock sector were not considered. If those by-products were considered, the extent of the impact of biofuel development on the livestock sector would be much smaller. The impact on the livestock sector also depends on which feedstock is used for biofuel production. For example, if more sweet sorghum were planted for biofuel processing, it may even increase the supply of feed because the stalks of sweet sorghum can be used as feed for cattle and sheep.

Summary and Policy Implications

The rapid growth of the People's Republic of China (PRC) economy has raised serious concerns about energy security. Despite rapid growth in domestic energy production, demand has grown even faster. The nation has shifted from being a net energy exporter to being net energy importer since the late 1990s. It is now one of the largest importers of energy. The major reason is the increased oil demand for transport. Most projections show that about 60%–75% of the country's oil demand will have to be met by imports in 2020.

To address the challenges ahead, the government has prepared a long-term development plan and associated policies, of which the development of renewable energy is one of the top priorities. The country has developed successful programs for national biogas development and biomass power generation in the past several decades. Recently, a large biofuels program—with an emphasis on bioethanol—has been initiated.

The PRC is now the third largest bioethanol producer in the world, but its biodiesel production is still small. Biodiesel production mainly uses industrial waste oil and waste cooking oil as feedstock. Due to lack of domestic feedstock supply, the PRC is planning to develop forestry-based biodiesel (e.g., jatropha) instead of rapeseed and soybean. The country produced 1.35 mt of bioethanol in 2007. All bioethanol is produced by large-scale, state-owned ethanol plants. Currently, grain—mainly maize and some wheat—is used as feedstock.

With the rising concern over the impact of biofuels on national grain security, the use of grain for the future expansion of biofuel production has been prohibited and non-grain feedstocks have been promoted since 2007. The prioritized potential feedstock crops include sweet sorghum, cassava, sweet potato, and sugarcane for bioethanol, and jatropha for biodiesel. However, large-scale biofuel production based on these crops has not begun.

The cost analysis of crops for biofuel production shows a large variation in the profitability of feedstock crop options. Given the current prices and production and processing technologies, cassava, sweet sorghum, and sweet potato are the most viable biofuel crops. However, this finding should be taken with caution because the prices of these crops may rise significantly as demand for them increases due to the future expansion of bioethanol production. Currently, the PRC needs substantial subsidies for biofuel production. Based on the authors' interviews with officials in government agencies, a subsidy of as much as CNY1,883/t ($277) was provided in 2005 and CNY1,373/t ($202) in 2008, in addition to value-added tax rebate and the waiving of consumer tax.

Potential arable land for feedstock production is very limited. The population is vast and the available arable land per capita is limited. To ease pressure on cropland, efforts have been initiated to promote the use of marginal land. It is estimated that only about 1.3 million ha of marginal land (or about 1% of current cultivated land) could be used for the production of ethanol crops (e.g., sweet sorghum, cassava, and sweet potato) in 2012 and slightly more than 3 million ha (or about 2.5% of current cultivated land) in 2020. The available marginal lands are mainly located in Inner Mongolia and Xinjiang provinces for sweet sorghum, in south PRC for cassava and sugar crops, and country-wide for sweet potato. There is also extensive winter fallow land suitable for rapeseed production, which could be used for biodiesel development in south PRC. However, caution should be exercised as there are large investment and environmental implications involved in bringing millions of hectares of marginal land into crop production. Moreover, the ecological and environmental consequences of more intense use of winter fallow land and marginal land should be investigated.

All biofuels in the PRC are produced by large-scale, state-owned companies. So far, there is no contract between farmers and biofuel companies. Feedstocks—mainly maize—are sourced from the local markets or from the government's grain stores, and ethanol is marketed under a regulated system.

An assessment of the likely impacts of biofuel development shows that the increase in demand for bioethanol feedstock could lead to a large increase in prices of these crops (if their imports are not increased). Price increases would trigger a significant rise in production of these crops and a shift in the crop production structure of each region. The gain in the production of the targeted commodity in a given scenario is partly obtained through higher yields but, more significantly, by substitution away from crops—such as wheat and rice—that are not associated with the bioethanol program.

Nearly all farmers who engage in crop production would gain from the expansion of biofuel production. However, the study also reveals that bioethanol competes with animal feed and that the price increases of animal feed would significantly lower farmer income from livestock production. There would also be a significant relocation of rural labor between the crop and livestock sectors. Labor input would increase in rainfed agriculture where most of the biofuel crops are grown. More importantly, the impact of alternative bioethanol programs on farmers in different regions varies substantially both between and within regions.

Summarized below are the potential implications on the PRC's future bioethanol development, food security, poverty reduction, and overall rural development.

Choice of feedstock. The viability of different crops as feedstock for bioethanol requires careful analysis prior to a large-scale expansion of the bioethanol program. A mix of several alternative feedstock sources should be explored. An exclusive, or near exclusive, focus on sweet sorghum, cassava, sugarcane, or other suitable crops is not possible without substantial imports of these commodities. The PRC is considering importing cassava from other countries, such as Thailand and Viet Nam, but since these countries are also planning to use cassava and other non-grains for their biofuel development, this may become difficult.

Household food security. The bioethanol program offers some potential for rural households to increase their farm income and improve their purchasing power. The PRC is an interesting case because all rural households have access to land, and nearly all rural households sell a portion of their agricultural products to the market. However, if feedstock is sourced from maize and/or cassava, there will be negative impacts for livestock producers.

Impact on income distribution. Ethanol development appears to have a pronounced impact on income distribution and poverty reduction. Marginal lands and rainfed areas could gain significantly in terms of value added, as the government plans to use them to produce most of the new feedstock crops. This would help to bridge the income disparity between urban and rural areas and between irrigated and rainfed areas.

Environmental implications. Because of the environmental implications of bringing marginal land into crop production, potential land suitable for biofuel feedstock crop production should be revisited, and the impact on land use, water resources, ecology, and other resources should be carefully assessed.

Potential financial implications. Promoting a large-scale bioethanol program could have substantial financial implications if the productivity of feedstock cultivation and biofuel processing are not significantly improved. The cost of feedstock would increase significantly as prices of maize, cassava, or sweet sorghum rise with their expanded use for bioethanol production. The level of subsidies could rise depending on the trend in oil prices on the international markets. Government support should focus more on productivity-enhancing investments in both feedstock crop production and biofuel processing.

Institutional arrangements to incorporate farmers into the biofuel industry. It is important to explore more innovative institutional and organizational arrangements to include small and poor farmers, and small and medium-sized enterprises in biofuel development. Efforts should also be made to develop a more integrated biofuel program that is directly linked with the farmers who produce the feedstocks. Because feedstock production on marginal land is dispersed, the cost of collecting, transporting, and storing these feedstocks will be high. It may be worth considering a more decentralized approach instead of concentrating biofuel production in a few places. The establishment of small-scale biofuel plants and household biogas facilities should be encouraged, since this will help incorporate farmers into the biofuel industry.

Second-generation biofuel technologies. While they are not examined in this study, second-generation biofuel technologies should be considered seriously by the PRC, given the trade-offs between grain security and energy security. The use of crop residues as feedstocks should also be considered, but this should be weighed against their important alternative uses in livestock feed and in sustainable crop production practices.

Appendix 1
Energy and Petroleum Balance Sheet of the People's Republic of China, 1990–2006

Table A1: Energy Balance Sheet of the People's Republic of China, 1990–2006
('000 million tons of coal equivalent)

Year	Supply			Demand		
	Production	Import	Stock Reduction	Consumption	Export	Dis-balance
1990	10.39	0.13	0.32	9.87	0.59	0.39
1991	10.48	0.20	0.09	10.38	0.58	(0.19)
1992	10.73	0.33	0.01	10.92	0.56	(0.41)
1993	11.11	0.55	(0.04)	11.60	0.53	(0.52)
1994	11.87	0.43	(0.07)	12.27	0.58	(0.61)
1995	13.14	0.55	0.05	13.12	0.68	(0.07)
1996	13.45	0.68	(0.06)	13.90	0.75	(0.58)
1997	13.29	1.00	0.15	13.82	0.77	(0.15)
1998	12.62	0.85	(0.09)	13.22	0.72	(0.56)
1999	11.08	0.95	(0.20)	13.01	0.65	(1.82)
2000	13.07	1.43	(0.11)	13.86	0.96	(0.42)
2001	12.28	1.35	(0.02)	13.49	1.12	(1.01)
2002	14.03	1.58	0.07	14.82	1.10	(0.25)
2003	16.20	2.01	0.08	17.09	1.27	0.08
2004	18.99	2.66	0.15	20.32	1.17	0.30
2005	20.87	2.70	0.10	22.47	1.15	0.06
2006	22.40	3.11	0.02	24.63	1.09	(0.20)

( ) = negative number.

Source: *Statistical Yearbook of China*. 2007.

Table A2: Petroleum Balance Sheet of the People's Republic of China, 1990–2006

('000 million tons of coal equivalent)

Year	Supply			Demand		
	Production	Import	Stock Reduction	Consumption	Export	Dis-balance
1990	1.38	0.08	0.00	1.15	0.31	0.00
1991	1.41	0.13	0.01	1.24	0.29	0.01
1992	1.42	0.21	(0.01)	1.34	0.29	0.00
1993	1.45	0.36	0.07	1.47	0.25	0.16
1994	1.46	0.29	0.03	1.50	0.24	0.04
1995	1.50	0.37	0.02	1.61	0.25	0.03
1996	1.57	0.45	(0.01)	1.74	0.27	0.01
1997	1.61	0.68	0.04	1.97	0.28	0.08
1998	1.61	0.57	(0.02)	1.98	0.23	(0.05)
1999	1.60	0.65	(0.01)	2.11	0.16	(0.04)
2000	1.63	0.98	0.12	2.24	0.22	0.27
2001	1.64	0.91	0.03	2.28	0.21	0.09
2002	1.67	1.03	(0.01)	2.48	0.21	(0.00)
2003	1.70	1.32	0.01	2.71	0.25	0.06
2004	1.76	1.73	0.05	3.17	0.22	0.15
2005	1.81	1.72	(0.01)	3.25	0.29	(0.03)
2006	1.85	1.95	0.04	3.49	0.26	0.08

( ) = negative number.

Source: *Statistical Yearbook of China*. 2007.

Appendix 2
Decision Support System for Sustainable Agricultural Development in the People's Republic of China

Chinagro is a multiregional equilibrium model developed by the Center for World Food Studies and the Chinese Center for Agricultural Policy, in collaboration with four other international institutes. The model comprises 28 outputs and a range of 14 farm types involved in crop and livestock production. The 28 outputs encompass most of the country's agricultural products, including rice, maize, wheat, sugarcane, oil crops, and livestock products. The 14 farm types include categories such as irrigated farming, rainfed farming, tree cultivation, traditional livestock farming, and specialized livestock farming. Farm supply is represented at county level. On the demand side, consumers in every province were divided into six groups according to their income levels.

Chinagro is structured as follows: The agricultural supply of each county acts in response to the market prices faced by various farm types in each county. Total area for cultivation, maximal yield potential on each farm type, and production technologies are imposed as exogenous constraints for agricultural expansion. Parameters of labor, fertilizer, and animal feed requirements per unit of output are estimated by econometric models on the basis of agronomic information. Consumers of agricultural products are represented for every income group in each province for rural and urban areas separately, and consumers' responses to prevailing consumer prices and income available to them. Supply and demand are balanced for all commodities simultaneously through inter-provincial and international trade, jointly with price adjustment, subject to various policy interventions, such as biofuel development. The specification of Chinagro is as follows:

$$V = Max \sum_r \alpha_r^u u_r^u(x_r^u) + \sum_r \sum_{c \varepsilon C_r} \alpha_c^v u_c^v(x_c^v)$$

Subject to:

$$(1) \quad x_r^u + \sum_{r'} v_{rr'} + \sum_{c \in C_r} z_c^+ + g_r + m_r^- = \sum_{r'} v_{r'r} + \sum_{c \in C_r} z_c^- + m_r^+ + \omega_r^u \quad (p_r)$$

$$(2) \quad g_r = \sum_{r'} \theta_{rr'}' v_{rr'} + \sum_{c \in C_r} (\tau_c^{+\prime} z_c^+ + \tau_c^{-\prime} z_c^-) + \zeta_r^{+\prime} m_r^+ + \zeta_r^{-\prime} m_r^-$$

$$(3) \quad \sum_r (\bar{p}_r^{+\prime} m_r^+ - \bar{p}_r^{-\prime} m_r^-) \le \bar{B}$$

$$(4) \quad x_c^v + e_c + z_c^- = q_c + \omega_c^v + z_c^+ \quad (p_c)$$

$$(5) \quad F_c(q_c, e_c) \le 0,$$

The objective is to maximize the sum of all consumers' utility, including different urban and rural consumers. $u_r^u(x_r^u)$ denotes the utility of urban consumers in region r, and α_r^u means the exogenous welfare weight of urban consumer in region *r*. Similarly, $u_c^v(x_c^v)$denotes the utility of rural consumers in county *c*, and α_c^v is the welfare weight of this rural consumer. The utility function is in the format of the Stone-Geary utility function.

Constraint function (1) means: the demand and supply of all commodities are balanced at the regional level. The shadow price of this constraint means the equilibrium prices vector of all commodities in each region. x_r^u is the consumption of urban consumers in region *r*; $v_{rr'}$ is the trade flows from region *r* to region *r'*; z_c^+ and z_c^- is the net buying or selling of county *c* from (to) the region r to which it belongs; g_r means the trade cost and losses of region *r*; m_r^+ and m_r^- means, respectively, the import and export of region *r* from the international market; ω_r^u means the endowments of urban consumers in region *r*.

Constraint (2) explains the components of trade cost and losses in each region. It includes transportation costs among regions ($\sum_{r'} \theta_{rr'}' v_{rr'}$, including losses during the transport process, and transaction costs between the regional market and county market ($\sum_{c \in C_r} (\tau_c^{+\prime} z_c^+ + \tau_c^{-\prime} z_c^-)$, taxes and tariffs and transaction cost of imports and export $\zeta_r^{+\prime} m_r^+$ stands for import and $\zeta_r^{-\prime} m_r^-$ for export.

Constraint (3) means the PRC's trade balance requirement. Among which, $\bar{p}_r^+$ and $\bar{p}_r^-$ means the exogenous import and import prices; $\bar{B}$ the balance requirement of the PRC's international trade.

Constraint (4) means the supply and demand balance at county level. The shadow price, $p_{c,}$ of this constraint means the commodity price vector at county level. Where $e_c$the intermediate inputs of county's agricultural production, and ω_c^v means the endowment of county *c*.

Function (5) is the constraint of agricultural production technology in county *c*, and Mitscherlich-Baule production function has been adopted for the production technology. Where, q_c means the output vector of county *c*, e_c means the inputs. For more details see footnote 25.

Status and Potential for the Development of Biofuels and Rural Renewable Energy: The People's Republic of China

This report contains a detailed assessment of the status and potential for the development of biofuels in the People's Republic of China and presents a country strategy for biofuels development consistent with the Greater Mekong Subregion Regional Strategic Framework for Biofuel Development. The findings of the report were endorsed at the Fifth Meeting of the Greater Mekong Subregion Working Group on Agriculture on 22-24 September 2008 in Vientiane, the Lao People's Democratic Republic.

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