The potential role that biofuels might play in China’s future transportation needs

by

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Abstract

From 1980 to 2010 China's energy use increased six fold to 2430 Mtoe/yr and it is projected to further increase by about 50% to 3359 Mtoe/yr by 2020. Currently renewable energy, such as bioenergy, hydro, solar and wind, contributes less than 9% of this total. During China's "industrial revolution" phase of economic growth (in the 1970/80's), coal was the major source of power and electricity with oil and natural gas playing a much lesser role. More recently, due to the rapid increase in the number of motorized vehicles, the country has gone from oil self-sufficiency in the early 1960's to importing more than 271 Mt/yr of oil in 2012.

China's biofuels industry is in its infancy with its current bioethanol production (primarily from corn) at 2.5 GL/yr and biodiesel production (primarily from waste cooking oil) at 0.4 GL/yr. Although the national goal is to produce 12.7 GL bioethanol and 2.3 GL of biodiesel by 2020, the potential for growth of so-called first generation or conventional biofuels is very limited due to food-vs-fuels concerns and China's desire to be as self-sufficient as possible in food production. Thus, research, development and demonstration (RD&D) is being encouraged to grow and process so-called one-and-a-half generation crops such as sweet sorghum with a goal of producing 9 GL of ethanol by utilizing 40% of the available marginal land. However, to date, few plantation or conversion facilities have been built. Regarding so-called second-generation facilities, China has the potential to annually produce 22 GL of cellulosic ethanol by utilizing 15% of its 874 Mt agricultural residues. This could increase to 29 GL bioethanol by 2020, using 15% of the 1150 Mt residue that is anticipated to be available at that time. Biodiesel growth is expected to be achieved by growing oil-bearing trees with the potential of producing 2.5-6.7 GL/yr grown on 10% of the available marginal land. However, it is unlikely that biofuels will contribute substantially to China's transport sector and that, even with aggressive importation, biofuels will play a relatively minor role for quite some time.

Preface

Part of the introduction, which describes China's economic growth and energy consumption trends, and the sections on the motorization process and the impact on increasing vehicle sales and oil demand of the country have been published as a conference proceedings in the Future Forestry Leaders: Graduate Student Research Symposium 2011. [Ling, Li], Karatzos, S. and Saddler, J. (2012) "*The potential of forest-derived bioenergy to contribute to China's future energy and transportation fuel requirements*". *The Forestry Chronicle*. 88 (05): 547-552.

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List of Abbreviations

AAGR: Average annual growth rate

BCG: Boston Consulting Group

BP: British Petroleum

CNOOC: China National Offshore Oil Corporation

COFCO: China National Cereals, Oil and Foodstuffs Corporation

CNPC: China National Petroleum Corporation

DOE: US Department of Energy

DOT: US Department of Transportation

DST: Department of Science and Technologies of China

EIA: US Energy Information Administration

EPA: US Environmental Protection Agency

FAO: Food and Agricultural Organization of the United Nations

FYP: Five-year plan

GHG: Greenhouse gas

GL: Billion liters

GovH: Hainan provincial government of China

GSI: Global Subsidies Initiative of the International Institiute for Sustainable Development

GWEC: Global Wind Energy Council

IEA: International Energy Agency

IMF: International Monetary Fund

IPCC: Intergovernmental Panel on Climate Change

LHV: Low heating value

mb/d: Million barrels per day

mha: Million hectares

MIIT: Ministry of Industry and Information Technology of China

ML: Million liters

MLR: Ministry of Land and Resource of China

MoC: Ministry of Commerce of China

MoF: Ministry of Finance of China

Mt: Million tonnes

Mtce: Million tonnes of coal equivalent

Mtoe: Million tonnes of oil equivalent

NBS: National Bureau of Statistics of China

NDRC: National Development and Reform Commission of China

NEA: National Energy Administration of China

NOCs: National oil companies

NPS: New policy scenario

OECD: Organization for Economic Co-operation and Development

PLDV: Passenger light duty vehicle

PM: Particulate matter

QIBBT: Qingdao Institute of Bioenergy and Bioprocess Technology of Chinese Academy of Science

REDC: Renewable Energy Development Center of NDRC

SCC: State Council of China

SFA: State Forestry Administration of China

Sinopec: China Petroleum and Chemical Corporation

SOEs: State-owned enterprises

TPED: Total primary energy demand

UCO: Used cooking oil

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I would like to thank my supervisor Dr. Jack Saddler for inspiring me with great ideas for my research, providing guidance in my thesis and offering financial support during my study. I appreciate the chance of coming to the Forest Products Biotechnology/Bioenergy Research group and being part of so many talented researchers and students from all over the world. My journey here significantly improved my skills of critical thinking and communication. I am sincerely grateful to have Dr. Sergios Karatzos coaching me throughout my study with encouragement that made me more confident of my research. I'm also very glad to have Dr. Susan van Dyk giving me valuable feedback and suggestions, particularly about discussion and conclusions in my thesis. Thank you both for sharing your writing skills that helped me to better translates my thoughts into words.

I appreciate that my parents and my husband are always being very supportive to my study. Without them, I could not make this far. Hope this thesis can make all of you feel proud of me.

Dedication

To my beloved parents and husband

1 Introduction

Energy demand usually goes hand in hand with economic development. This introductory chapter briefly describes China's industrialization process and how it changed the country's energy profile from the 1960's to today. The driving forces behind China's development of biofuels are also discussed within this context. The potential importance, urgency and uniqueness of the world's largest emerging economy and its attempts to develop and use bioenergy and biofuels in particular are the main goals of this thesis. The various biofuels technologies and their commercialization status are also briefly described.

1.1 Economic growth and energy demand in China

China has experienced a compressed process of industrialization that has taken place over a few decades in comparison to the century or more that many western countries took to develop their economies. This has resulted in unprecedented rapid economic development within China and soaring fossil fuel demand. With heavy industry leading this initial stage of economic growth, especially the manufacturing sector, there was huge demand for electricity and power. China is recognized as a primary goods manufacturer and it has been called the "world's factory" (Hennock, 2002). However, the global economic downturns, the appreciation of Chinese currency (Yuan/RMB) and increasing domestic labour costs have all had a negative impact on the manufacturing sector. The country's GDP growth rate is slowing down and is projected to plateau at about 8% over the next decade (International Energy Agency [IEA], 2012; International Monetary Fund [IMF], 2012). Given these challenges, the Chinese government may shift its economic driving force from the export of goods to domestic consumption. However, this economic change-of-direction will likely lead to more domestic goods transportation and more oil demand in the transportation sector. At the same time the country is undergoing a process of increased urbanization and increased motorization. This is primarily because the middle classes of China are growing and they wish to upgrade their lifestyle to that of western countries with car ownership being one of their highest aspirations. As a result, China's oil demand is expected to grow faster than any other country over the next few decades.

1.1.1 Industrialization and energy consumption

As mentioned earlier, China's industrialization process has resulted in rapid economic growth and soaring energy consumption (Fig. 1.1). As a result, the country became the world's largest energy user and the second largest economy (British Petroleum [BP], 2012). However, as China has the largest population in the world (1.3 billion), its per capita energy consumption is still lower than the OECD (Organization for Economic Co-operation and Development) countries' average (BP, 2012). China's industrialization process started in the 1980's when Deng Xiaoping initiated the free-market policies that partially opened China to the world. This opening-up of China's markets followed the chaotic ten-year "Cultural Revolution" where there was little economic growth. As a result, the rate of industrialization was compressed and fast tracked when compared to western economies (Li, Karatzos & Saddler, 2012).

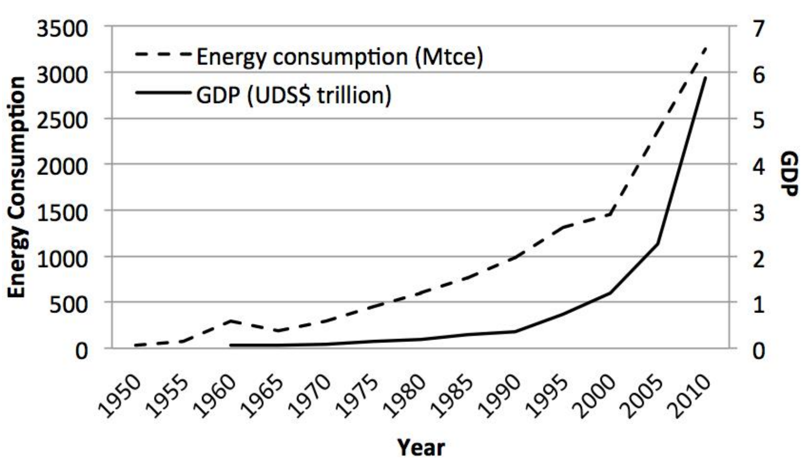

Figure 1.1 Energy consumption and GDP growth of China, 1950-2010
Data obtained from National Bureau of Statistics [NBS], 2010; World Bank, 2013a

China's industrialization process can be divided into three distinct periods and during each phase government policy drove both economic growth and energy consumption.

The People's Republic of China (PRC) was founded in 1949.

- ***1949 - 1970's:***

During this time the rapid growth in heavy industries such as the military and steel mills dramatically increased energy use. During the same period a series of "social drivers", such as the Great Leap Forward, the Great Famine, and the Great Cultural Revolution, resulted in very little GDP growth for the country (Fig. 1.1) (NBS 2010).

- ***Late 1970's - late 1990's:***

Starting in 1978 Deng Xiaoping initiated the "opening-up policy" that partially opened up China's markets to the world. This catalyzed the country's industrialization with the growth of light industries, such as the textile and clothing, hotels, food and beverage, and household electrical appliances companies (Wang, 2008). This rapid expansion of manufacturing contributed to the significant growth of both the country and individuals' GDP and energy consumption (Fig. 1.1).

- ***The late 1990's until 2010:***

The growth in both heavy and light industries continued to China's drive towards industrialization with the country joining the WTO (World Trade Organization) in 2001 (Fig. 1.2). Many multinational enterprises relocated their manufacturing facilities to China to benefit from low production and cheap labour costs. Massive reinvestment in upgrading aging heavy industry equipment and infrastructure construction resulted in China becoming the world's largest user of raw materials, such as steel, cement and ferrous metals. As a result, energy consumption soared during the last ten years or so (Wang, 2008). China became the world's second largest economy in 2010, based on an average annual growth rate (AAGR of GDP) during 2003 and 2011 of 10.75% in comparison to a growth of 2.69%, 1.62% and 3.91% for the world, the US and Brazil, respectively (World Bank, 2013b). The average individuals income also increased with the per-capita GDP surpassing $1000 in 2003 and $3000 in 2008 (Fig. 1.2).

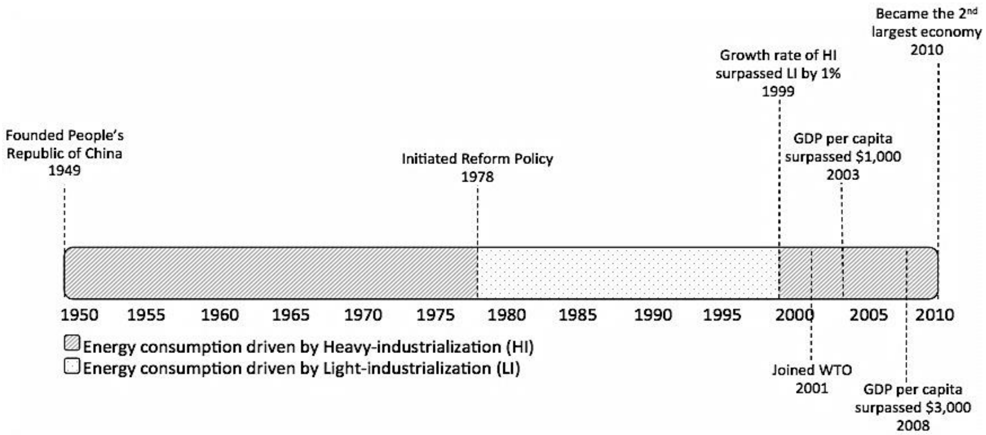

Figure 1.2 Energy revolution timeline of China, 1950-2010
Data obtained from NBS, 2000, 2003, 2008, 2010

Government investment in heavy industry during 2008 economic crisis:

During the global economic crisis of 2008, the Chinese government initiated an investment plan worth USD$ 635 billion to continue the country's GDP growth rate and infrastructure construction projects accounted for over 85% of this total investment (items 3, 5, 6 and 7 in Table 1.1). Raw materials, such as the steel and cement industry benefited considerably, while China's energy demand soared.

Table 1.1 Chinese government investment plan allocation of 2008

Items	**Percentage**
1.Medical, health, culture and education projects	1%
2.Independent innovation and structural adjustment	4%
3.Sustainable housing	7%
4.Environmental projects	9%
5.Rural livelihood & rural infrastructure projects	9%
6.Post-disaster* restoration & reconstruction	25%
7.Railway, highways, airports & power grids in urban and rural areas	45%
Total	100%

*Note: The disaster refers to the Great Sichuan Earthquake, which happened on May 12, 2008 in Sichuan Province. It was a magnitude 8.0 earthquake with an estimated total death of 68,000 people.
Data obtained from Jia & Zhao (2009)

China's energy consumption (1957-2010):

Coal is usually the primary energy source for countries in the process of industrialization.

This was the case in the late 19th century for Europe and the US with coal being the largest energy source until oil replaced it in the middle of the 20th century (US Energy Information Administration [EIA], 2011). Similarly, coal has remained the primary energy source for China over the last six decades. Oil has had a much lower share of total primary energy consumption than coal as coal accounted for nearly 90% of China's total energy consumption before 1957 (NBS, 1996). When the country discovered its own oil fields in the late 1950's the share of coal decreased to 70% and the share of oil increased to over 20% by the middle of 1970's. It has remained at the same level since then (Fig. 1.3).

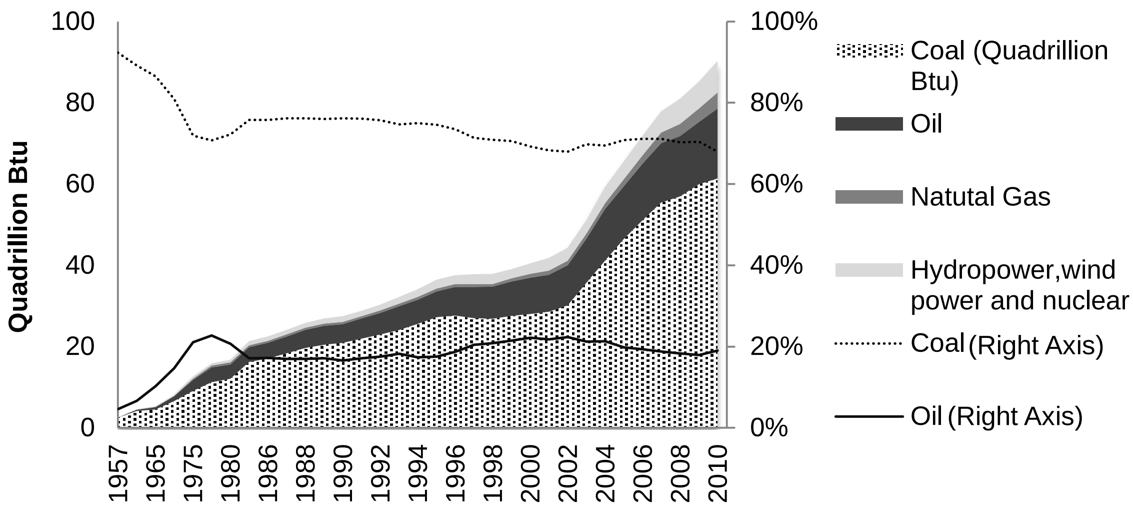

Figure 1.3 China's energy consumption by source, 1957-2010
Data obtained from NBS (1996, 2011)

1.1.2 Future trends of China's economy

As a result of several factors such as the global economic downturn, the appreciation of China's currency (RMB) and increasing labour costs, the country's economic growth has slowed down. In contrast, many Chinese people's income has increased, resulting in an enlarged middle class that is eager to have a lifestyle similar to western countries. As a result, domestic consumption is expected to take over from the international export of manufactured goods to become the primary driving force behind the country's future economic development.

- ***GDP growth rate is slowing down:***

China's GDP growth rate has already decreased from double digits to single digits and it is projected to remain at a plateau over the next decade (IEA, 2012). In 2012, the country's GDP growth rate dropped from 8.1% in the first quarter to 7.6% in the second quarter, the first time it has been below 8%for some time (Liang & Guo, 2012). In fact, it was the sixth quarter in succession that the GDP growth rate decreased since the beginning of 2011 (Liu, Wang, & Lei, 2012).

- ***Currency (RMB) appreciation:***

In addition to the global economic crisis, the appreciation of the Chinese currency (RMB or ￥) contributed to a decrease in the country's annual export growth rate from 26% in 2006 to -16% in 2008 (Fig. 1.4). The RMB has appreciated by nearly 30% since 1994 and it is projected to continuously increase by another 10% by 2012 (Phoenix New Media [PNM], 2012). Export based enterprises in China, particularly the labour-intensive manufacturing of goods have been greatly affected by the appreciation of the RMB (Yuan & Zhuang, 2009).

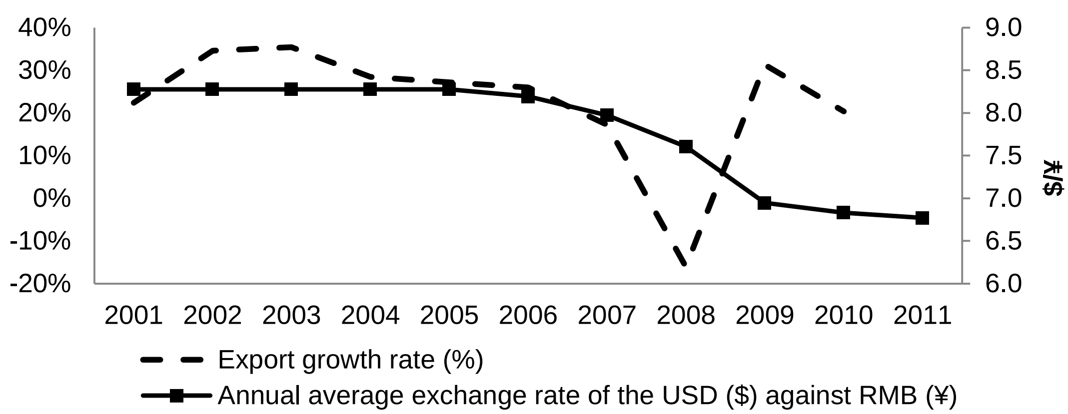

Figure 1.4 Export growth rate and currency appreciation of China, 2002-2012
Data obtained from China Foreign Exchange Trade System [CFETS] (2011), NBS (2011, 2012b), PNM (2012)

- ***Increasing cost of labour:***

China is losing its advantage of low labour costs since the Chinese government increased the minimum wages of the working class by nearly 22% in 2011,and it may be further increased in the future (Boston Consulting Group [BCG], 2012; Rabinovitch, 2011).

Low labour costs were a key factor in attracting foreign investors to choose China as a location for manufacturing facilities. However, due to the projected shrinking of the overall cost advantage of being based in China, some US industries, such as transportation goods, appliances and electrical equipment, furniture, plastic and rubber products, machinery, fabricated metal products and computers and electronics, are considering shifting 10% to 30% of their production capacity back to the US (BCG, 2012).

- ***Transition to a domestic consumption driven economy and lifestyle changes:***

China is at a transition stage where the driving force for economic development is switching from the export of goods to domestic consumption. This is due to multiple factors, from people's increasing incomes to the accelerating progress of urbanization (IMF, 2012). The urban population of China, which just surpassed 50% in 2011, earns more money than people in rural areas. The middle class is highly motivated to upgrade their lifestyles closer to that of western countries (NBS, 2011). It is projected that China will lead the rapid growth of middle class consumption in the next decade followed by India. It is likely that the two countries will account for approximately half of the world's middle class consumption by the middle of this century (Fig. 1.5). More domestic consumption means more goods transported by trucks, and railways, consequently increasing transportation fuel demand in China.

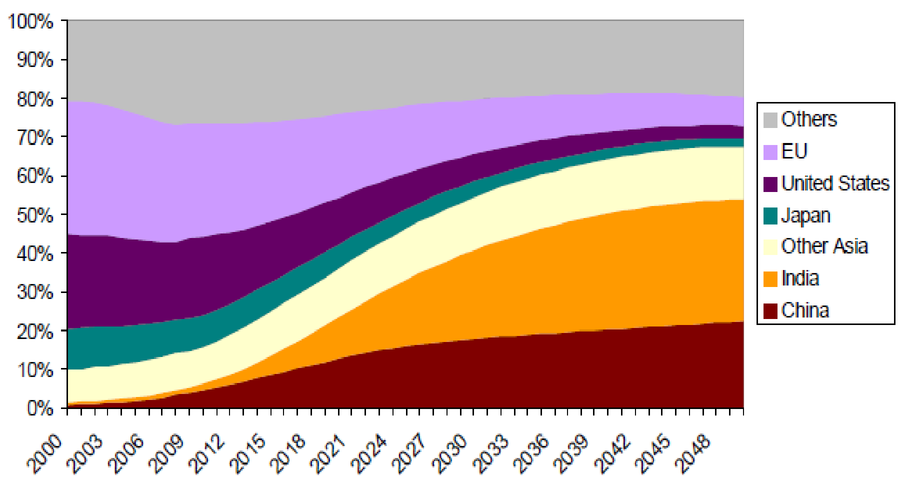

Figure 1.5 Shares of global middle class consumption, 2000-2050
Source: Kharas, 2010

From the 1950's and 1970's, it was rare for Chinese people to own the so called "big four items" such as a sewing machine, a bicycle, a wrist-watch and a radio. In the 1980's and 1990's these four items changed to a TV, a washing machine, a refrigerator and an air conditioner. Today, the middle class now aspires to own at least one car, particularly those living in urban areas, and this is driving the double-digit growth of automobile sales (Waldmeir, 2013).

1.1.3 China's energy profile changing trends

Over the next two decades, China will require more of the world's oil. This will occur at the same time as a decreasing trend in oil demand is projected for OECD countries, particularly North America during 2020 and 2035 (Fig. 1.6). The average annual growth rate of China's oil demand over the next decade is projected to be 3.9% while coal will increase by 2.1%. Coal will remain the largest energy source, accounting for nearly 60% of China's total primary energy demand (TPED) by 2020（IEA, 2012).

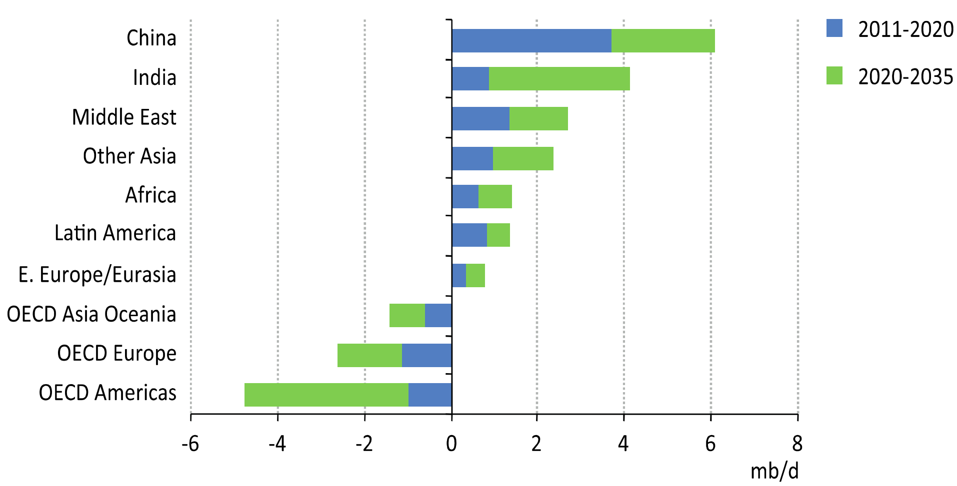

Figure 1.6 Comparison of oil demand by region in New Policy Scenario

Note: New Policies Scenario refers that existing policies are maintained and recently announced commitments and plans, including those yet to be formally adopted, are implemented in a cautious manner.

Source: IEA, 2012

Currently, the manufacturing sector contributes to nearly half of China's total GDP compared to 20-30% for most OECD countries (Fig. 1.7). Thus, China's primary energy source is not likely to suddenly change from coal to oil, despite the fact that the country's economy is undergoing a major restructuring.

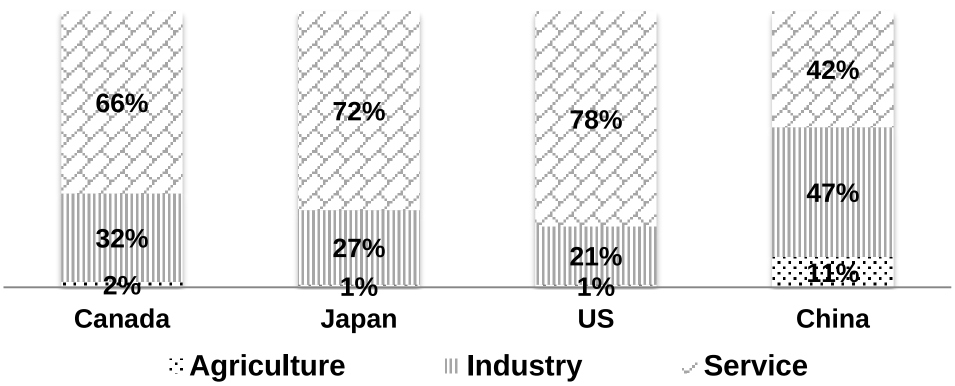

Figure 1.7 Comparison of GDP contributions by sector, 2008
Data obtained from World Bank (2012a, 2012c, 2012d)

A specific comparison of energy use between China and the US indicates the differences between the two countries. The former is typical of a coal dependent, emerging economy and the latter of an oil dependent, developed economy. In China, coal is the dominant energy source for both industrial use (75%) and power generation (81%) as shown in Fig. 1.8. In the US, both oil and natural gas are the largest energy sources in the industry sector (Fig. 1.9). Power generation is also the largest energy user in the US, while less than half of total energy supply for generating electricity is from coal (Fig. 1.9).

The current energy profile of the US is not likely to be replicated by China in the future due to this country's limited domestic reserves of oil and natural gas (BP, 2012). Although China is projected to replace the US and become the largest oil consumer by 2035, the oil share of China's total primary energy demand (TPED) is very likely to remain at current levels, while coal's share may gradually be reduced due to the increasing use of both nuclear power and renewable energy, such as hydroelectricity, wind power, solar energy and biomass-based energy (bioenergy and biofuels). This will be further explored in section two.

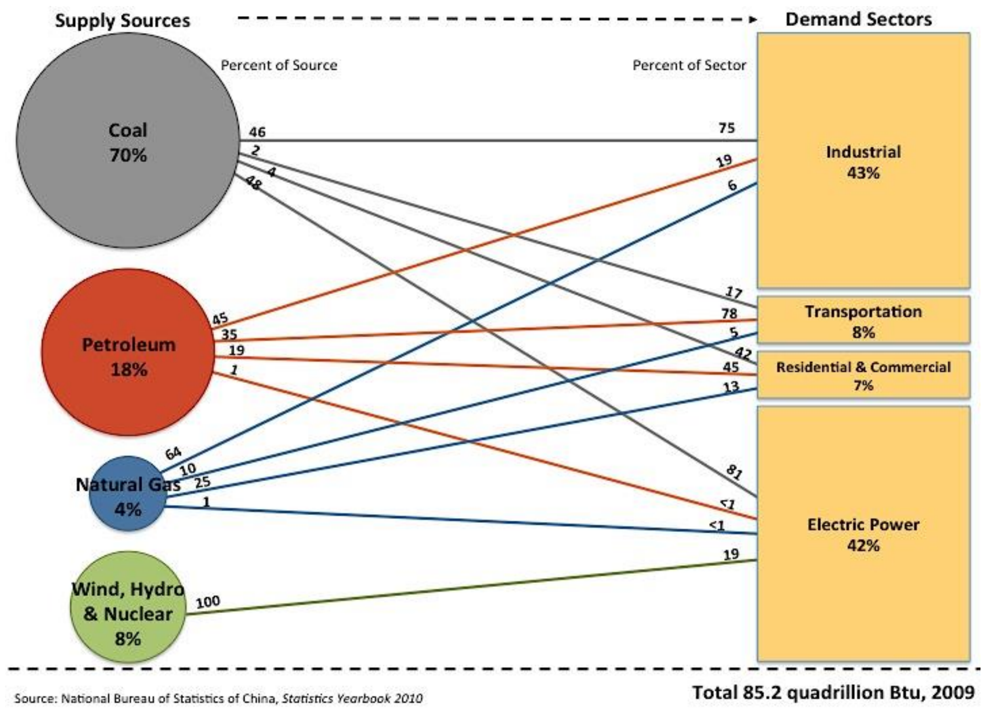

Figure 1.8 Energy use by supply and demand sources in China, 2009

Data obtained from NBS (2009)

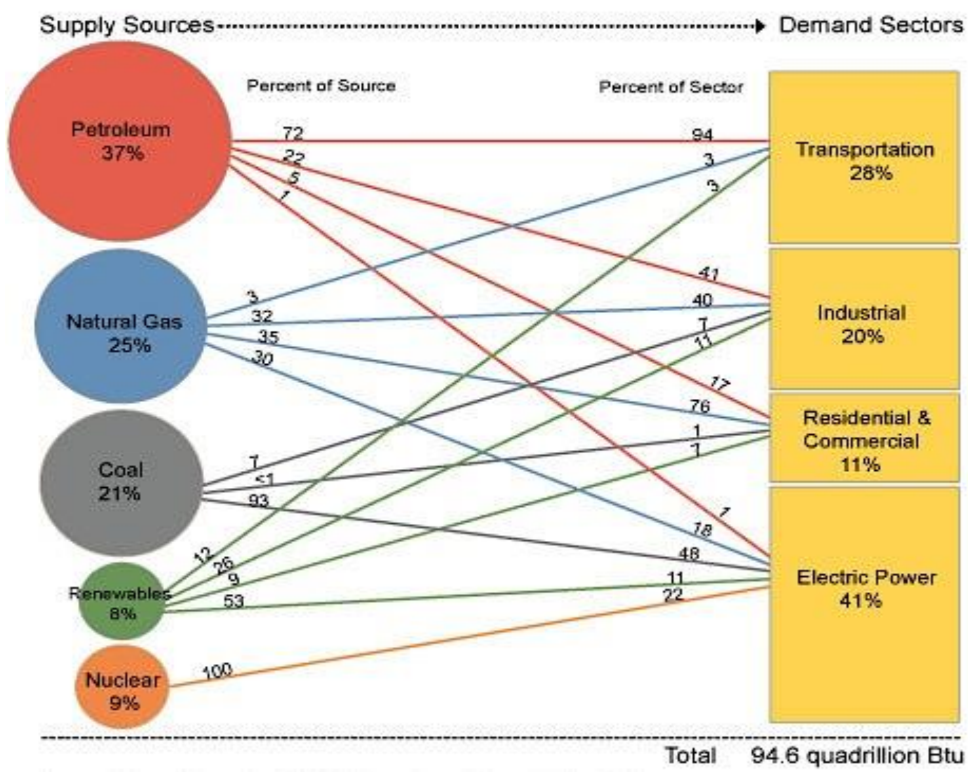

Figure 1.9 Energy use by supply and demand sources in the US, 2009

Source: EIA, 2010

1.2 Renewable energy in China

1.2.1 Leading in renewable power and heat generation

Although China is the world's largest GHG emitter, the country is also a leader in the development and deployment of renewable power and heat utilization. Currently, China is the number one consumer of hydroelectricity, wind power and solar water heat, accounting for 20%, 27% and 60% of the world's total capacity/consumption, respectively, followed by Brazil as the second largest hydroelectricity consumer and the US as the second largest wind power consumer (Table 1.2).

Table 1.2 Comparison of solar energy, hydroelectricity and wind power (% of world's total)

	Solar heat[1]	Hydroelectricity[2]	Wind power[3]
China	60%	20%	27%
Brazil	2%	12%	0.8%
US	8%	9%	21%
World total	195.8 GW	791.5 Mtoe	282.5 GW

Notes:

1. Installed capacity in operation of 2010 (Weiss & Mauthner, 2012)
2. Consumption in 2011 (BP, 2012)
3. Cumulative installed capacity by the end of 2012 (Global Wind Energy Council [GWEC], 2013)

1.2.2 Biomass-based energy

Besides hydropower, wind power and solar energy, renewable energy can be derived from biomass. Biomass is an organic source including but not limited to biomass/energy crops such as willow, polar, switchgrass, etc., agricultural residues, forest residues, animal wastes and industrial & municipal wastes. Bioenergy can consist of solids (e.g. pellets), liquids (e.g. biofuels), and gases (e.g. biogas) (Bauen et al., 2009). Wood pellets are an example of solid bioenergy typically used for heat and power generation. Bioethanol and biodiesel are often mixed with petroleum-derived fossil transportation fuels in different proportions and they are termed biofuels. Biogas is another form of bioenergy that is widely used for heat and power generation (IEA, 2011b).

In China, the utilization of biomass-based energy is far behind other forms of renewable energy and it predominantly used for power and heat generation not transportation fuel production. In 2010, China consumed a total of 294 million tonnes of coal equivalent (Mtce) renewable energy (Wang et al., 2012), of which 87% was used to produce electricity followed by 12.5% to produce heat. Biomass-based energy only accounted for approximately 8% of the total and was mostly attributed to the use of biogas (for heat) and bioenergy (for power), while the consumption of biofuels was less than 1% of the country's renewable energy matrix (Fig. 1.10). It is evident that neither biofuels nor biomass-based energy is a renewable energy priority for China.

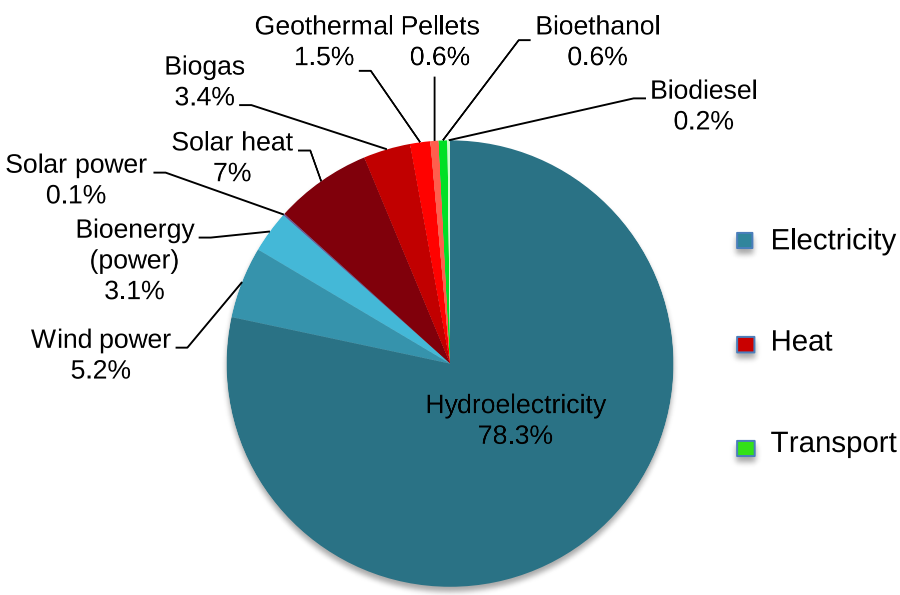

Figure 1.10 Renewable energy consumption share in China, 2010
Data obtained from Wang et al. (2012)

1.3 Driving forces analysis of biofuels in China

In many OECD countries, oil security issues and GHG emissions reductions are the main driving forces for biofuels development. Typically, the transportation sector is not only the primary user of imported oil, but also the second largest GHG emitter. China has severe oil security issues and its oil self-sufficiency is predicted to further decrease over the next two decades. However, the Chinese government has continuously increased investment in acquiring overseas oil resources to better secure its oil supplies. Currently, GHG emissions from China's transportation sector are too low to make it the priority of GHG emissions reductions compared to emissions from other energy sectors, such as coal-fired power, heating and industrial sectors. However, acquired foreign oil resources can be affected by political factors and regional conflicts, which is not as secure as the government might expect. Meanwhile, the absolute amount of GHG emissions in China's transportation sector is considerable and already higher than the UK's total emissions from fuel combustion in 2009, and it is predicted to double its share of world's total transportation emissions by 2035 (IEA, 2011a). In addition, air pollution arising from China's transportation sector in urban areas is a possible third driving force for China to promote biofuels consumption, which may be the most urgent driving force among all the three as it is a public health concern (Pan, Li, & Gao, 2012).

1.3.1 Oil security issues

Oil security issues in China are already severe and it is projected to become more problematic in the coming decades. In 1950, imported oil used to account for 65% of China's total oil consumption, and then the country became oil self-sufficient in 1965 after China discovered its own oil resource in the late 1950's (Wang, 2004) However, with the accelerated process of industrialization, China became a net oil importer in 1993, and within ten years, the country became the world's second largest oil consumer due to a decrease in its domestic oil supply (BP, 2004; NBS, 1996). China ranks 14th in terms of proven oil reserves, which is estimated to last around 10 years based on current rates of consumption (Fig. 1.11).

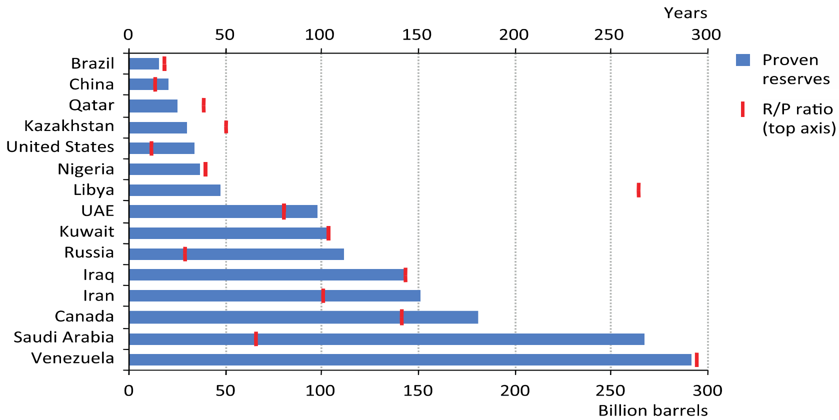

Figure 1.11 Proven oil reserves in the top 15 countries, end-2011
Note: UAE: United Arab Emirates; R/P ratio=reserve-to-production ratio
Source: IEA, 2012

Imported oil accounted for 55% of China's total oil supply in 2011, and it is projected to further increase to approximately two thirds by 2020 and over 80% by 2035 (IEA, 2012; NBS, 2012b). Net oil imports into China are projected to rapidly grow from 3 million barrels per day (mb/d) in 2005 to over 8 mb/d in 2020 and 12 mb/d in 2035, while at the same time OECD countries, particularly the US, are projected to decrease their level of imports significantly (Fig. 1.12).

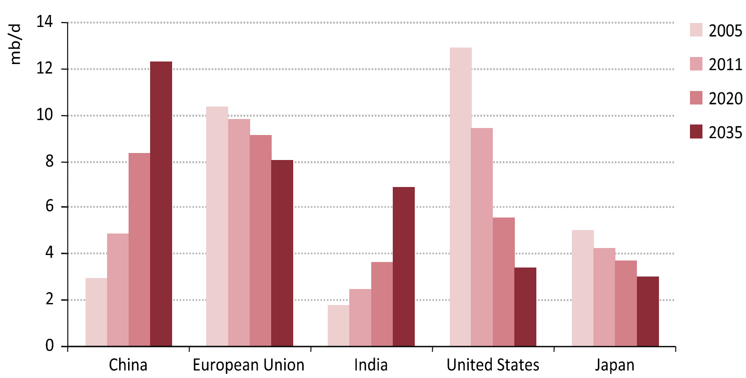

Figure 1.12 Net oil imports comparison in New Policy Scenario
Source: IEA, 2012

In the early 2000's, in order to ensure oil security, three National Oil Companies (NOCs), including China National Petroleum Corporation (CNPC), China Petroleum and Chemical Corporation (Sinopec), and China National Offshore Oil Corporation (CNOOC), which are considered as strategic state-owned enterprises (SOEs), started to acquire foreign oil companies. The three state-owned NOCs invested a total of USD$65 billion between 2002 and 2010, most of which was spent in 2009 (USD$18 billion) and 2010 (USD$30 billion) (Jiang & Sinton, 2011). In 2012, CNOOC bought Nexen, a Canadian oil and gas company, for a price of over USD$ 15 billion. This was historically the highest single deal and indicated the rising trend in China's overseas energy acquisition ("Canada OKs China's largest overseas energy acquisition", 2012). Currently, the Middle East and Africa are the two largest oil supply regions for China accounting for 42% and 19% of its total imported oil, respectively (Fig. 1.13). However, oil sources in these regions can be easily influenced by international politics or cut off by wars and armed territorial conflicts. For example, the US has persuaded many countries to reduce oil imports from Iran. China responded by reducing imports by 21% in 2012 and plans a further reduction of 5-10% in 2013 (Dong, Man, Liang, & Huang, 2008; Goswami & Tasukimori, 2013; Wang, 2004).

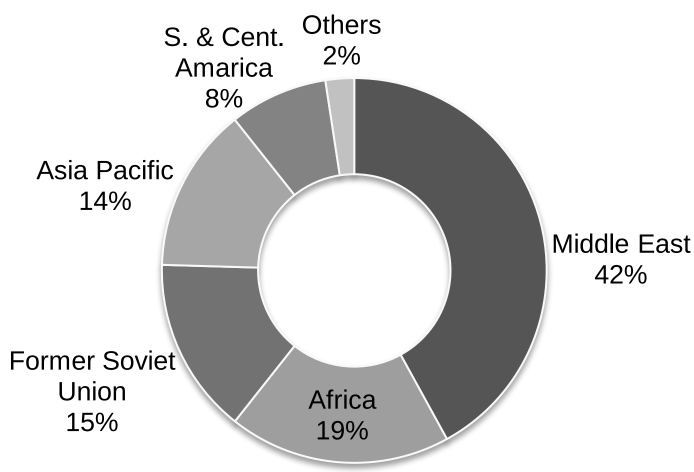

Figure 1.13 Import oil sources of China by region, 2011
Data obtained from BP (2012)

1.3.2 Green House Gas (GHG) emissions

GHG emissions, particularly CO_2 emissions from fuel combustion, are viewed as major contributors to human induced climate change (IEA, 2011a; Intergovernment Panel on Climate Change [IPCC], 2007). China's accelerated industrialization process has been coupled with great consumption of coal for power generation. In 2007, China surpassed the US and became the world's largest CO_2 emitter releasing 7 gigatonnes of energy-related CO_2 emissions each year, projected to gradually increase to 10 gigatonnes by 2035 (IEA, 2012). However, the US remains the world's largest emitter on both a per capita basis and a cumulative basis since 1850 (Fig. 1.14). Looking forward, developing countries, such as China and India, are forecast to accelerate their transportation related emissions due to rapid economic growth and increased car production and use over the next decades (UNHabitat, 2011).

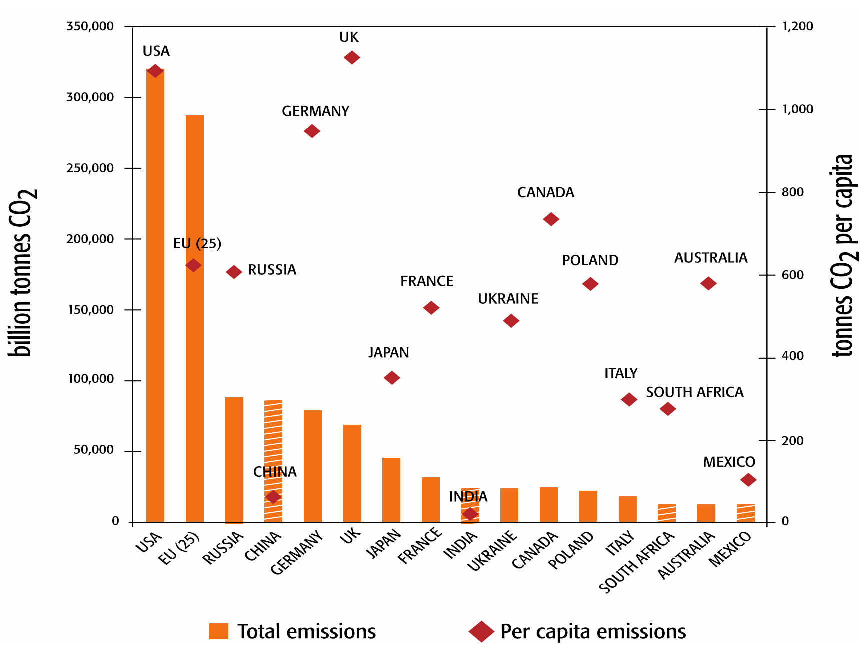

Figure 1.14 Top 20 countries contribution to CO_2 emissions, 1850-2003
Note: Developing countries are striped and developed countries are solid
Source: The Climate Institute [TCI], 2007

Coal, oil and natural gas consumption accounted for 41%, 23% and 20% of global total CO_2 emissions in 2009, respectively (IEA, 2011a). In the same year, China's CO_2 emissions from coal combustion alone contributed nearly 84% of the country's total CO_2 emissions, followed by oil combustion at only 14% (IEA, 2011a).

Typically, the transportation sector is the second largest emitter after electricity and heat production for most countries (Fig. 1.15). Exceptions include Brazil and Canada where transportation accounts for the largest share of the country's emissions (Fig. 1.15).

However, CO_2 emissions from China's transportation fuel combustion accounted for only 7% of the country's total CO_2 emissions, although this percentage may increase to 13% by 2035 (IEA, 2011a). It is worth noting that the absolute amount of the 7% transport related emission was still higher than the UK's total CO_2 emissions from fuel combustion in the same year (IEA, 2011a). In addition, the share of China's CO_2 emissions from transportation fuel combustion will be doubled to 16% of the world's total transportation CO_2 emissions by 2035 (IEA, 2011a).

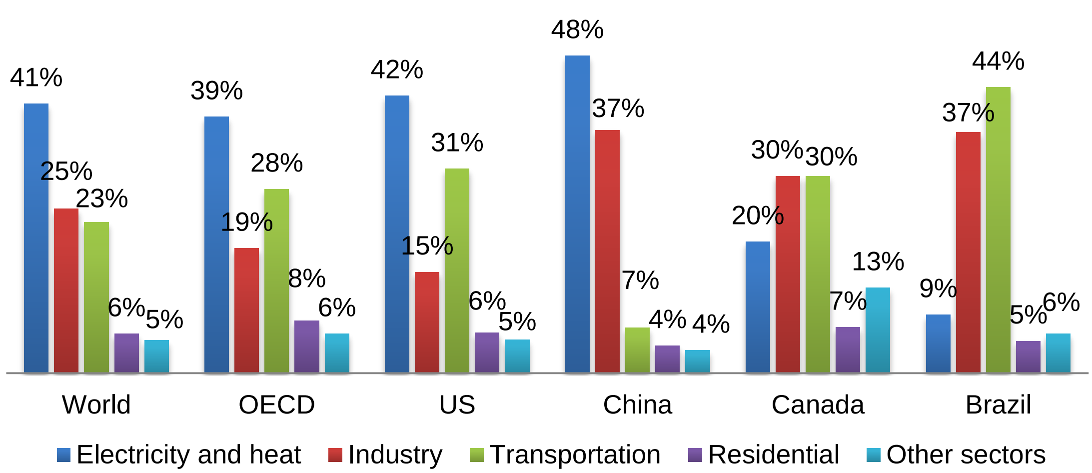

Figure 1.15 Comparison of CO_2 emissions from fuel combustion by sector, 2009
Data obtained from IEA (2011a)

Although it is undoubtedly urgent that China should reduce its CO_2 emissions resulting from coal combustion, it is becoming increasingly apparent that oil use in the transportation sector in particular will motivate the drive towards alternatives, such as advanced biofuels. China has already significantly decreased its CO_2 emissions intensity over the last two decades (Fig. 1.16), and using biofuels would help achieve the government mandate of further improving carbon intensity by 17% by 2015 (compared to 2010 level), and by 40-45% by 2020 (compared to 2005 level) (State Council of China [SCC], 2013).

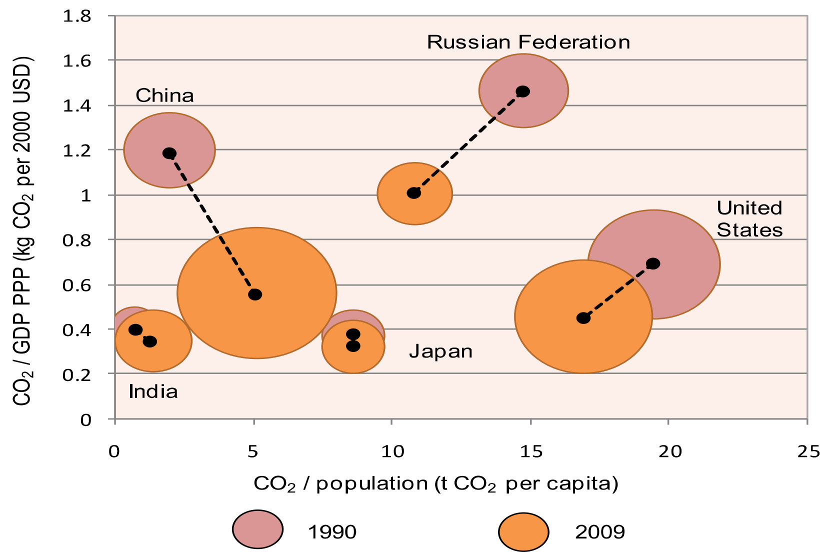

Figure 1.16 Carbon intensities changing trends of the top five emitting countries, 2009
Note: Size of circle represents total CO_2 emissions of the country in that year
Source: IEA, 2011a

1.3.3 Air pollutions in cities

Although China's industrialization has resulted in rapid economic growth and accelerated the country's processes of motorization and urbanization, it has also brought environmental issues and health concerns, such as air pollution emissions from the transportation sector in urban areas. Urban centers account for 60-70% of the world's total GHG emissions when using a consumption-based method for calculation, and the transportation sector is the largest emission source for air pollution in urban areas (OECD, 2007; UNHabitat, 2011).

Currently, China is facing a grave air pollution issue and some Chinese cities in the early 2000s had the most polluted air quality in the world (OECD, 2005). China's Ministry of Environmental Protection [MoEP] (2010) stated that car emissions are the major source of air pollution in urban regions of the country. Usually, $PM_{2.5}$ and PM_{10}, (particulate matter size smaller than 2.5 micrometers and 10), are measured to monitor air quality that includes particle pollution, such as acids, organic chemicals, metals and soil/dust (US Energy Protection Agency [EPA], 2013). The finer the size of PM the more it can lead to health problems, heart disease and lung cancer. Thus, $PM_{2.5}$ levels are widely monitored in developed countries and it has been reported that emissions from vehicles are the major source of $PM_{2.5}$ pollution in urban areas (OECD, 2007; UNHabitat, 2011). In 2011, a third of a total 31 major cities in China's annual mean PM_{10} level were higher than 100 μg/m^3 and that of another 16 cities ranged between 70-99 μg/m^3 compared to the world's average of 71 μg/m^3 (NBS, 2012a; WHO, n.a.). $PM_{2.5}$ has not been measured in China until recently and it is reported that $PM_{2.5}$ level of Beijing had once surged to 886 μg/m^3, which is far beyond the maximum allowed value of the China's Air Quality Index (500 μg/m^3), in which a level of 400 already represents a "hazard to all people" ("Daily chart: Choked", 2013).

High PM levels can result in severe health consequences as was demonstrated almost 60 years ago already during London's Great Smog of 1952 which was reported to claim 12,000 lives (MetOffice, n.a.; Rosenberg, n.a.). Unfortunately, the tragedy of London has repeated itself in some cities of China where air pollution has caused a total of 8572 deaths in 2012 in Beijing, Shanghai, Guangzhou and Xi'an (Pan et al., 2012). The Chinese government recently announced that 74 cities would start monitoring $PM_{2.5}$ level instead of PM_{10} ("74 Chinese cities to publish daily PM2.5 reports: ministry", 2012). It has been suggested that the wider adoption of biofuels would go some way to reducing the unacceptably high level of air pollution in China's cities.

1.4 Biofuels in China

1.4.1 Conversion technologies and classification

This section includes a brief introduction to biofuels terminology, classification, and conversion technologies. In this study, the term "biofuels" is used to refer to two types of liquid transport fuels, bioethanol and biodiesel. As mentioned previously, biofuels are mixed with petroleum and its content is usually expressed in blending ratio by volume, such as E10 and B5. E10 means mixing 10% bioethanol with 90% gasoline by volume, and B5 contains 5% biodiesel with 95% diesel by volume.

Groups, such as the IEA, have recommended not using the first/second generational terminology that is often used, but instead to classify biofuels as conventional (sugar or starch to ethanol) or advanced (cellulosic ethanol, pyrolysis oil, or Fischer-Tropsch fuels derived from biomass) (IEA, 2011b).

- Conventional biofuels include biofuels derived by mature conversion technologies that are currently produced at a commercial scale. This includes starch- and sugar-based ethanol, oil crops or waste oil derived biodiesel (Fig. 1.17), and biogas derived through anaerobic digestion (IEA, 2011b). Sugar crops, such as sugarcane and sugar beet, starch crops, such as corn and wheat, and oil crops, such as rapeseed, soybean, oil palm, animal fats, and used cooking oil (UCO), are usually the feedstocks for conventional biofuels production (Bauen et al., 2009). However, conventional biofuels, which use food as a feedstock, have been criticized for competing with food production and land/water resources, and resulting in increased food/feed prices.

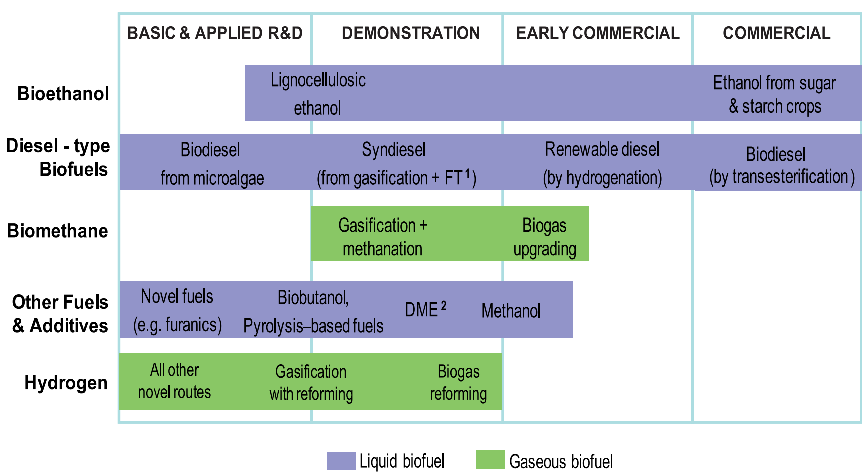

Figure 1.17 Status of biofuels conversion technologies

[1]Fischer Tropsch, [2]Dimethylether

Source: Bauen et al., 2009

- Advanced biofuels commonly refer to conversion technologies that typically use biomass as their initial feedstock with most of these technologies at an early stage of research and development (R&D), or pilot/demonstration phase (IEA, 2011b).

Cellulosic ethanol, biomass-to-liquids (BtL)-diesel, bio-synthetic gas (bio-SG), and algae-based biofuels are categorized as advanced biofuels (Fig. 1.17) (Bauen et al., 2009). Some form of biomass (e.g. agricultural and forest residues), is the typical feedstock for cellulosic ethanol production. Cellulosic ethanol has less "food/feed vs. fuel" concerns than conventional biofuels (Sims, Taylor, Saddler, & Mabee, 2008). However, due to the high capital and production costs of the biochemical conversion technologies, cellulosic ethanol is not cost competitive compared to conventional biofuels (Stephen, Mabee, & Saddler, 2010 & 2011).

1.4.2 Production trends

World total biofuels production increased from 10 Mtoe (million tonnes of oil equivalent) to 59 Mtoe over the last decade led by the US and Brazil (Fig. 1.18). Europe & Eurasia, particularly Germany and France, have led the growth in biodiesel production due to diesel engines being more widely used than gasoline engines in these regions (IEA, 2009). China only accounted for 2% of the world's total biofuels production in 2010 compared to the US, which accounted for the largest share of 48% followed by Brazil (22%) and the EU (17%) (BP, 2011).

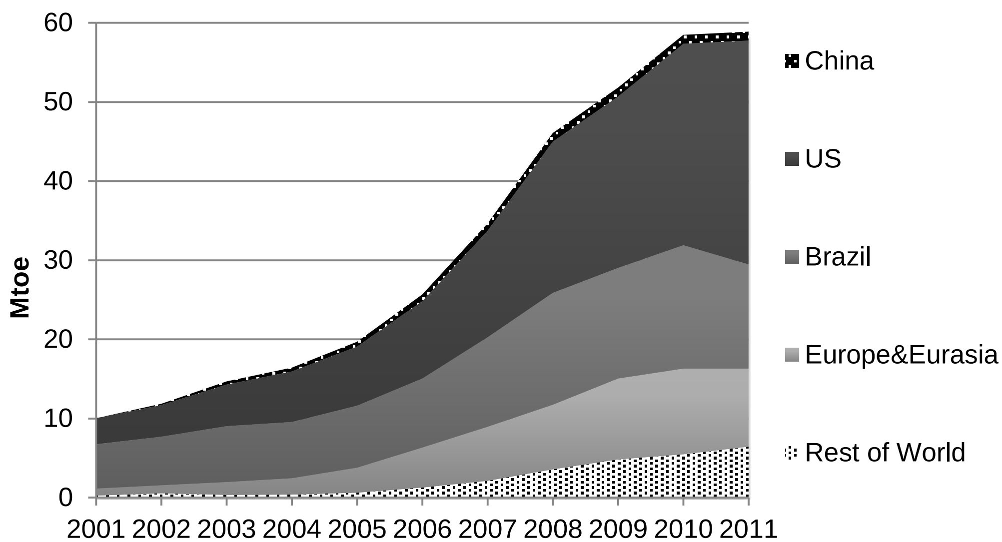

Figure 1.18 Global biofuels production trends, 2001-2011

Data obtained from BP (2012)

1.4.3 Biofuels industry in China

Before October 2012, China only produced conventional biofuels (first-generation) and 70% of total production was corn/wheat-based bioethanol (Chang, Zhao, Timilsina, & Zhang, 2012). There were five government-designated and authorized plants producing bioethanol with a total capacity of about 2.5 billion liters (GL) per year. Four of the five plants use corn/wheat as feedstock to produce bioethanol, accounting for 80% of total bioethanol production in China, while the fifth facility in Guangxi Province uses cassava as the feedstock (Fig. 1.19). These five plants were designated to supply bioethanol for the six provinces of Heilongjiang, Jilin, Liaoning, Henan, Anhui and Guangxi and another 27 cities in Hebei, Shandong, Jiangsu and Hubei provinces with mandatory of E10 blends (NDRC et al., 2004). Quite the opposite, conventional biodiesel production in China was initially carried out by private companies working on a small scale using feedstock, such as used cooking oil (UCO) from restaurants and waste oil from animal fats and vegetables. By the end of 2007, there were 14 private owned biodiesel plants with a combined capacity of 540 million liter per year (ML/yr) (Fig. 1.19). By 2010, the number of private owned biodiesel plants increased to 34 resulting in a total capacity of 5.5 billion liter per year (GL/yr). However, less than 30% of the total capacity was operational in 2010 (Qingdao Institute of Bioenergy and Bioprocess Technology of Chinese Academy of Science [QIBBT], 2010)

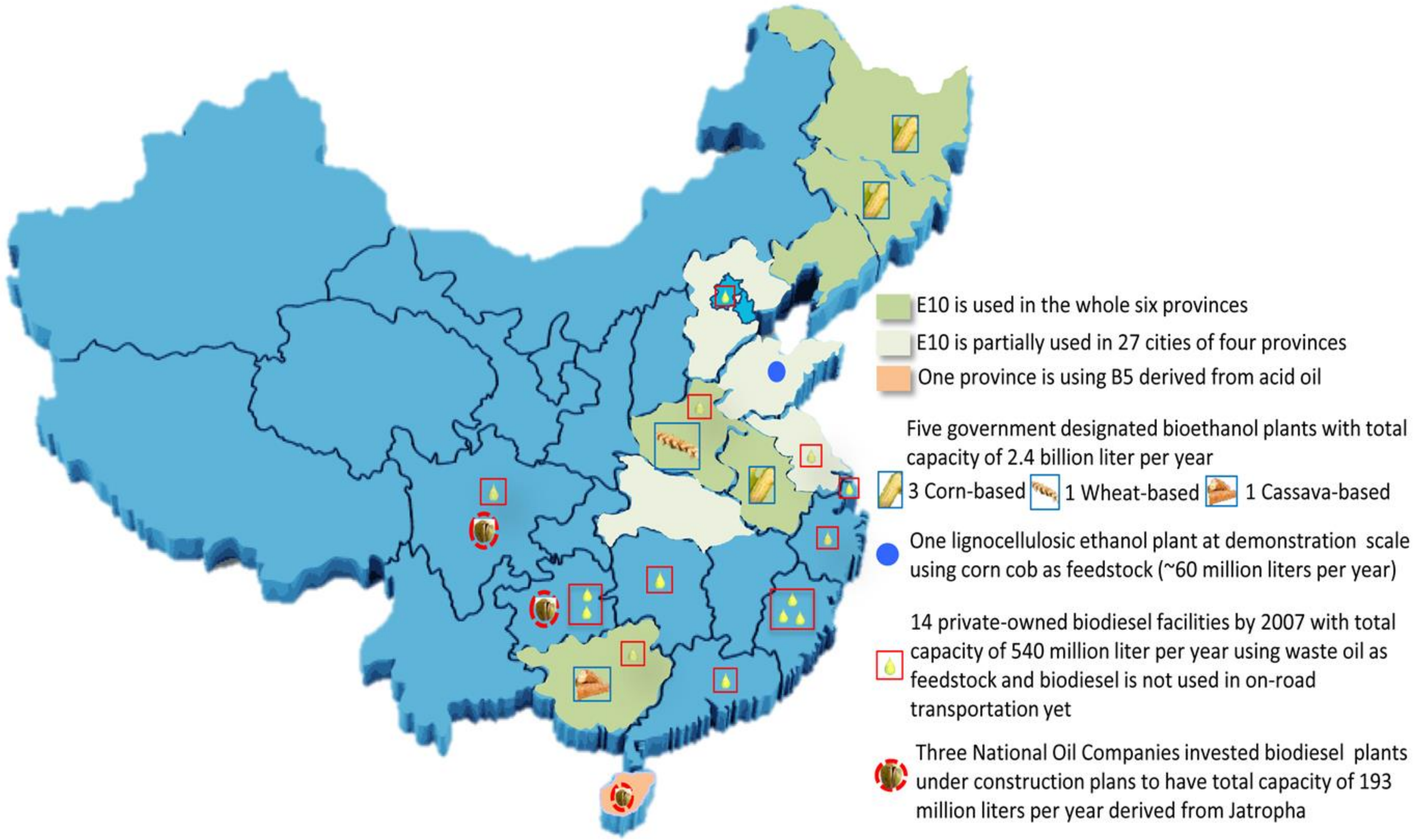

Figure 1.19 Biofuels production facilities and consumption regions in China

Data obtained from Energy Research Institute of NDRC [ERI] (2010), Government of Hainan Province [GovH],(2010),), Longlive (2012a), NDRC et al. (2004)

As mentioned earlier, the production of advanced biofuels in China are at an early stage of development. Currently, there is only one facility producing cellulosic ethanol in Shandong province with a claimed capacity of 60-65 ML/yr, which is the sixth government authorized bioethanol plant in China (Longlive, 2012a). In December 2012, the first order of 3 million liters of cellulosic ethanol derived from corn cobs was delivered to Sinopec (Shandong) Co. from Shandong Longlive Bio-technology Co. Ltd. (Longlive, 2012a).

In 2008, NDRC, which is under the lead of Chinese State Council and in charge of planning and managing China's economic and social development, approved three biodiesel facilities construction projects in Sichuan, Guizhou and Hainan provinces aiming to use Jatropha fruits/seeds as feedstock (Fig. 1.19) (NDRC, n.a.). In 2009, China first implemented a B5 mandate partially in Hainan province, which was expanded to the whole province in 2010 with a capacity of nearly 70 ML/yr (GovH, 2009 & 2010). However, biodiesel used in Hainan is not derived from oil-bearing trees, but from industrial waste lipids because the growth of oil-bearing trees is taking longer than expected (three to five years) to grow and bear fruits (GovH, 2010; Hainan Daily, 2010).

1.5 Scope and objectives of the thesis

1.5.1 Scope

There are many factors that can impact biofuels commercialization, including, but not limited to, market demand, feedstock supply, policy support, conversion technologies, production cost, etc. This study looked at: 1) biofuels market demand in China; 2) feedstock availability for both conventional and advanced biofuels in China; and 3) government biofuels policy support from the Chinese government. These three factors will have a major influence on the future of biofuel development in China. Market demand will be a primary factor in fostering a robust biofuels industry, although government mandates are usually required to initiate the initial use of a product, such as biofuels. A sustainable feedstock supply is another key factor that is needed to ensure effective biofuel production, particularly from a domestic biomass resource. Thus one of the goals of this study is to assess if China already utilized most of its agriculture residues for other uses. Finally, government policy support is a key factor. It will probably play the most important role in biofuels commercialization throughout the whole supply chain, from farmers growing the feedstock crops to end users fueling their vehicles with biofuels.

In this study we have compared biofuels development strategies that have been used in the US and Brazil with how effective these three factors have been in comparison to China. The US and Brazil are the two largest biofuels producers and users in the world and they have developed the largest biofuels markets. Comparing the potential US and Brazilian biofuels markets of 2020 with that of China should provide an interesting perspective on how the biofuels market might develop in China. The US and Brazil are countries that have a similar land size to that of China. Thus the possible feedstocks that could be used for conventional or advanced biofuels could be compared between the three countries. Lastly, all three countries have economies that lead the world's GDP growth. For instance, the US and China are currently the two largest world economies. Meanwhile, China and Brazil are two of the leading emerging economies of the BRICS countries (Brazil, Russia, India, China, and South Africa) (IEA, 2011a). This means that China should have enough financial "clout" to promote biofuels development and show that biofuels are not just an option for only OECD countries. However, China's biofuels industry is far behind that of the US and Brazil and one of the goals of this study was to find out why this is the case and how things might change in the future.

1.5.2 Objectives

The main objectives of this thesis were to try to find answers to the three questions listed below:

1. What volume of bioethanol and biodiesel would China need by 2020 if the whole country uses only E10 and B5 as transportation fuels compared to the government 2020 biofuels mandates?

2. Will China have enough feedstock supply, particularly from agricultural and forestry sectors, for conventional and advanced biofuels production to meet its 2020 biofuels mandates?
3. How does Chinese government policy support biofuels development compared to those policies that the US and Brazil have used to develop their production and use? What future role might biofuels play in China's renewable energy matrix, particularly its transportation fuels needs in the future?

In summary, the main focus of the thesis is to describe the potential role that biofuels might play in China's transportation energy demand by 2020.

2 China's biofuels demand by 2020

The objective of this chapter is to project biofuels demand in China by 2020 and compare it to the Chinese government mandates as well as biofuels mandates and demand in the US and Brazil. An overview of China's transportation fuel consumption growth driven by motorization, and its future increasing demand trends are introduced as the first section. In the second section, biofuels volume demand is calculated on the basis of China's projected market share of gasoline and diesel fuel in the transportation sector by 2020. Finally, the results are compared with the Chinese government biofuels mandates of 2020 and with that of the US and Brazil. It was found that, unlike the US and Brazil, China's biofuels mandates do not correspond to the country's transport fuel demand structure. Although China became the world's largest automobile market due to the rapid growth of passenger cars sales over the last decade, China's ethanol demand by 2020 (14.3 GL), calculated based on the assumptions of this study, is well below that of the US and Brazil. Conversely, China will have a considerable demand for biodiesel (14.5 GL) by 2020 due to diesel fuel remaining the primary transport fuel of the country in the next decade. The role of biofuel mandates in China is different from that of the US and Brazil. The reasons behind this "mismatch" of demand and mandates will be further discussed in Chapter 3.

2.1 Transportation fuel consumption trends in China

2.1.1 World's leading new automotive sales market

The growth in the need for transportation fuels has significantly led China's oil consumption growth over the last two decades. This has resulted in the transportation sector surpassing the industry sector and becoming the largest oil user of the country in 2008 (Fig. 2.1). This rising trend of transportation oil demand is consistent with the booming trend of automobile sales in China during the same time period due to the process of motorization (Fig. 2.2). Over the last decade, the world's largest automobile market shifted from the US to China. In 2009, the Chinese government provided a one-year subsidy of US$960 million dollars as well as a tax reduction ranging from 5% to 10% to stimulate the production and consumption of cars with a small engine capacity (Table 2.1). Consequently, China surpassed the US and became the world's largest automobile market in the same year (Fig. 2.2). Although the average annual growth rate (AAGR) of car sales is projected to ease from 24% during 2005 to 2011 to 8% during 2012 to 2020, the forecast of total annual car sale is still projected to be 22 million units by 2020 compared to less than 1.5 in 2001 and 18.5 in 2011 (Atsmon, Ducarme, Magni, & Wu, 2012).

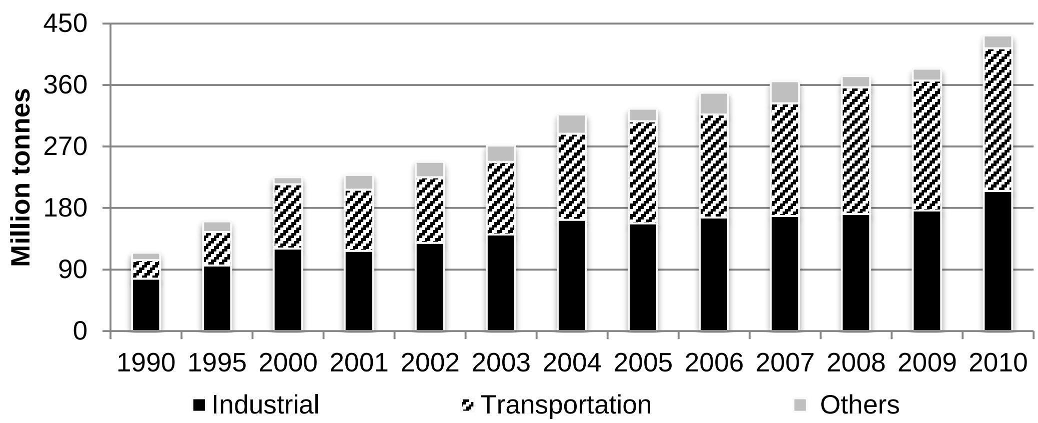

Figure 2.1 Oil consumption in China by sector, 1990-2010
Data obtained from NBS (1996-2002, 2009-2011, 2012a)

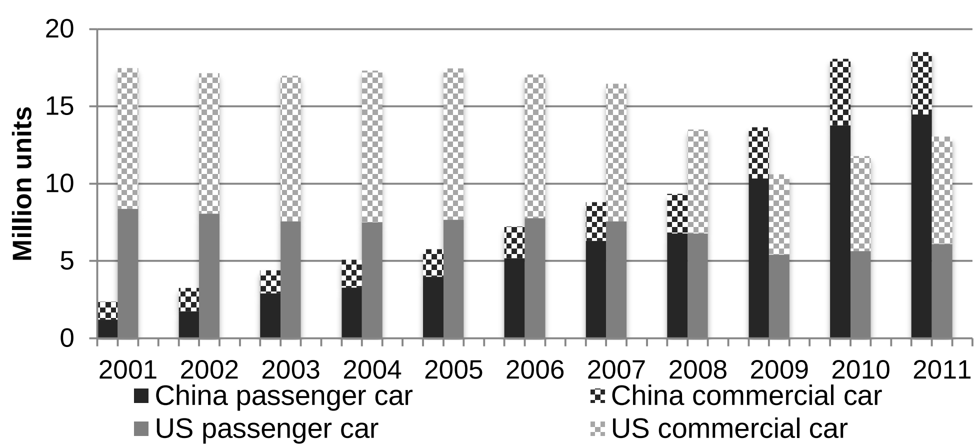

Figure 2.2 Automobile sales comparison between the US and China, 2001-2011
Data obtained from Autohome (2011), CAAM (2012), Shi (2012), WardsAuto (2013)

Table 2.1 China's policies for stimulating automobile sales in 2009[1]

Eligible conditions and policies	Light vehicles[2]	Light trucks[3]	Trade-in
Purchase tax reduced from 5% to 10%	✔	✔	
Total ~US$800[4] million subsidy for rural consumer		✔	
Total ~US$160[4] million subsidy			✔

1. Policy validity period was from 20th Jan to 31st Dec in 2009
2. Light vehicles refer to engine displacement smaller than 1600 cubic centimeters (cc)
3. Light trucks refer to engine displacement smaller than 1300 cc
4. US$ to RMB rate used here is 6.3

Data obtained from SCC (2009)

Over the last ten years, China's vehicle sales grew dramatically mostly driven by passenger car sales, while in comparison, the US market stopped growing in 2001 and it has actually decreased since 2006 (Fig. 2.2). In China, passenger cars refer to vehicles with nine seats or less mostly running on gasoline, such as SUVs and sedans. Commercial vehicles are defined as those used to transport goods or carry more than nine passengers, such as freight cars and buses mostly running on diesel (Wagner, An, & Wang, 2009). According to the IEA's World Energy Outlook (2012), China has greatly increased its ownership of PLDV (passenger light duty vehicles), which mostly running on gasoline. This growth is projected to surpass that of all of the OECD countries by about 2025. With this in mind, the present study assumes that China's biofuels potential, particularly bioethanol demand, could grow very fast as well.

The rapid growth in China's car market has led to severe traffic congestion and air pollution in big cities, such as Beijing and Shanghai. In response, some of the Chinese local governments have implemented regulations to curb car consumption. For instance, one needs to win a lottery to get permission to buy a car license plate in Beijing. A bid for a car license plate in Shanghai recently rose to about $13,000/car license plate ("More Chinese cities consider limiting car consumption", 2013). However, these regulations hardly reduced people's aspiration to own a car, particularly as Chinese people's incomes are increasing. By the end of 2012, China's total vehicle ownership achieved 115 million units (excluding three-wheel cars and low speed trucks), which is projected to increase to 200-230 million units by 2020 and approximately 400 million units by 2030 (Dargay, Gately, & Sommer, 2007; IEA, 2009; "China's motor vehicles top 233 mln", 2012; NBS, 2013). By comparison, the US had 250 million cars on the road in 2010 and Brazil 65 million in the same year (Moreira, 2011; US Department of Transportation [DOT], 2012).

2.1.2 Increasing need for Chinese domestic transportation of goods

Besides passenger car sales resulting in a rising demand for gasoline in the transportation sector, increasing demand for transportation of domestic goods, due to increased domestic consumption is another driving force for transportation fuel demand growth. As discussed in the previous chapter, domestic consumption is expected to drive China's future economic growth in the next decades. This trend will result in increased goods transportation, which will increase demand for diesel as most domestic goods are transported by trucks/lorries that run on diesel fuel. China is projected to lead road freight growth through the next two decades (Fig. 2.3). Besides road transportation, China's aviation fuel demand is projected to expand rapidly as the number of Chinese airplanes in service number is estimated to grow from 1910 units in 2011 to 5890 units in 2031 (Boeing, 2012).

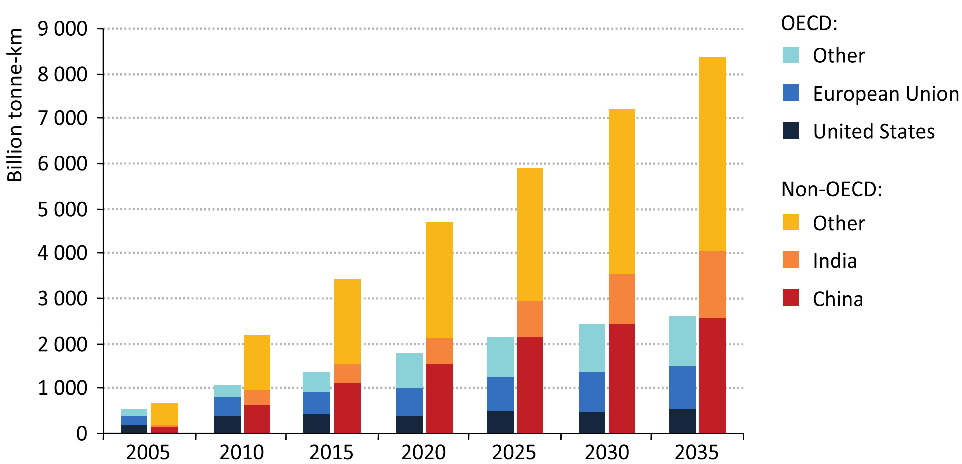

Figure 2.3 Historical and future trends of road freight growth by region, 2005-2035
Source: IEA, 2012

2.2 Biofuels demand in China by 2020

Biofuels consumption and demand are usually reported and projected by authorized institutions, such as BP and IEA in unit of oil equivalent (BP, 2012; IEA 2012). There is no further split for bioethanol and biodiesel especially for future projection by volume in the IEA's report (2012). This section combines historical gasoline and diesel consumption data with IEA's biofuels projection to estimate China's bioethanol and biodiesel volume demand by 2020. Detailed calculation and results will be explained in the following sub-sections.

2.2.1 Methods

Although other fuels, such as coal (for rail transport), liquid natural gas, methanol, DME (dimethyl ether) and electricity, have been used as transportation fuels in China, oil (gasoline and diesel) accounts for nearly 92% of total transportation fuel consumption (IEA, 2012; Wu, 2010). The present thesis assumes that only E10 and B5 blends of biofuels will be used in China's transportation sector by 2020, which results in a scenario of maximal biofuels demand. In order to project bioethanol and biodiesel volume demand for 2020 in China, three parameters need to be defined: 1) total transportation fuel demand for 2020; 2) market share for gasoline and diesel in the same year; and 3) heating values of E10 and B5 per liter. This can be combined in the following equation:

Biofuel volume demand=blending ratio × (energy content ÷ heating value per liter), where energy content=total transportation demand for 2020 × market share

1) Total transportation fuel demand for 2020

The value for total transportation demand in China for 2020 was based on the IEA's *World Energy Outlook (2012)*. Various scenarios are set out in the IEA report (2012), namely the New Policy Scenario (NPS), Current Policies Scenario, 450 Scenario, and Efficient World Scenario. Of these scenarios, NPS is regarded in this study as the best scenario as it represents a balance between conservative and optimistic assumptions.

The NPS considers polices that currently exist and will likely be maintained. It also considers policies that have recently been announced and that will be adopted and implemented by governments. According to the NPS in the IEA Report, China's total energy demand for the transportation sector will increase to 351 Mtoe by 2020 and this projection was used to calculate biofuels demand.

2) Gasoline and diesel fuel market share for 2020

In order to split this total transportation energy demand into E10 and B5, a market share (calculated by energy content) of gasoline and diesel for 2020 estimated based on historical fuel consumption figures of China's transportation sector from 2001 to 2010. In addition, three factors are considered in the estimation of market share for gasoline and diesel for 2020. Firstly, the share of diesel use over the last decade increased steadily, despite the fact that new car sales in China were mainly passenger cars. In addition, the growth rate of new car sales in the current decade is predicted to slow down (Yang, 2013). Secondly, as discussed in the previous section, China will lead road freight growth, mainly due to increasing domestic goods transportation, which will result in a higher diesel demand. Thirdly, more and more provincial governments and coastal cities are implementing regulations to restrict the use of private vehicles, such as Beijing and Shanghai, due to the worsening situations of traffic congestion and air pollution ("More Chinese cities consider limiting car consumption", 2013; Yang, 2013). Thus, growing passenger car sales will not necessarily lead to increased gasoline consumption in the future, compared with diesel. Considering these three factors, the present study assumes that the market share of diesel for 2020 will likely maintain a similar growth rate to the previous decade and increase by about 5% by 2020.

3) Energy content

This study adopts low heating value (LHV) instead of high heating value (HHV) for purposes of calculation. This is because HHV is the amount of heat produced during complete combustion of a unit quantity of fuel when the water vapor is condensed, while

LHV excludes the heating value stored in water vapor (Iowa State University Extension and Outreach [ISUE], 2008). In a car engine, the water vapor is vented to the open air and thus its heating value is not captured. Accordingly, LHV is used for transportation fuel energy content calculation in this study.

2.2.2 Results

2.2.2.1 Gasoline and diesel energy content share by 2020

China has a clear preference for diesel than for gasoline in its road transport fuel consumption, and this trend has been more pronounced over the last decade (IEA, 2009). The share of diesel consumption grew from 59% in 2001 to 65% in 2010 (energy content base) (Fig. 2.4), despite the fact that passenger car sales have, until now, been driving the country's motorization process. At this rate, the present study estimates that the diesel share in China's transportation fuel consumption will grow to 70%, leaving gasoline with an all-time low of 30% (energy content base) by 2020 (Ministry of Commerce [MoC], 2011). These ratios are used in order to calculate biofuels demand (volume base) in the next section.

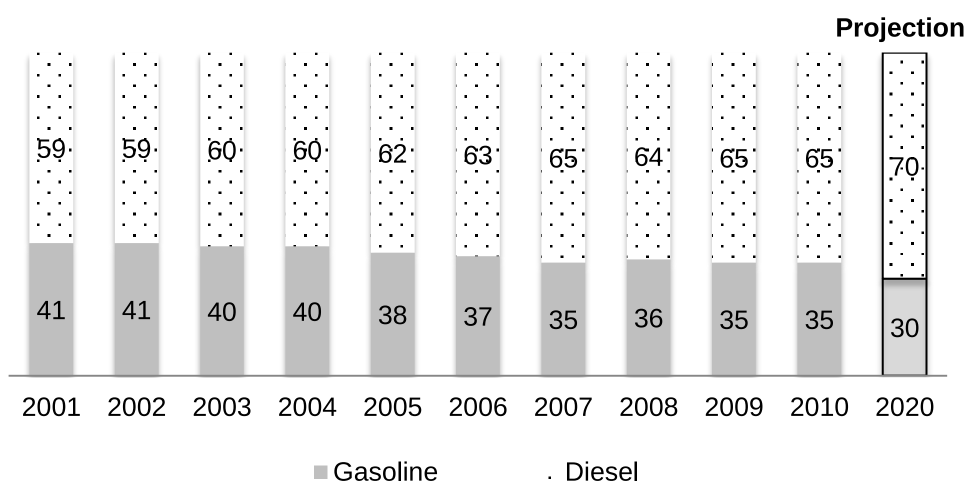

Figure 2.4 Gasoline and diesel consumption percentage in China's transportation sector, 2001-2010, 2020

Note: Calculated in low heating value (LHV)

Data of 2001 to 2010 obtained from NBS (2002-2011, 2012a)

2.2.2.2 Biofuels volume demand by 2020

As mentioned in the methods section, NPS of IEA's report (2012) predicted that China's total transportation energy demand will increase to 351 Mtoe by 2020. Using this figure and the previous estimation of gasoline and diesel market share for 2020 in China, it is calculated that the country may need 105.3 Mtoe for gasoline and 245.7 Mtoe for diesel by the year. Using LHV of E10 and B5 are used as transportation fuels across the whole country that 14.3 GL of bioethanol and 14.5 GL of biodiesel will be needed by 2020 according to the formulas listed below:

1. $\text{Volume demand}_{\text{Bioethanol}}$=Ethanol blending ratio (10%)×$\text{Volume demand}_{E10}$=10%×Gasoline demand (105.3 Mtoe) × 40×10^6 Btu/toe ÷LHV_{E10}=10%×105.3×10^6 toe×40×10^6 Btu/toe÷29439.30 Btu/liter=14.3 GL
2. $\text{Volume demand}_{\text{Biodiesel}}$ =Biodiesel blending ratio (5%) × $\text{Volume demand}_{B5}$=5%×Diesel Demand (245.7Mtoe) ×40×10^6 Btu/toe÷LHV_{B5}=5%×245.7×10^6 toe×40×10^6 Btu/toe÷33849.65 Btu/liter=14.5 GL

Notes:

a. 1 toe=40 million Btu (LHV)

b. LHV_{E10}=0.1 liter×LHV_{Ethanol}+0.9 liter×LHV_{Gasoline} =0.1 liter×19992 Btu/liter+0.9 liter×30489 Btu/liter = 29439.30 Btu/liter

c. LHV_{B5}=0.05 liter×$LHV_{\text{Biodiesel}}$ +0.95 liter×LHV_{Diesel} =0.05 liter×30936 Btu/liter+ 0.95 liter×34003 Btu/liter = 33849.65 Btu/liter

d. 1 metric tonne ethanol=1267.43 liters=334.8 gallon; 1 metric tonnes biodiesel=1136.36 liters=300.2 US gallon

Source: a. BP, 2012; b.& c.:ISUE, 2008

2.3 Biofuel mandates and demand comparison by 2020

Biofuels mandates are typically announced by the official government documents, such as laws or legislations, which define compulsory biofuels consumption requirements for the countries. For instance, the US has developed the RFS2 (Renewable Fuel Standard 2) biofuels mandate to try to annually increase biofuels use through to 2022, which was first established in 2005 and known as RFS (Schnepf & Yacobucci, 2013).

Brazil has mandated a minimum ethanol-blending ratio of 25% and a biodiesel ratio of 5% (Barros, 2012). In China, the government has set a biofuel mandate of consuming 10 million tonnes (Mt) bioethanol and 2 Mt biodiesel by 2020 (NDRC 2007).

Many factors can impact on real biofuel demand, which can be higher or lower than the government mandates. Firstly, if a country has a fixed blending ratio of biofuels, the biofuels demand will depend on total transportation fuel demand. Once the country's transport oil demand remains at a certain level the biofuels demand will stop increasing as well. This is the case in the US due to the "blend wall" of 10% bioethanol blending ration, which is currently limiting expansion of the bioethanol fuel market in the US. Secondly, biofuels might be unattractive to end-users because biofuels have less energy content per liter compared to that of petroleum. In addition, consumers have concerns about using high blend ratio of bioethanol that may be harmful to car engines. Other factors, such as economic performance of a country and petroleum prices, can also influence biofuels real demand of a country.

The present section will assess whether biofuels mandates of China correspond to its transport fuel demand structure and compare it to the US and Brazil by 2020. A recent IEA report (2012) has projected the total biofuels demand of many countries in terms of million tonnes of oil equivalent (Mtoe). The estimated 2020 biofuels demand of the US and Brazil were used in this study.

2.3.1 China's biofuel mandates for 2020

According to the *Medium and Long-Term Development Plan for Renewable Energy in China* (NDRC, 2007), the Chinese government planned to increase total bioethanol consumption of the country from 2 Mt by 2010 to 10 Mt by 2020, and biodiesel total consumption from 0.2 Mt to 2 Mt over the same time. After converting these amounts from weight to volume, the 2020 consumption mandates of biofuels calculates to 12.7 GL of bioethanol and 2.3 GL of biodiesel, which are in agreement with Bacovsky et al.'s (2009) calculation. However, these figures do not line up with the expected biofuel demand figures of 14.3 GL for bioethanol and 14.5 GL for biodiesel as presented in the previous section. The mandate for bioethanol is almost equal to the expected demand, while the biodiesel mandate is six times lower than the expected demand. This is probably due to the fact that the biodiesel industry is not as well established as the bioethanol industry in China. As described in Chapter 1, compared to bioethanol, biodiesel production capacity is very low and only one biodiesel facility is currently producing transportation fuel commercially. In addition, the scarcity of feedstock supply for biodiesel production could be another reason behind the "mismatch" of biodiesel mandates and expected demand by 2020. This and other feedstock supply issues will be further assessed and discussed in the next chapter.

2.3.2 Biofuel mandates and demand in the US

The US RFS2 renewable transportation fuel mandated target for 2020 is 30 billion US gallons (114 GL). This volume includes 15 billion US gallons of corn ethanol (57 GL), 10.5 billion US gallons of cellulosic biofuels (39.9 GL), at least 1 billion US gallons (3.8 GL) of biodiesel and 3.5 billion US gallons (13.3 GL) of other advanced biofuels (Schnepf & Yacobucci, 2013). In the RFS2, cellulosic biofuels refer to not only cellulosic ethanol, but also other biomass-to-liquid fuel, such as cellulosic gasoline or diesel (Schnepf & Yacobucci, 2013).

To estimate the possible US biofuels demand for 2020, the work presented here used IEA's (2012) projection of 39 Mtoe while converting all of it to bioethanol volume (GL) equivalents (energy basis). This is justified on the grounds that bioethanol accounts for over 90% of total biofuels consumption (Schnepf & Yacobucci, 2013). This assumption will also be applied for Brazil's 2020 bioethanol demand calculation in the next section because bioethanol accounts for over 90% of total biofuel use in Brazil as well (Barros, 2012). As noted earlier, the low heating value (LHV) of ethanol is 19,992 Btu/liter, and one tonne of oil is equal to 40 million Btu (LHV). Thus, bioethanol demand for the US as predicted by IEA's report (2012) would be below 78 GL by 2020. This is well below the biofuels mandates for 2020, which is 114 GL in total.

Both Tyner and Viteri's study (2010) and the present study found that the US might hit the blend wall with maximal bioethanol demand of 52.9 GL in 2010, which is lower than the government mandates for 2020. This mismatch can be attributed to three main reasons. First, the US is already a fairly motorized country, thus vehicles ownership in the US is not likely to grow. Thus the real demand for biofuels, particularly bioethanol demand, which depends on existing registered gasoline engine vehicles, will not grow significantly. Secondly, the US has a "blend wall" issue as the 10% blending ratio of ethanol limits the growth of bioethanol consumption. Thirdly, increasing fuel economy standards will result in less transportation fuel demand, which leads to less biofuel demand (Tyner & Viteri, 2010). In 2010, the US has become a net ethanol exporter, which indicates that the country's production capacity has already exceeded its bioethanol demand (IEA, 2013). In addition when the RFS2 was announced in 2007 it projected much healthier economic growth, which did not take place due to the 2008 economic crisis.

2.3.3 Biofuel mandates and demand in Brazil

As mentioned earlier, Brazil has mandated a minimal ethanol-blending ratio of 25% and a biodiesel-blending ratio of 5% (Barros, 2012). The Brazilian government projection of the transportation fuels market is nearly 121 GL of gasoline and 115 GL of diesel by 2020 (Barros, 2012). Thus, Brazil's 2020 bioethanol mandate will be 30.3 GL and the biodiesel mandate will be 5.8 GL.

Bioethanol demand in Brazil is always higher than the government mandate due to the growth of flexible-fuel vehicles (FFVs), which are now widely used in the country (Meyer et al., 2012). Actual ethanol-blending ratios between 2006 and 2011 were between nearly 35% to over 47% (Table 2.2). The government projections for 2012 and 2013 are conservatively set around 35% (Table 2.2). The minimal 25% ethanol-blending mandate was adjusted to 20% in 2011 due to sugarcane harvest reduction and rising sugar prices during that year (IEA 2012). Therefore, this study estimated that the overall bioethanol-blending ratio would range from 35% to 40% by 2020 (Table 2.2). Considering that the government gasoline market projection for 2020 is 121 GL (Barros, 2012), this percentage corresponds to a bioethanol demand of 42.4 GL to 48.4 GL. This calculation is in close agreement with IEA's (2012) 52 GL projection of biofuel demand for Brazil by 2020. It is likely that Brazil can readily achieve this government target of bioethanol use. For example, in 2011 the minimal blending ratio was 20% and the overall ethanol/gasoline-blending ratio in Brazil was over 35% (Table 2.2).

Table 2.2 Overall biofuels blending percentage by volume in Brazil, 2006-2020

	Actual*						Estimation		
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012***	**2013***	**2020**
Ethanol	34.6	40.0	43.8	47.3	42.6	35.2	34.4	35.6	35-40
Biodiesel	0.2	0.9	2.5	3.4	4.8	4.8	4.8	4.8	5*

Note: data with * are obtained from report of Barros (2012).

2.3.4 Role of biofuel mandates in driving biofuel demand

Government mandates are a critical driving force in the development of renewable energy, such as biofuels demand (IEA, 2013). However, in practice, the role of biofuel mandates plays a different role in each country's biofuel demand growth. In the US, the demand driver is policy, namely the RFS2, which is leading biofuels consumption across the country. In Brazil, where blend walls do not limit demand, the price fluctuation of sugar is the most determining factor of biofuel demand in the country. In contrast, in China, bioethanol and biodiesel mandates are adjusted according to the current capacity and are thus not influenced by prices or policy. Unlike the US and Brazil, China's biofuel targets are not binding and they follow the availability of feedstock rather than aiming to achieve biofuel industry growth. As discussed in Chapter 4, the country failed to achieve its 2010 bioethanol mandate of 2.5 GL (NDRC, 2007; SCC, 2012b). China's biodiesel mandate for 2020, in particular, is very low, which contrasts with existing high and increasing demand for diesel fuel in China. The net effect of these trends is that the percentage of biofuel use in the Chinese transport fuel market is likely to drop.

The low level of biofuel mandates in China indicates that biofuels do not appear to be a policy priority in China's energy strategy planning. The reasons for this vary and they include feedstock scarcity, the relatively low contribution of transport to the country's GHG emissions, toughening fuel economy standards and promotion of energy saving vehicles, such as EVs. All of these issues are further discussed in Chapter 4.

2.4 Discussion

China's future transportation fuel trends are being mainly driven by two factors. One is the rapidly growing car ownership, particularly passenger cars, that will likely result in higher gasoline consumption. The second is the increasing amount of inter-China transportation of goods (as the economy is shifting from goods export to domestic consumption) that will likely lead to increased domestic diesel consumption. However, the rate of new car sales in China is slowing from double-digit to single-digit growth while, at the same time, more and more local governments are limiting the use of private vehicles in cities (Yang, 2013). My review of the various trends in China predicts that the market share for diesel will increase from 65% in 2010 to 70% in 2020. This projection differs by about 5% when compared to the official projections of growth by 2020, which is supposed to be 35% for gasoline and 65% for diesel (MoC, 2011).

The work described within the thesis assumed that China's gasoline and diesel fuel will all be replaced by E10 and B5, respectively, and the country will have a similar volume demand for bioethanol (14.3 GL) and biodiesel (14.5 GL) by 2020. However, the Chinese government has set a mandate of using 12.7 GL of bioethanol and 2.3 GL of biodiesel for the same year, which prioritizes bioethanol as the main focus for biofuels development for the country during the current decade. Although gasoline and diesel are the dominant transportation fuels used in China, they are not the only ones. Thus, the projected biofuels volume demand calculated within the thesis might be slightly higher than actual biofuels needs for 2020.

For comparison China's biofuel market to the two biofuels leading countries, we estimated that less than 78 GL of bioethanol would be used in the US by 2020 due to the "blend wall" issue. Thus, as the total biofuels mandate for the country is 114 GL in the same year, of which nearly 4 GL will be provided by biodiesel. The US biofuels mandates are significantly higher than its potential demand. In Brazil, bioethanol demand will likely range between 42 GL and 48 GL, while bioethanol and biodiesel mandates for 2020 are around 30 GL and 6 GL, respectively. Other than expected biodiesel demand, China has a remarkably low biofuels mandate as well as bioethanol demand compared with the two leading biofuels producing and using countries.

There are a number of reasons why China's rapidly growing car ownership will not directly lead to an increase in bioethanol demand to the level of the US or Brazil. Firstly, China has a history of favoring diesel more than gasoline, although passenger car sales are leading the process of motorization. Secondly, as China's motorization started from a much lower fleet base than the US, which is the world's leader in total vehicle ownership, it is unlikely for China to take over the US's position within the current decade. Therefore, gasoline demand in China will not surpass that of the US by 2020. In addition, the blending ratio for bioethanol applied in China is limited at 10% by volume because FFVs are not sold in China. Thus, unlike Brazil, the Chinese government is not in a position to implement a higher blending ratio to increase bioethanol use in the country. What is more, some of the cities in China already have regulations to curb private car use in order to ease traffic congestion and improve air quality ("More Chinese cities consider limiting car consumption", 2013). Last but not least, China is implementing stricter fuel economy standards than the US, (which will be further discussed in Chapter 4), that results in lower projections of total transport fuel demand in China than in the US (An, Earley, & Green-Weiskel, 2013).

With all these above-mentioned factors in mind, it is apparent that the rapid process of motorization in China will not immediately result in soaring bioethanol demand, which is likely to remain low compared to that of the US and Brazil by 2020. However, China does have large demand for biodiesel. In terms of total biofuels volume demand for 2020, these relatively low mandates for biofuels are already ambitious given the scarce feedstock availability in the country including land availability (Novozymes, 2010). This will be further explored in Chapter 3. In summary, by 2020, China will undoubtedly produce and consume much less bioethanol than either the US or Brazil regardless of which of the scenarios of projected demand that are described in the thesis. It is also highly likely that the official biodiesel and bioethanol targets that have been set by Chinese government mandates will not be met.

3 China’s land resources and feedstock availability for biofuels production by 2020

The objective of this chapter is to estimate biofuel feedstock potential supply both from the agriculture sector and the forestry sector in China by 2020. This estimation includes feedstock potential for both conventional and advanced biofuels. It excludes wet biomass, such as livestock manure and municipal wastes, because these are and will be used for biogas production by the Chinese government, particularly in rural areas (NDRC, 2007).

In the first part of the present chapter, challenges of arable land conservation in terms of quality and quantity are discussed. It appears that the biggest challenge for China is that there is insufficient feedstock available for biofuels production due to limited land resources. The process of industrialization and urbanization further exacerbates this land resource scarcity. Knowing these land limitations, a conservative definition of marginal land has been used in the calculations presented in the work here. In the second and the third sections of this chapter, China’s feedstock availability for both conventional and advanced biofuels production, particularly 1.5-generation ethanol, cellulosic ethanol derived from agricultural residues, and biodiesel derived from oil-bearing trees, is estimated. Although the results illustrate that there is sufficient and accessible agricultural residue supply in China for enough cellulosic ethanol production to exceed the 2020 bioethanol mandate/demand (Chapter 2) it can only be realized if the following three conditions are met. The crop yield growth rate remains the same as the past decade. The quantity and quality of arable land is well protected from urbanization and industrialization. The advanced biofuel plants are built.

3.1 Limited land resources

3.1.1 Land size and land resources

China ranks as the world’s fourth largest country in land area with 960 million hectares (mha) compared to the US with 983 mha and Brazil with 851 mha (CIA, 2013). However, unlike the other two countries, China has limited high-yielding arable land and a population that exceeds 1.3 billion people. The land area required for agricultural, industrial and urban uses are limited due to geographical features of the country, such as mountains, plateaus, and hills, which account for 33%, 26% and 10% of total land, respectively (NBS, 2009).

The latest official land resource assessment of China indicates that arable land represents 13% and forests 20% of total land area (NBS, 2009, 2012a; SFA, 2010b). When taking population figures into account, China's per capita arable and forest land are significantly lower than those of the US and Brazil (Table 3.1).

Table 3.1 Land resources comparison among the US, China and Brazil

	US	China	Brazil
Land area (mha)	983 [1]	960 [3]	851 [1]
Population (million)	313.8 [1]	1343.2 [1]	199.3 [1]
Arable land share	18% [1]	13% [1]	7% [1]
Arable land per capita (ha)	0.56	0.091	0.30
Forests share	33% [2]	20% [4]	61% [2]
Forests per capita (ha)	1.04	0.15	2.62

Sources: 1.CIA, 2013; 2. World Bank, 2012b; 3. NBS, 2009, 2012a; 4. SFA, 2010b

3.1.2 Quantity and quality of land resources in China

Land quantity and quality in China is threatened by urbanization and industrialization through competition for land for other uses. For example, shares of arable land, forestry land including forest area and land dedicated to forestry, and grassland areas decreased rapidly during 1998 and 2008, while the other types of land including urban areas and unutilized land increased by 104% from 167 mha to 340 mha during the same decade (Table 3.2).

Table 3.2 Land use change of China, 1999-2008

	Land area (mha)		Percentage change from 1998 to 2008
	1998	**2008**	
Arable land	130.05[1]	121.72[2]	-6.4%
Forestry land	263.30[1]	236.09[3]	-10.3%
Grassland	400.00[1]	261.84[2]	-34.5%
Others*	166.65[1]	340.35[2]	104.2%
Total land area	960[1, 2]		0%

*Others include urban areas, water areas, unutilized land and etc.

Source: 1. NBS, 1999; 2. NBS, 2012a; 3. SFA, 2010b

The urbanization process in China has contributed to land use change, especially arable land, over the last decade. For example, China's agricultural land accounted for 67% of total granted approval land for construction and industrial uses in 2011, and 41% of total was arable land (Ministry of Land and Resource [MLR], 2011). China's urban population increased rapidly from 1995 to 2010 compared to the previous 15 years (Fig. 3.1), which is in line with land use changes shown in Table 3.2. However, the country's urban population percentage did not reach the 50% mark until 2011(NBS, 2011). According to the former Chinese Premier Wen Jiabao's opening speech at the 12th National People's Congress on 5th March 2013, the government will accelerate the urbanization process in medium and small cities/towns in the future (Liu, 2013). This can result in further substantial land use changes around these newly urbanized towns.

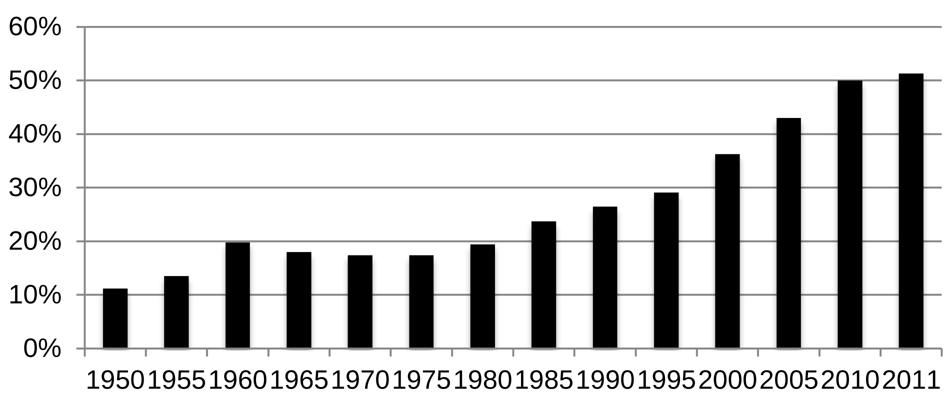

Figure 3.1 Urban population percentage change in China, 1950-2011

Data obtained from NBS (2011)

Despite the decreasing land resource quantity, the quality, particularly of China's arable land, is low and increasingly contaminated by pollution from the industrial sector. The Ministry of Land and Resource of China has classified the total 121.72 mha of arable land in to 15 levels according to the land productivity (level 1 being the highest productivity) (Hu, 2009). According to this classification 57% of the country's arable land is categorized between level 10 and 15 (Hu, 2009). In addition, the compressed industrialization process described in Chapter 1 has further degraded China's land resources. In 2011 alone, 10 mha or 8% of the total arable land was degraded (Hu, 2009).

Arable land is critical to ensure feedstock supply for both conventional and advanced biofuel production. This is even more important to a country's food security, especially in a country like China, which had experienced a food crisis, such as the Great Famine in the early 1960's. Thus, the Chinese government has stressed that the country's arable land area should not drop below the total of 120 mha marked as the "red line" (NDRC, 2006). Considering all the above-mentioned challenges, such as the accelerated process of urbanization and industrialization, it is very difficult for China to develop without dropping its arable land cover below the "red line". The latest arable land area recorded was 121.72 mha as updated in 2008 (NBS, 2012a), and it is very likely that the country's total arable land area has already dropped below the red line due to the arable land reduction over the past decade.

In general, China has an extreme scarcity of arable land in terms of quantity and quality, which is prioritized for food production, while it is likely to further decrease due to the urbanization process and industrialization in the future.

3.1.3 Marginal land for biofuel feedstock plantation

Besides arable land and existing forest area, energy crops/trees growing on marginal land are expected to supply feedstock for biofuel production. The definition of marginal land in China refers to land with poor natural conditions for crop cultivation, which nevertheless has potential to be developed for growing adaptable energy crops/trees (Shi, 2011; Yan, Zhang, Wang, & Hu, 2008). Some researchers, such as Shi (2011), have also included 21 mha of low productivity arable land (level 13-15) and nearly 59 mha of fuel-wood forest, shrubbery and oil-yielding trees as marginal land in their calculations.

In this study, a conservative, more realistic approach was taken in order to calculate marginal land available for biofuel feedstock supply. As such the above-mentioned 21 mha of low productivity arable land, which needs to be improved and used for food production, and the 59 mha of land that will be used for forestry were excluded. The present study assessed the marginal land potential from a total of 245 mha of unutilized land In China. Nearly 74% should not be considered as marginal land because these lands are bare rock/gravel (42%), desert (21%), wetland (5.5%), or raised paths through fields (5.5%) (Hu, 2010). Thus, the remaining 26% of the unutilized land in China is equal to approximately 65 mha, which is the total marginal land for bioenergy/biofuel feedstock production, including 78% of unused grassland, 16% of saline alkali land and 6% of bare soil caused by natural disaster (Hu, 2010).

However, not all of the 65 mha marginal land is suitable for energy crops/trees plantation because the climate, soil and topographic conditions are determining factors as well. Additionally, large contiguous areas are more practical than fragmentary small pieces of land especially for mechanized agricultural operations. As a result, for the calculation of biofuels feedstock availability by 2020, we assumed an arable marginal land availability of between 7 and 9 mha and forest marginal land of between 13 and 36 mha (Chang et al., 2012; ERI, 2010; Li & Chan-Halbrendt, 2009; Qiu et al., 2010; Tao, Yu, & Wu, 2011; SFA, 2013; Shi, 2011; Tian, Zhao, Meng, Sun, & Yan, 2009; Zhang, 2011). These feedstock calculations are also discussed in the remaining sections of this chapter.

3.2 Agricultural feedstock potential for biofuels production

Sugar/starch crops and oil crops are the main feedstock for conventional biofuels production, and primarily agricultural residues, such as corn stover and wheat straw, are used as feedstock for producing advanced biofuels, such as cellulosic ethanol. Although advanced biofuel technologies are not yet economically viable, these feedstocks represent a promising future source of biofuel for China. The objective of this section is to assess the potential availability of three types of feedstock from China's agricultural sector by 2020 including: 1) grain crops growing on arable land; 2) non-grain crops growing on arable marginal land, such as sweet sorghum and cassava, which are called 1.5-generation biofuel feedstock; 3) and agricultural residues. It is found that: 1) China will have little opportunity to expand biofuel production from grain crops because the country is already a net food importer; 2) no substantial capacity of 1.5-generation biofuel has been built; and 3) assuming an agricultural residue availability rate of 15%, China has the potential to produce 29 GL (23 Mt) of cellulosic ethanol by 2020.

3.2.1 Conventional biofuels potential

Conventional biofuels include bioethanol derived from sugarcane, corn and wheat, and biodiesel derived from oil crops, such as rapeseeds, palm, and soybeans, which are also known as first-generation biofuels. Other sugar/starch crops, such as sweet sorghum, cassava, and sweet potato, are considered as non-grain feedstocks for conventional biofuel production as they do not form part of the typical Chinese diet. When grown on marginal land, bioethanol derived from these non-grain crops is considered "1.5-generation" by the Chinese government (NDRC, 2007). Biodiesel derived from trees, such as Jatropha, is also categorized as 1.5-generation because the oil derived from the fruit seed is inedible. Section 3 of this chapter discusses the potential of such forest-derived biofuel feedstock.

The present section aims to evaluate the potential of further expanding conventional biofuels production from both grain crops (corn/wheat) and non-grain crops (cassava/sweet potato/sweet sorghum) in China. As discussed below, neither of these two types of conventional biofuel feedstock can meet the country's 2020 mandates or demand due to food security concerns and lack of substantial progress in growing 1.5-generation biofuel feedstocks.

3.2.1.1 Little potential for first-generation biofuels expansion

China as well as the US and Brazil are the world's leading countries for production of grain/oil crops, which are the most common feedstock for conventional biofuels production. In 2011, China was the world's largest producer of wheat, the second largest corn producer (after the US), and the third largest producer of sugarcane (Table 3.3). However, in the same year, soybean production of Brazil and the US was 5 to 6 times than that of China. In contrast China's rapeseed production was approximately 20 times higher than that of the US while Brazil was not in the top 20 (Food and Agriculture Organization of the United Nations [FAO], 2011). China's total food production increased by 26% from 453 million tonnes (Mt) in 2001 to 571 Mt in 2011, while over the same time the amount of arable land decreased (NBS, 2012a). This is attributed to the fact that the average grain productivity has risen from 4800 kg/ha to 5707 kg/ha over this time period (NBS, 2012a).

Table 3.3 Food production comparison (Mt), 2011

	China		**US**		**Brazil**	
	Production	**Rank**	**Production**	**Rank**	**Production**	**Rank**
Corn	193	2	314	1	56	3
Wheat	117	1	54	4	6	19
Sugarcane	115	3	27	8	734	1
Soybeans	14	5	83	1	75	2
Rapeseed	13	2	0.7	13	NA	

Notes: Food production units are rounded figures. None of the three countries are leading in palm oil production, but Brazil and China ranked the 11th and 13th, while the US was not in the top 20 list in 2011.
Data obtained from FAO (2011)

Nevertheless, this remarkable growth of food production will not be enough to meet a growing demand for food/feed in China. Except in the case of wheat, China is a net importer of all the other sugar/starch and oil crops listed in Table 3.4. Currently, China's corn ethanol conversion rate is 3 tonnes of corn per tonne of ethanol (QIBBT, 2010). Thus, the country would need 30 Mt of corn to meet its 2020 bioethanol mandate (10 Mt), which accounts for 15.5% of total corn production in 2011. However, the Chinese government is slowing down the expansion of non-feed industrial use of corn (Bi & Dobson, 2011).

Table 3.4 Comparison of net export of crops by commodities (Mt), 2010

	Corn	Wheat	Sugar raw centrifugal*	Palm oil	Rapeseed oil	Soybean oil
US	51	25	-2	-0.8	-0.8	1.7
Brazil	11	-5	21	NA	NA	1.6
China	-6	NA	-1.8	-6	-1	-1.3

Data obtained from FAO (2011)

Note: Figures are rounded and "NA" indicates s that the trade amount was not on the top 20 countries of a certain commodity. * Sugar raw centrifugal can be further refined to produce sugar (FAO, n.a.).

Unlike the US, where the largest demand for corn has shifted from feed to ethanol production, nearly 60% of China's total corn consumption is used for feed production due to the increasing demand for red meat especially pork and chicken, with non-feed industrial use accounting for approximately 30% (Gale, Tuan, Wang & Cao, 2009; Bi & Dobson, 2011; Collins & Erickson, 2012). Moreover, it is not corn ethanol production but other products leading the growth of non-feed industrial demand for corn, such as starch sugars, beverage and industrial alcohol (Fig. 3.2). Therefore, corn ethanol has little opportunity to contribute to bioethanol production expansion in China.

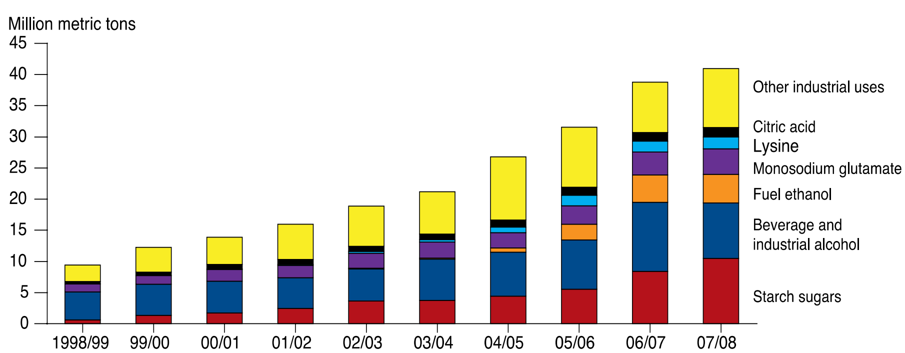

Figure 3.2 Corn consumption trends by non-feed industrial products in China

Source: Gale et al., 2009

Similar to corn, sugar crops and oil crops will be prioritized for sugar and oil production in China because the country's sugar and oil demand is expected to rise as people's incomes increase. For example, Chinese people's average annual sugar consumption is 10.6 kg per capita, which is far below the world average of 24.5 kg per capita (Ministry of Industry and Information Technology of China [MIIT], 2012).

As a populous country with 1.3 billion people, the priority of the Chinese government is to ensure food security. The Chinese government has already restricted first-generation bioethanol production to remain at current levels (2 GL/yr), and prohibited expansion of grain-based bioethanol since 2006 (NDRC, 2007). No biofuels in China are derived from sugar crops or oil crops. It is thus evident that China has very little opportunity to expand first-generation biofuels production. In other words, the country needs to build the capacity for 1.5-generation biofuels and advanced biofuels to make up its 2020 biofuels mandates, which is further discussed in the following sections.

3.2.1.2 Uncertainties of 1.5-generation bioethanol

As mentioned in the previous section, biofuels derived from non-grain crops growing on marginal land are classified as 1.5-generation by the Chinese government. Examples of such crops include cassava, sweet potato and sweet sorghum (NDRC, 2007). These three types of crops cannot grow on all of the 65 mha of marginal land because they require different cultivation conditions, such as temperature, precipitation and soil quality. For example, suitable plantation areas for cassava are mostly found in the south of China, and sweet potato is more suitable for cultivation in the middle and lower regions of the Yangtze River, while suitable regions for sweet sorghum range from north east to north west of China (Li et al., 2009; Qiu et al., 2010; Tao et al., 2011; Tian et al., 2009). In terms of the arable marginal land area potential of the three crops, sweet sorghum has the largest area of 5.1-5.6 mha, followed by sweet potato of 1.6-1.7 mha, and cassava has only about 0.44 mha, which in total ranges from 7.1-7.8 mha (Table 3.5). This range is close to Qiu, Sun, Huang and Rozelle's (2012) estimation for suitable marginal land of 7.0

mha to grow these 1.5-generation crops in China.

Table 3.5 Marginal land potential for 1.5-generation crops (1000 ha)

	NE[2]	N[3]	LP[4]	IMX[5]	MLY[6]	S[7]	SW[8]	Total
CA[1]	/	/	/	/	316	120-124	/	436-440
SP[1]	/	252-285	402	/	697	/	256-321	1607-1705
SS[1]	428-453	252-285	402-879	3662-3696	316	/	/	5060-5629
Total	428-453	504-570	804-1281	3662-3696	1329	120-124	256-321	7103-7774

Notes:

1. CA: Cassava, SP: Sweet potato, SS: Sweet sorghum;
2. NE: Northeast (Heilongjiang, Jilin, Liaoning);
3. N: North (Beijing, Tianjing, Hebei, Henan, Shandong);
4. LP: Loess Plateau area refers to upper and middle reaches of China's Yellow River that mostly in Shanxi and Shannxi provinces and partly in Gansu province, Ningxia Hui Autonomous Region and the Inner Mongolia;
5. IMX: Inner Mongolia & Xinjiang (Inner-Mongolia, Ningxia, Xinjiang);
6. MLY: Middle and lower reaches of Yangtze River (Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan);
7. S: South (Fujian, Guangdong, Guangxi, Hainan);
8. SW: Southwest (Chongqing, Sichuan, Guizhou, Yunnan);

*Some regions in the table are suitable for two types of crops and the area was divided equally, such as N for SP and SS, MLY for CA and SS.

Source: Tian et al., 2009; Qiu et al., 2010; ERI, 2010

However, not all of the potential arable marginal land can be developed into commercial scale plantation base because the land productivity is very low. For example, total potential marginal land area for sweet sorghum cultivation ranges from 16-17 mha (Table 3.5). When considering factors, such as climate, soil quality, topography and land productivity, only 2.8 mha of total potential marginal land area located in Heilongjiang, Inner Mongolia and Shandong provinces is the most suitable for sweet sorghum to grow (Zhang, Xie, Li, Gai, & Qi, 2010). Thus, in the work described below we have postulated three utilization ratios of arable marginal land for each crop: 1) the lowest level of 10%, 2) a moderate level of 30%, and 3) the highest level of 50%, for estimating1.5-generation bioethanol potential in China by 2020.

According to the most conservative scenario (10% utilization rate of suitable marginal land) the 1.5-generation starch/sugar crops could potentially produce nearly 4

GL/yr of bioethanol by 2020. However, the country needs to achieve the moderate scenario of land utilization (30%) in order to meet its projected bioethanol 2020 mandate. However, it is unlikely that 30% utilization will be achieved, considering that both urbanization and industrialization are reducing China's land resources. Therefore, the present study considers that the most practical potential of 1.5-generation bioethanol is 4 GL/yr, of which sweet sorghum contributes the largest share (64% of total production), followed by sweet potato (27%) and cassava (9%) (Table 3.6).

Table 3.6 1.5-generation biofuels potential in China by 2020

	Suitable marginal land potential[a] (mha)	Productivity (wet tonnes/ha) [1]		Conversion rate[2,3] (wet tonnes/ tonne ethanol)	Bioethanol potential in different land utilization scenarios (GL)		
		Current	2020		10%	30%	50%
CA	0.44	19-22[b]	45[c]	7[e]	0.36	1.08	1.80
SP	1.65	20-38[b]	45[c]	9[f]	1.05	3.15	5.25
SS	5.34	60[b,d]	60[b,d]	16[f]	2.54	7.62	12.70
Total	7.43	NA	NA	NA	3.95	11.85	19.75

Notes:

a. Suitable marginal land potential is the mean value of each crop's marginal land potential listed in Table 3.5.

b. Productivity of cassava and sweet potato refer to roots and sweet sorghum refers to stem.

c. With new breeding varieties and intensive cultivation, productivities of cassava and sweet potato can be high, up to 90 wet tonnes/ha and 60 wet tonnes/ha, respectively (Tian et al,. 2009), while a conservative estimation of 45 wet tonnes/ha is used in this study as an average productivity for both crops.

d. Productivity of sweet sorghum is assumed to remain the same as current level, though some new varieties can achieve 80 wet tonnes/ha (Xu, Wang, Jin, & Wu, 2008).

e. Current industrial conversion rates of cassava are assumed to remain at the same level by 2020.

f. Conversion rates of sweet potato and sweet sorghum range from 8-9 and 15-16 wet tonnes/tonne ethanol, respectively (Li & Chan-Halbrendt 2009, Tao et al., 2011). In order to have a relatively conservative calculation, lower conversion rates, which are the higher numbers, are used in this study.

Source: 1. Tian et al., 2009; 2. Li & Chan-Halbrendt, 2009; 3. Tao et al., 2011

Even though the most conservative land utilization ratio is considered as a relatively practical scenario, several uncertainties remain in being able to produce 4 GL/yr, of

1.5-generation ethanol. When reviewing the development process of 1.5-generation biofuels over the last few years it can be observed that, firstly, no commercial scale bioethanol facility is available for sugar crops-based ethanol production yet. Although there were some pilot projects initiated during 2006 and 2007, such as the COFCO (a state owned and the largest food processing manufacturing and trading company) and BP joint venture project in 2007, they were suspended in 2008 (QIBBT, 2010). The Chinese government cannot utilize existing sugar manufacturing plants to create a new sugar crop-based production line due to these facilities being mostly located in the south and southwest of China, such as Guangdong, Guangxi, Yunnan and Hainan provinces. To add to the difficulty the potential marginal land for sweet sorghum production is in the north of China (MIIT, 2012). Secondly, China does not have a sufficient feedstock supply of sweet sorghum at present, because it is not a major crop cultivated in China (Chang et al., 2012). This means that the country needs a period of time to acquire knowledge and skills to grow sweet sorghum, such as breeding and cultivation. Sweet sorghum can be planted only once a year (Qiu et al., 2012). Third, the technologies of deriving ethanol from sweet sorghum are not efficient that takes about 14 days to complete the traditional fermentation process (Li & Chan-Halbrendt, 2009). Fourth, it has been reported that sweet sorghum ethanol production in China requires more energy input and emits more GHG than conventional petroleum fuels, mostly due to consumption of high amounts of fertilizer, resulting in a high environmental impact (Chang et al., 2012; Ou, Zhang, Chang, & Guo, 2009). This overuse of fertilizer is very likely to be the case for all 1.5-generation biofuels feedstock because the marginal land productivity is so low.

Compared to sweet sorghum and sweet potato, cassava has the least potential to contribute to the proposed 1.5-generation bioethanol production expansion. However, the only commercial scale 1.5-generation bioethanol plant is cassava-based and located in Guangxi province (ERI, 2010). In 2007, COFCO built this cassava-based ethanol facility, starting operations in 2008 with an initial annual capacity of 0.25 GL which was more recently increased to 0.5 GL (Chang et al., 2012; ERI, 2010). However, the growth of cassava ethanol production is very limited, because the total potential marginal land for cassava cultivation is less than 0.5 mha (Table 3.6). Even in the high land utilization scenario only 1.8 GL of ethanol could be produced. As for sweet potato, although the bioethanol production potential is higher than that of cassava, it is not currently included in the Chinese government development plan for 1.5-generation biofuel feedstock supply (NDRC, 2007). This means that the potential for sweet potato derived bioethanol (1.05 GL/yr) will be even harder to realize than sweet sorghum or cassava. Therefore, if we exclude this unrealizable sweet potato potential, the total potential for 1.5-generation bioethanol is likely to range from 3 GL/yr to 4 GL/yr.

3.2.2 Agricultural residues potential and cellulosic ethanol capacity

Agricultural and forest residues are likely to be the most commonly used feedstock supply for advanced biofuels production, such as cellulosic ethanol. However, there are few commercial scale facilities operating in the world at present (Stephen et al., 2011; Longlive, 2012a). In this part of the thesis the potential availability of agricultural residues for cellulosic ethanol production in China was assessed. (Forest residues are discussed in the next section). The calculation was based on two assumptions, namely: 1) China's crops yields remain at the same annual average growth rate as was obtained over the last decade; and 2) the cellulosic ethanol conversion technologies are economically viable by 2020. As corn, rice and wheat are the top three agricultural crops in China they will supply the majority of agricultural residues that could feed a potential biomass-to-biofuel process. A provincial distribution map of 2011 (Fig 3.3) displaying the combined agricultural residues from these three crops, is included to illustrate the most likely regions that could build new capacity for cellulosic ethanol in the future. The challenges for realizing this potential are presented in the discussion (section 3.2.3).

3.2.2.1 Residues availability and bioethanol potential by 2020

1) Agricultural residues potential

The major crops cultivated in China include corn, rice, wheat, legumes, tubers and oil crops (mainly peanuts, rapeseed, sesame), cotton, sugar crops (sugarcane and sugar beet), and bast-fiber crops (NBS, 2012a). The country's total crop yield increased by 28% from nearly 574 Mt in 2001 to over 736 Mt in 2011, while the annual average growth rate (AAGR) of each crop yield varies from 5.39% for corn to nearly -8% for bast-fiber crops (see Table 3.7) (NBS, 2011). The present study projects that China's total crop yield can reach 936 Mt by 2020 using the equations listed below, of which equation a) and b) are for projecting major crop production, and equation c) is for estimating residue yield of each crop for 2020:

a) $AAGR_x = \left(\sqrt[10]{\text{Actual production}_{2011} \div \text{Actual production}_{2001}} - 1\right) \times 100\%$

b) $2020\ Production\ Estimation_x = (AAGR_x + 1)^{10} \times 2010\ \text{Actual production}_x$

c) $2020\ Residues_x = 2020\ Production\ Estimation_x \times (R/C)_x$

Note: x refers to each individual crop; R/C refers to residue to crop ratio

It should be noted that the R/C ratios of the major cultivated crops are different from each other, and even one single crop has different R/C ratios, such as rice, corn and wheat. As these three crops rank as the top three crops in terms of total yield, the present study specifically assesses and adjusts the R/C ratios of these three crops according to a series of peer reviewed papers (Bi, Wang, Wang, Gao, & Wang, 2011; Shi, 2011; Xie, Wang, & Ren, 2010; Chen, Xing, & Han, 2009; Zhang et al., 2009). For example, the R/C ratio of early rice is 0.68 (planted in February to April), whereas the R/C ratio of intermediate-late rice (planted in March to June) is 1.0 (Bi et al., 2011). In 2009, an average R/C ratio of rice was 0.945 according to China's cultivation volume of different types of rice, and the present study adopts this R/C ratio for rice residues calculation (Bi et al., 2011). The R/C ratio of corn varies from 1.2 to 2 depending on whether or not corncob is included (US Department of Energy [DOE], 2011; Shi, 2011; Xie et al., 2010). In view of the fact that corncob is now used as a feedstock for ethanol production in the first cellulosic ethanol plant in Shandong province, the present study uses 2 as the R/C ratio for corn residues calculation. R/C ratio of wheat ranges from 0.73 to 1.4, and the most adopted ratio in literature is 1.1, which is adopted in the present study (Chen et al., 2009; Xie et al., 2010; Zhang et al., 2009). The R/C ratios of the other major crops are relatively consistent according to the study of Chen et al. (2009), Xie et al. (2010), and Zhang et al. (2009), which are adopted in the present study for calculation (Table 3.7).

Based on the above-mentioned R/C ratios of major crops and the actual 2010 crop yield, it was calculated that the equivalent agricultural residues yield was about 875 million dry tonnes for the year, which is close to 2010 actual agricultural residues yield of 840 million dry tonnes (NDRC, 2011). This suggests that the R/C ratios used in the present study are relatively accurate. By applying the previous mentioned calculation methods, it is projected that China may have nearly 1150 million dry tonnes of agricultural residues by 2020, of which corn, rice and wheat have the largest share accounting for 52%, 18% and 14% of total residues yields, respectively (Table 3.7).

Table 3.7 China's agricultural residues potential production by 2020 (Mt)

	Actual production			AAGR	Crops production	R/C**	Residues production	
	2001[1]	2010[1]	2011[2]	(2001-2011)	2020		2010	2020
Grain	**452.6**	**546.5**	**571.2**		**717.5**		**762.8**	**1017.7**
Rice	177.6	195.8	201.0	1.25%	221.5	0.945	189.9	209.3
Wheat	93.9	115.2	117.4	2.26%	144.0	1.1	129.1	158.4
Corn	114.1	177.2	192.8	5.39%	299.5	2.0	385.6	599.0
Legumes	20.5	19.0	19.1	-0.71%	17.7	1.55	29.5	27.4
Tuber crops*	35.6	31.1	32.7	-0.85%	28.6	0.5	16.4	14.3
Others*	10.9	8.2	8.2	-2.81%	6.2	1.50	12.3	9.3
Non-grain	**121.2**	**158.7**	**165.1**		**218.5**		**111.5**	**131.9**
Oil crops*	28.6	32.3	33.1	1.47%	37.4	2.0	66.2	74.8
Cotton	5.3	6.0	6.6	2.22%	7.4	3.0	19.8	22.2
Bast-fiber crops	0.7	0.3	0.3	-7.99%	0.1	1.8	0.5	0.2
Sugar crops*	86.6	120.1	125.2	3.75%	173.5	0.2	25.0	34.7
Total	**573.8**	**705.2**	**736.3**		**936**		**874.3**	**1149.6**

Notes: *Tuber crops refer to sweet potato and potato; others include millet and grain sorghum; oil crops include peanuts, rapeseed and sesame; sugar crops include sugarcane and sweet beet; **R/C ratio refers to dry tonne residues per tonne crop

Source: 1. NBS 2007; 2. NBS, 2012

2) Cellulosic ethanol potential from agricultural residues

In China, particularly in rural areas, agricultural residues have been mostly combusted as fuel, with some used as feed, while a small amount was left in the fields as fertilizer. About 15% to 30% of the residues are wasted ("Discarded or directly burned" in Table 3.8).

Table 3.8 Agricultural residues utilization in China and its ethanol potential by 2020

	Sources				Harvest rate (Million dry tonne & Ethanol potential (GL ethanol)		
	1	**2**	**3**	**4**	**15%**	**30%**	**60%**
Fuel in rural areas	40%	28%	21%	45%			
Feed	27%	26%	20%	20%	172	345	690
Left in the field	15%	16%	36%	15%	&	&	&
Discarded or directly burned	15%	28%	20%	16%	29	58	116
Industrial use	3%	2%	3%	4%			

Note: The conversion rate of deriving ethanol from agricultural resides ranges from 4 to 7.5 dry tonnes per tonne ethanol according to literature of Chinese researches and government report (Tao J. et al. 2011; ERI, 2010), while IEA's report (Sim R. et al. 2008) has a conversion rate ranging from 5-12 dry tonnes per tonne ethanol. This study used the rate of 7.5 dry tonne per tonne ethanol for calculation (one tonne ethanol =1267.43 liters).
Source: 1. Zhang et al., 2009; 2. ERI, 2010; 3. Tian, 2010; 4. Shi, 2011

In Wang, Yang, Steinberger, Liu, Liao and Xie's (2013) research, 42% of total crop residues can be potentially available for biofuels production, which includes 26% of residues burned in fields or wasted and 16% of residues directly burned as fuel. The present study estimates that agricultural residues harvest ratio for cellulosic ethanol production ranges from 15-60% by 2020. It combines agricultural residues share of both "Fuel in rural areas" and "Discarded or directly burned" in Table 3.8. Given that China is in an accelerated process of urbanization, agricultural residues consumed as fuel in rural areas are potentially available for ethanol products, as modernization will utilize alternative energy sources, such as natural gas and renewable power. However, this percentage range is further classified into three levels of 15%, 30% and 60%. According to the most conservative scenario (15%), it is projected that China can potentially produce 29 GL/yr of cellulosic ethanol from agricultural residues by 2020 (Table 3.8), which is sufficient to meet the government 2020 bioethanol mandate (12.7 GL/yr). If the crops residues yield remain at 2010 values, 22 GL of cellulosic ethanol could be produced from 15% of the available crop residues.

3) Comparison of the amounts and types of agricultural residues available in China and the US

In the US, corn stover (stalk and leaves), followed by residues of other major grains including wheat, barley, oats and sorghum have the largest potential for agricultural residues supply. It is reported that the US has total potential of 915 million dry tonnes feedstock supply from forestry biomass, agriculture residues, with an annual average growth rate (AAGR) of 2%, and energy crops, with an AAGR of 4%, for bioenergy and bioproducts production by 2022 (feedstock cost of $60 per dry short ton), excluding biomass that is already utilized (DOE, 2011). Corn stover has the largest share accounting for 77% of total 275 million dry tonnes agricultural residues, compared to China, which has 127 million dry tonnes available in the most conservative scenario.

The calculation methods of DOE's projection are different from the present study for China. For example, the US calculated the corn stover sustainable retention coefficient at county levels that ranges from 0 to 1, while the present study adopted 0.15 as an average ratio of residues left in the field and used as fertilizer (DOE, 2011). In addition, the R/C ratio for corn is 1 in the DOE's calculation, as corncobs are not considered as a feedstock, while the present study used 2 for R/C ratio of corn residue calculation (DOE, 2011). Corn's annual average growth rate in China is over 5%, while the US is only 2%. Moreover, feedstock cost is not considered as a key parameter for agricultural residues availability in the calculations used in the present study. Therefore, the projections described in the present study have used the most conservative scenario in order to have a very basic estimation of agricultural residues availability compared to the US DOE's methods for calculation.

3.2.2.2 Residues distribution and cellulosic ethanol plants in China

In China, corn, rice and wheat are the three main crops with the largest shares of feedstock supply for advanced biofuels production. The distribution of combined total residues yield of 2011 is presented in Fig. 3.3. It indicates that Heilongjiang, Henan and Shandong are the top three provinces that account for 11%, 10% and 9% of the total combined residues yield, respectively, followed by Jilin and Hebei provinces (NBS, 2011). Heilongjiang is the largest province for corn residues and the second largest for rice residues. Henan province alone accounted for nearly one third of the country’s total wheat residues yield. Shandong is the second province for wheat residues and the third largest for corn residues (NBS, 2011). These three provinces are the most likely to build new facilities for cellulosic ethanol, particularly Heilongjiang. However, Heilongjiang province is located in the far north east of China and therefore fuel ethanol delivery can be an issue, as the greatest demand areas for transportation fuel is in the east coastal areas of the country.

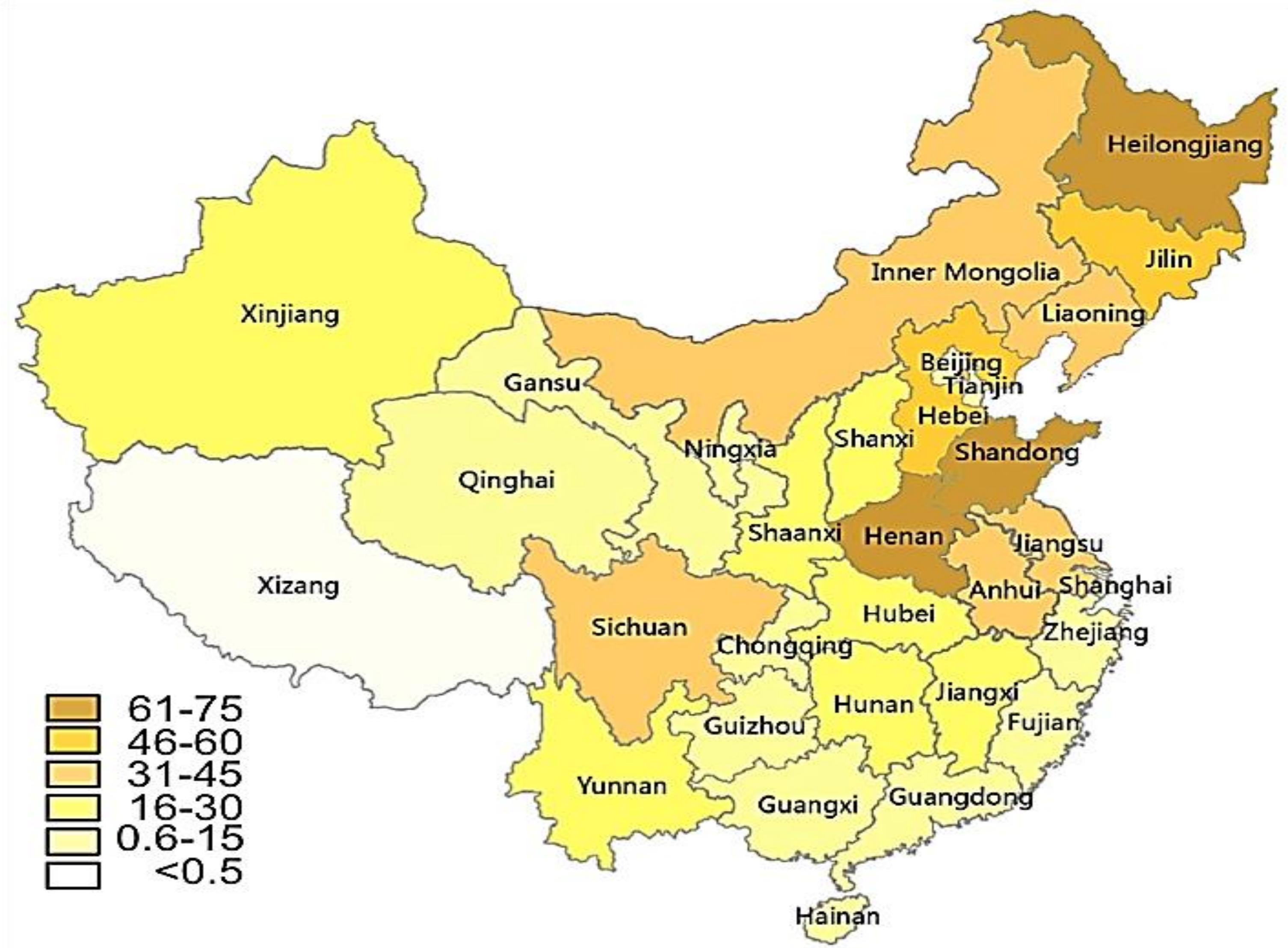

Figure 3.3 Total residues distribution of corn, rice and wheat in China, 2011 (million dry tonnes)

Data obtained and consolidated from NBS (2011)

Compared to Heilongjiang province, Henan and Shandong provinces have advantages in terms of delivering cellulosic ethanol to southeastern coastal areas of China. The Chinese government authorized the first commercial scale cellulosic ethanol facility in Shandong province called Shandong Longlive Bio-technology Co. Ltd. It has delivered the very first order of 3 ML of advanced bioethanol to local gasoline stations in August 2012, and the company claims to have an annual capacity of over 63 ML in 2013 (Longlive, 2012a, 2012b). In fact, the main business scope of Longlive is not only for cellulosic ethanol production, but corn-based bioproducts production, including starch sugar, xylitol, and lignin (Table 4.2). However, the company's ethanol production line may not be integrated with other bioproducts', which means it will not be a true biorefinery. Creating a new production line in this kind of corn-based products company could reduce costs by sharing existing infrastructures and making use of existing logistics and distribution. This could be a short-to-medium term strategy to expand advanced biofuels capacity in China.

In contrast, pilot scale facilities of cellulosic ethanol built during 2005 and 2009 have not been further scaled up. It has been estimated that they have annual capacities varying from 0.4 ML to 12.7 ML, mainly using corn stover as feedstock. The facilities are based at either state owned research institutes or universities (Table 3.9). It is reported that COFCO Zhao Dong scaled up its pilot project of cellulosic ethanol in 2011, and it aimed to launch in 2013 with a capacity of 63 ML/yr (50,000 tonnes per year), although no progress updates have been reported for some time (Lane, 2013). COFCO Zhao Dong Co. and Tianguan Croup are two of the four authorized conventional bioethanol plants, which have similar advantages to Longlive Bio-technology Co. Ltd. with the potential of "piggy-backing" cellulosic ethanol production using corn residues as feedstock.

Table 3.9 Pilot scale facilities for cellulosic ethanol production in China

Industries	Research Institutes/ Universities	Feedstock types	Capacity (ML/ year)	Location	Built year
COFCO Zhao Dong Co.	NA	Corn stover	0.4	Heilongjiang	2006
NA	Energy & Chemical Department of East China University of Science and Technology	Agricultural and forest residues	0.8	Shanghai	2005
Zedong Biotech Co.	Institute of Process Engineering of China Academy of Science	Corn stover	3.8	Shandong	2006
Tianguan Group	Shandong University & Henan Agricultural University	Corn stover	12.7	Henan	2009

Source: QIBBT, 2010; Hu, 2011

3.3 Forestry feedstock potential for biofuels production

In 2008, China already had 29 facilities using forest residues as well as agricultural residues to generate power through direct combustion with a total installed capacity of 618,000 kW (ERI, 2010). According to the recently announced *National Forestry Biomass Energy Development Plan (2011-2020)*, China's forest residues will continue to be utilized for bioenergy (heat and power) production instead of advanced biofuels production. Several oil-bearing trees have been identified as a potential feedstock for biodiesel production (SFA, 2013). The plan has targets of utilizing 22 Mtce of woody biomass (45 million tonnes biomass), including forest residues, for bioenergy generation and using the "fruit" of oil-bearing trees to produce 5.8 Mtce (5.2 GL) of biodiesel by 2020 (SFA, 2013). The State Forestry Administration of China has identified 4.22 mha of suitable land to grow oil bearing-trees, of which 34% of the land area is for *Jatropha curcas L.* plantations, followed by *Xanthocerus sorbifolia Bunge* (shinyleaf yellowhorn) with a share of 23% and *Pistacia chinensis* (Chinese Pistache) of 21%, the rest land area is for *Vericia fordii* (tung oil tree), *Cornus wilsoniana*, and *Sapium sebiferum (L.) Roxb* (Chinese tallow tree) (SFA, 2013).

The objectives of this part of the thesis was to assess the possibility of achieving the targets of the *National Forestry Biomass Energy Development Plan (2011-2020)* by 2020 by: 1) estimating forest residues availability and the potential for cellulosic ethanol production as well as, 2) assessing the potential of deriving biodiesel from oil-bearing trees, such as Jatropha, shinyleaf yellowhorn and Chinese Pistache. Although forest residues are unlikely to be used for advanced biofuels production, the present study calculates the theoretical cellulosic ethanol production potential of forest residues. By comparing the cellulosic ethanol potential of forest residues with the potential from agricultural residues, it gives an idea which sector is larger in terms of biofuels feedstock supply in China.

3.3.1 Forest residues potential in China

Forest residues in China include wood processing residues, logging residues, and thinning residues from shrub forest (Shi, 2011; Tian, 2010). Thinning residues are excluded from the calculation of this study due to the difficulty of recovering the fiber and its unreliable nature annual supply (Tian, 2010). Forestry residues from wood processing and logging are calculated according to: 1) residues to wood ratios (R/W); 2) availability rates; and 3) conversion to dry matter. The detailed calculation method is shown in Table 3.10, together with a theoretical cellulosic ethanol production projection in order to give a general idea of how much biofuels could be derived if these forest residues were used as feedstock for advance biofuels production.

3.3.1.1 Forest residues from wood processing

Wood processing residues as calculated in the present study, include residues from processing of both domestic and imported logs. According to domestic log production and imported log volumes during 2002 and 2011, it is estimated that total log volume can increase to 166 million m^3 by 2020, 70% of which can originate from domestic supply (Fig. 3.4).

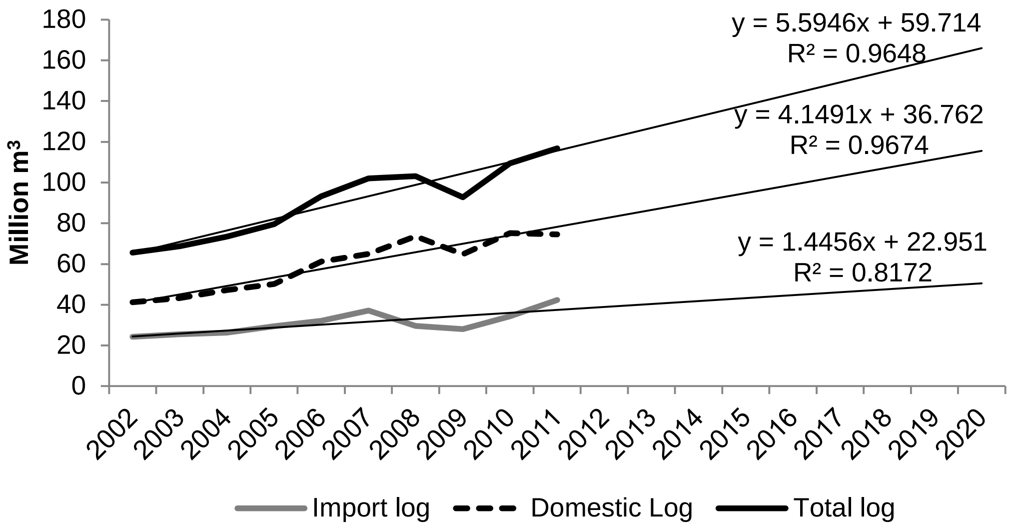

Figure 3.4 Projection of China's total log supply by 2020

Note:

1. In the linear equations: x_{2002}=1, x_{2020}=19

2. Actual production of 2002 to 2011 obtained from SFA (2004-2009, 2010a, 2011a, 2012)

3.3.1.2 Forest residues from logging

The estimation of China's logging residues is based on annual logging quotas of the government for every five-year plan (FYP). The logging quota was 250 million m^3 for the 11th FYP (2006-2010) and it increased by 8.4% to 271 million m^3 for the 12th FYP (2011-2015) (NDRC, 2012; Tian, 2010). As the 13th FYP (2016-2020) has not been announced yet, the present study assumes that the growth rate will remain the same (8.4%), resulting in an annual logging quota of 294 million m^3 by 2020.

3.3.1.3 Total forest residues potential in China by 2020

Both processing and logging residues are converted from volume to weight (dry matter) and the available ratios for renewable energy use are listed in Table 3.10. It shows that China may have nearly 22 million dry tonnes of forest residues by 2020, with logging residues accounting for 60% of the total amount. This amount of forest residues can be theoretically converted to 2.7-6.5 GL of cellulosic ethanol (Table 3.10), which is much less than the potential of the agricultural residues in the most conservative scenario (29 GL/yr). Projections in the present study for China's total available forest residues accounts for only 25%-30% of that of the DOE (2011) estimated that the US would have a total 74-90 million dry tonnes of forestry biomass and wood waste by 2022, of which 41-45 million dry tonnes are residues from logging and wood processing.

Table 3.10 Projection of forest residues and its potential for ethanol production in China by 2020

	Fresh forest residues (Million tonne)[1]	Available rate for bioenergy[a]	Residues for bioenergy (Million dry tonne[2])	Conversion rate[b] (liter/dry tonne)	Ethanol potential (GL/year)
Processing residues	57	30%	8.6	125-300	1.1-2.6
Logging residues	129	20%	12.9		1.6-3.9
Total	186	NA	21.5		2.7-6.5

Notes:

1. Processing residues=Est. log amount 2020 (166 million m^3) X R/W ratio[a] (0.344 tonne/m^3); Logging residues=Est. log quota 2020 (294 million m^3) X R/W ratio[a] (0.44 tonne/m^3)
2. Moisture content is assumed as 50%[b]

Source: a. Tian, 2010; b. Sims et al., 2008

The *National Forestry Biomass Energy Development Plan (2011-2020)* of China allocated 9.43 mha of forestland for energy trees plantation in order to supply 45 Mt of forest biomass for bioenergy production by 2020, of which half of the land area would be new plantations (SFA, 2013). According to the SFA's (2013) energy conversion ratio of utilizing forest biomass, each dry tonne of forest biomass can generate 0.5 Mtce of energy. As the present study projects that 21.5 Mt of wood processing and logging residues could replace 10.5 Mtce of energy in heat and power generation, this could account for nearly half of the government's 2020 target.

3.3.2 Biodiesel potential from oil-bearing trees

The *National Forestry Biomass Energy Development Plan (2011-2020)*, identified six oil-bearing trees as potential biodiesel feedstock including (1) *Jatropha curcas L.*, (2) *Xanthocerus sorbifolia Bunge* (shinyleaf yellowhorn), (3) *Pistacia chinensis* (Chinese pistache), (4) *Vericia fordii* (tung oil tree), (5) *Sapium sebiferum (L.) Roxb.* (Chinese tallow tree), and (6) *Cornus wilsoniana* (SFA, 2011b, 2013). As mentioned previously, it was proposed that 78% of total designated land area would be for the plantation of Jatropha, shinyleaf yellowhorn and Chinese pistache. For example, the SFA proposed several potential regions to build demonstration plantations for these three oil-bearing trees, namely 1) Chifeng in Inner Mongolia province for shinyleaf yellowhorn, 2) Three Gate Gorges area in Henan province for Chinese pistache, and 3) Chuxiong in Yunnan province for Jatropha (Du, 2010). In the work described below we looked at the potential of three of these trees for biodiesel production.

According to the SFA plan, 4.22 mha of land could be used to plant oil-bearing trees and they were targeted to produce 5.2 GL biodiesel by 2020. In other peer-reviewed literature the total potential marginal land area for these three oil-bearing trees ranged from 13 mha to 36 mha (Chang et al., 2012; ERI, 2010; SFA, 2013; Shi, 2011; Zhang, 2011). As this range is quite wide, different projections for biodiesel potential in the three different scenarios of land utilization ratios are shown in Table 3.11. The most conservative scenario could result in the production of 2.45 GL/yr to 6.74 GL/yr of biodiesel by 2020 (Table 3.11). Unlike the government plan, which projected that Jatropha would have the largest share of biodiesel production, the present study indicated that Chinese pistache would likely account for over 60% of total potential biodiesel production. This is because more than 40% of the potential land area is suitable for Chinese pistache plantation followed by shinyleaf yellowhorn, while Jatropha had the least land area share of only 5% (Chang et al., 2012).

Table 3.11 Biodiesel potential derived from major oil-bearing trees in China by 2020

Oil-bearing trees	Marginal land potential[1,2,3] (mha)	Est. 2020 fruit productivity[3] (tonnes/ha)	Biodiesel projection in different scenarios of land utilization ratios (GL/yr)		
			10%	30%	50%
Jatropha	0.65-1.80	5[a]	0.12-0.34	0.36-1.02	0.60-1.70
Xanthocerus sorbifolia	6.89-19.08	3[b]	0.79-2.15	2.37-6.45	3.95-10.75
Pistacia chinensis	5.46-15.12	7.5[c]	1.54-4.25	4.62-12.75	7.70-21.25
Total	**13-36**		**2.45-6.74**	**7.35-20.22**	**12.25-33.70**

Notes:

a. Jatropha's current productivities are1.5-3 tonnes/ha in then southwest and 6-9 tonnes/ha in the south so that the average productivity is assumed as 5 tonnes/ha by 2020.

b. *Xanthoceras sorbifolia*'s productivity ranges from 1.5-5 tonnes/ha currently and assumes that the average can achieve 3 tonnes/ha by 2020.

c. *Chinese pistache*'s productivity is assumed to remain at current levels of 7.5 tonnes/ha by 2020.

d. A conversion rate of 375 liter/tonne fruit is used for calculation for all the three trees, as the oil content is similar to each other (between 30% and 45%).

Source: 1. ERI, 2010; 2. Shi, 2011; 3. Chang et al., 2012

Although the Chinese government prioritized Jatropha in terms of biodiesel feedstock plantations, the development of biodiesel has not been as rapid as was hoped. For example, although the Chinese government authorized the first three Jatropha-based biodiesel plants in the south and south west of China, two of them are still under construction. The one plant in operation is not using Jatropha fruit seeds but industrial waste oil as the feedstock (GovH, 2010). Thus, it may take longer than the government planned to achieve the target of deriving 5.2 GL biodiesel from oil-bearing trees (Huang, 2012). And China is very likely to miss its biodiesel mandate for 2020 (2.3 GL/yr).

3.4 Discussion

As mentioned earlier, although China has the world's fourth largest land area, a considerable proportion of the country consists of mountains and deserts, which are not particularly suitable for cultivating crops. As a net food importer with a population of 1.3 billion, there is little scope for China to expand first generation biofuels production. This is because grain crops are prioritized to meet the growing demand for food/feed, sugar, and edible oil, especially when people's incomes are rapidly increasing. In fact, the Chinese government announced no further expansion of food-based biofuels in 2007.

The present study projected that non-grain feedstoks, such as cassava, sweet sorghum and sweet potato, can potentially produce nearly 4 GL of 1.5-generation bioethanol. Oil-bearing trees, mostly from Jatropha, Chinese pistache and shinylead yellowhorn, could produce 2.5-6.7 GL of biodiesel by 2020 if 10% of the potential arable and forest marginal land can be utilized. In comparison, the government recently announced the intention to derive 5.2 GL of biodiesel from oil-bearing trees by 2020 (SFA, 2013).

However, two key challenges make the realization of the 1.5-generation biofuels targets problematic. Firstly, barely any progress has been made in the establishment of feedstock plantations for 1.5-generation biofuels. Although the Chinese government has goal of establishing large-scale plantation projects for oil-bearing trees, stronger policies are required to confront the challenge of growing energy crops/trees on marginal land and resulting in low productivity. Secondly, other than two plants (a cassava-ethanol plant, with a capacity of 0.5 GL/yr which was built in 2008, and a biodiesel facility with a capacity of less than 70 ML/yr built in 2009, which uses industrial waste oil instead of oil-bearing trees), no other 1.5-generation biofuels plant has been built. Therefore, the combination of insufficient feedstock and conversion facilities are two key issues that will limit China's development of 1.5-generation biofuels.

In general, conventional biofuels, both first-generation and 1.5-generation biofuels, are not a suitable strategy for China to increase its biofuels production. However, China may have sufficient agricultural residues and forest residues for advanced biofuels production, such as cellulosic ethanol, in terms of meeting their low level of bioethanol mandate/demand by 2020. Using residues as biofuels feedstock has no conflict with food security compared to first-generation biofuels and has no need for land resources for plantation compared to 1.5-generation biofuels.

In fact, China is leading in grain production, particularly wheat, corn and rice, which can provide considerable crops residues. Excluding the factors of production cost and feedstock cost, the present study projected that 172 million dry tonnes of agricultural residues could be available for production of 29 GL/yr of cellulosic ethanol. Even though the process of urbanization and industrialization may have a negative impact on crop yields, China can still produce about 22 GL of cellulosic ethanol if the country can retain crop residues yields at 2010 values.

Corn, rice and wheat are the major crop residues and are mainly found in Heilongjiang, Henan and Shandong provinces. It is therefore likely that these areas where any future biomass-to-ethanol facilities would be built. China currently has only one operational cellulosic facility, which is the Longlive Bio-technology Co. Ltd plant, with a claimed capacity of nearly 65ML/yr. Assuming that all the new cellulosic ethanol plants would have the same capacity as Longlive Bio-technology Co. Ltd, then China needs a total of 195 facilities in less than seven years to just meet the country's 2020 mandate of producing 12.7 GL of bioethanol. This number of plants could be reduced to about 156 if all of the existing conventional bioethanol production capacity is taken into account.

As for the forest residues, the present study projected that nearly 22 million dry tonnes of logging residues and wood processing residues might be available in 2020, with a theoretical ability to produce about 2.7-6.5 GL/yr of cellulosic ethanol. However, it is more likely that all of the available forest residues will be used to generate bioenergy (heat and power) rather than biofuels production. According to the *National Forestry Biomass Energy Development Plan (2011-2020)*, 45 million dry tonnes of woody biomass will be needed to generate 22 Mtce of bioenergy by 2020, half of which is supposed be sourced from new energy (tree) plantations (SFA, 2013).

4 Policy comparisons to see if biofuels might play a bigger role in China's future transportation fuel needs

4.1 Comparing policy with the US and Brazil

As part of the project we next compared China's biofuels policies with those of the US and Brazil in order to understand if and how the world's largest biofuels producers and users might provide examples for China. We assessed the successes and failures of Brazil and the US's biofuels policies to see if China could learn anything from these experiences and then apply them to China's current biofuels policies. Hopefully, the Chinese government might learn from the US and Brazil experiences to define its own policies to develop the sustainable production and use of biofuels. An objective assessment of the availability and sustainability of potential biofuel feedstocks is also an essential part of any roadmap aimed at long-term biofuels development.

Some of the main drivers for biofuels development in the US and Brazil was to lower the costs associated with importing high priced oil while trying to establish more energy self-sufficiency after the oil crisis of the 1970s. Initial biofuel development in these two countries was based on the production of conventional or so-called first generation biofuels as both the US and Brazil have sufficient feedstock for biofuel production. This is corn in the US and sugarcane in Brazil. Both countries had developed strong policies to support the whole supply chain of the biofuels industry, from feedstock supply to production cost, and to end use.

One of the reasons for the current study is that China's reliance on imported oil threatens the energy security of the country. Thus, this is a similar driver as the US and Brazil had for their initial biofuels development. However, defining the feedstock that could be used for conventional biofuels development in China poses a significant problem as sugar/starch is not as readily available as it is in the US or Brazil. As noted in chapter 3, China has very limited potential to increase the production of conventional biofuels (as opposed to cellulosic), although the country should have enough agricultural residues to support a "pioneering" biomass-to-ethanol sector (discussed in chapter 2) for biofuels in the future. However, as described in the main body of the thesis, China's current or planned advanced biofuels capacity is limited and it is very unlikely that they will meet the country's 2020 biofuel targets. Therefore, it is necessary to discuss what policies China might use to try to develop the production and use of sustainable biofuels.

Additionally, a comparison with China's domestic renewable energy policy, particularly transport fuels, was also included to try to better understand the role of biofuels in the country's renewable energy matrix as well as in the transportation sector. Compared to China's other renewable energy development plans, which include wind and solar, biofuels are not a major priority. The Chinese government has primarily focused on replacing coal with renewable and clean energy. Biofuel is only one of the country's strategies aimed at easing the reliance on import oil. Others strategies include promoting the production and use of energy saving cars by implementing tighter fuel economy requirements. It is likely that this strategy will be more effective and cost competitive in slowing down the rapid growing demand for petroleum. For all of the reasons discussed above, it is very likely that biofuels will only play a small role in China's transport fuel matrix through to 2020.

4.1.1 Biofuels story in the US

Oil security was one of the major driving forces for the US government to develop and promote biofuels. In 2010 imported oil accounted for more than 55% of total consumed oil consumed in the US (IEA, 2012). In addition, in the US, the transportation sector is the second largest emitter of GHG, accounting for one third of total emissions (IEA, 2012). Government policy has played a very large role in the US particularly in mandating increasing biofuels consumption. These policies include the Renewable Fuel

Standard (RFS), subsidies for biofuels blenders, and import tariffs on biofuels to protect the domestic industry. Besides strong policy support, sufficient corn production ensured that the country had enough feedstock supply for conventional biofuels production. The US has a considerable amount of cellulosic biomass for advanced biofuels production, as long as the conversion technologies become economically viable. All these above-mentioned advantages for biofuels development in the US are introduced in the following paragraphs.

1) Renewable Fuel Standard

In 2005, the US congress announced a mandatory minimum volume of 4 billion gallons (15 GL) of biofuels consumption in the national transportation fuel supply chain in 2006, gradually increasing to 7.5 billion gallons (28 GL) by 2012 (Energy Policy Act [EPAct], 2005). This mandate is known as the initial Renewable Fuel Standard or RFS1, which was later revised and named as RFS2 in 2007. RFS2 dramatically expanded the consumption mandates with a cap on corn ethanol consumption of 15 billion gallons per year (57 GL/yr) after 2015 and the rest of the mandates would be met by cellulosic biofuels and other advanced biofuels (Table 4.1). The RFS 2 strongly boosted the US biofuel market supply over the past few years and it will likely continue to do so over the next decade.

Table 4.1 RFS1 and RFS2 in the US (billion gallons)

Year	RFS 1	RFS 2				
		Total renewable fuels	Cap on corn ethanol	Other advanced biofuels		
				Cellulosic biofuels	Biodiesel	Other
2006	4.0	-	-	-	-	-
2010	6.8	12.95	12.00	0.10[a]	0.65	0.20
2015	7.8 (est.)	20.50	15.00	3.00	b	1.50
2020	8.4 (est.)	30.00	15.00	10.50	b	3.50
2022	8.6 (est.)	36.00	15.00	16.00	b	4.00

a. The cellulosic ethanol mandate for 2010 was revised from 0.1 bgal to 0.0065 bgal in February 2010

b. To be determined by EPA, but should be no less than 1.00 bgal

Note: RFS are set by year and this table only includes part of the US mandates; one US gallon=3.78541 liters

Source: Schnepf & Yacobucci, 2013

2) Biofuels subsidies and import tariffs

In addition to RFS2, a subsidy of 45-cent per gallon ethanol was provided to induce oil companies to blend corn ethanol with gasoline. This subsidy cost US$6 billion in 2011 (Pear, 2012). The US government also implemented an import tariff of 54-cent per gallon of ethanol in order to protect domestic corn ethanol producers from competition with sugarcane ethanol from Brazil (Pear, 2012).

3) Sufficient feedstock supply

Two key factors that were critical to biofuels commercialization including: 1) sustainable feedstock supplies, and 2) cost competitive conversion technologies. Fortunately, the US was able to meet both requirements in their production of corn-based ethanol. It is the world’s largest corn producer and the conversion technology is mature enough for commercial scale production. Corn used as bioethanol feedstock accounted for 40% of its total corn production in 2010, while corn consumption for livestock (feed) and the corn export sector has decreased. This used to be the largest two corn markets in the past (Schnepf & Yacobucci, 2013). As mentioned earlier, in order to accelerate the development of advanced biofuels, a cap of 15 billion gallons of corn-based ethanol by

2015 was established (Schnepf & Yacobucci, 2013). In a recent report, the USDA projected that the US will have a total potential of over one billion dry tons of biomass supply by 2030 which could be used for bioenergy, biofuels, and bioproducts production (DOE, 2011).

4.1.2 Biofuels pathway in Brazil

Like the US, oil security was also a key driving force for Brazil to develop biofuels. The success of biofuels in Brazil is not only due to the country's climate advantage in sugarcane cultivation, but also due to the strong policy support for the whole supply chain of the biofuel industry. The Brazilian government has adjusted its policies over the last four decades to essentially establish a sustainable and flexible system in terms of biofuels consumption. The development of Flexible fuel vehicles (FFVs) has played a critical role in removing the "blend wall" of the country, which is currently a limitation for increasing bioethanol consumption in the US. Once the whole supply chain of sugarcane-based ethanol was well established, the supply and demand of biofuels in Brazil is now more influenced by sugar price. However, the flexibility of biofuels consumption is limited to some extent as the Brazilian government still mandates a minimal blending ratio of bioethanol.

1) Biofuel initiatives in Brazil

Back in the early 1970's, imported oil used to account for nearly 80% of Brazil's total transportation fuel consumption (Meyer et al., 2012). The 1973 oil crisis resulted in the military government of Brazil at that time initiating an ethanol program called ProAlcool (Brazilian Alcohol Program) in 1975 and an initial mandatory consumption between E5 and E10 (Furtado, Scandiffio, & Cortez, 2011). In 1979, ethanol-only cars were introduced with incentives, such as lower sales taxes, and car sales rapidly increased due to the second oil crisis happening in the same year (Furtado et al., 2011). By 1985, ethanol-only cars accounted for nearly all of new car sales in Brazil, but oil prices started decreasing in the late 1980's (Furtado et al., 2011; Meyer et al., 2012). Consequently, sales of ethanol-only cars dropped significantly after ethanol became more expensive than gasoline (Furtado et al., 2011; Meyer et al., 2012).

2) Promoting Flexible Fuel Vehicles (FFVs)

The Brazilian government took a smart move to deal with the unpredictable volatile oil price by promoting flexible fuel vehicles (FFVs) instead of ethanol-only cars. FFVs can run on any blending ratio between pure gasoline and pure ethanol, which provides consumers with a choice. It is evidenced that FFVs sales increased rapidly since they were launched into the car market in 2003, and accounted for nearly 81% of total new car sales in 2008 (Meyer et al., 2012). FFVs solved the problem of the "blend wall" that the US is now confronting. It is reported that the maximal ethanol demand of the US would be limited at the level of 53 GL/yr by the "blend wall" (a maximum of 10% blending ratio of ethanol by volume) (Tyner & Viteri, 2010). However, Brazilian car users have no concern that a blending ratio higher than 10% could harm their car engines.

3) Reducing ethanol production cost

Increasing the share of FFVs in Brazil's vehicle fleet is not enough to drive biofuel consumption, unless the biofuel price is competitive with gasoline prices. Thus, reviving the sugarcane industry and especially reducing ethanol production costs was a priority for the Brazilian government after the oil price decreased in the later 1980's. The sugarcane ethanol production cost was significantly reduced by 65% in 2005 compared to the level of 1976 and another 5% in 2010 (Jank, 2011; Meyer et al., 2012). Essentially, sugarcane ethanol producers are profitable without government subsidies in Brazil (Goldemberg, Coelho, Nastari, & Lucon, 2004).

4) Increasing sugarcane productivity

Largely increasing sugarcane productivity by breeding new varieties is another key contribution to the success of Brazil's biofuel. The research work initially started in the early 1970's when the country had only about 3 sugarcane varieties with an average ethanol productivity of 2800 liters/ha, which has increased to current levels of nearly 70 plants and a land productivity of 7000 liters/ha (Cruz, 2011; Furtado et al., 2011). This significant improvement in sugarcane yield means that there has only been a slight increase in the proportion of arable land that is being used for sugarcane cultivation with only 8.7 mha of arable land required for sugarcane cultivation, equivalent to 1% of Brazil's total land (Jank, 2011). These areas are mostly located around Sua Paulo and the northeast of Brazil, far from the Amazon Rain Forest area (Fig. 4.1). What is more, typically, only half of the sugarcane harvest in Brazil is used for ethanol production, while the other half is for sugar production (Hermele, 2011). Nevertheless, the split of sugarcane use has some fluctuations depending on the sugarcane harvest and how global sugar price changes as both ethanol price and sugar price are unregulated in Brazil (Goldemberg et al., 2004). This will impact on whether the country can meet its minimal blending ratio of ethanol (25%) by volume (Barros, 2012). For example, the Brazilian government adjusted the minimal blending ratio to 20% due to decreasing sugarcane production and increasing sugar prices in 2012 (Barros, 2012).

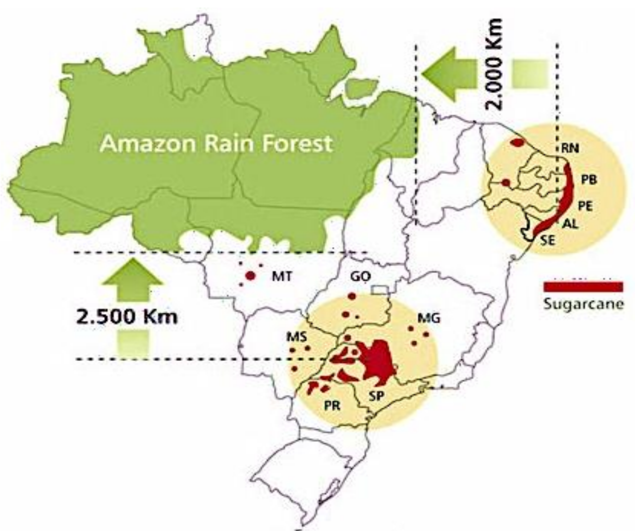

Figure 4.1 Sugarcane production regions in Brazil
Source: Sugarcane Industry Association of Brazil (UNICA), 2008

5) Subsidies and incentives

In order to further ensure stable feedstock and ethanol supply, the Brazilian government provided subsidies and incentives as well as tax breaks to sugarcane growers, ethanol producers and blenders. For example, lower tax rates have been offered to ethanol producers and distributors since the 1990's and a regional subsidy of US$2.5 per tonnes to nearly 20,000 sugarcane growers in the North-Northeast of Brazil (Barros, 2012). Credit lines of US$1.25 billion have also been provided to support ethanol storage and US$2 billion for people who renew and/or expand sugarcane fields after 2011(Barros, 2012).

In general, Brazil has a longer history of biofuel development compared to China. The Brazilian government experienced a stagnant stage of ethanol development after oil prices declined in the late 1980's and before FFVs became widely used. However, using a series of supporting policies applicable to the key stakeholders in the biofuel industry, Brazil has made biofuels a success. The Brazil experience reveals that each part of the biofuel supply chain, from feedstock suppliers to fuel ethanol end users, can be a limiting factor for biofuel development. For the US, the "blend wall" is currently the biggest limiting factor, while the limiting factors for China are discussed in the following section.

4.1.3 History of biofuels in China

The driving force for China to produce biofuels is very different from that of the US and Brazil. Unlike the two largest biofuels producers and users, the purpose of deriving bioethanol from corn/wheat was the Chinese government wanting to utilize state owned grain reserves, which had been in storage for many years (Renewable Energy Development Center of NDRC [REDC], 2008). This unusual driving force resulted in a lack of a long-term vision for biofuels development in China, such as not recognizing the food/feed vs. fuel concern at that time. Consequently, the Chinese government policies for biofuels to date have not helped in the development of the industry in a sustainable way.

1) Initial stage of biofuels development in China

In the early 2000's, four government authorized plants produced corn/wheat-based ethanol using state owned grain reserves, which had been in storage for many years, while biodiesel production was not included at that time (Table 4.2) (QIBBT, 2010, REDC, 2008). Exemption of 5% consumption tax and refundable Value Added Taxes (VAT) of 17% were provided to the four plants together with an average subsidy of US$4-cent per gallon in 2006 (REDC, 2008). Two national oil companies (NOCs), Sinopec and CNPC, were instructed to purchase the bioethanol from the four plants at a price of 0.9111 X #90 gasoline (ex-factory price of gasoline with octane number of 90) and sell it as E10 (10% of bioethanol with 90% of gasoline by volume) partially in China as shown in Fig. 1.19 (NDRC et al., 2004)

Table 4.2 Six authorized bioethanol facilities in China

Companies	Location	Ethanol[1] (Million liters/year) Capacity	Yield 2009	Feedstock	Initial operation year	Other bioproducts	Majority Stockholder	Company Website[4]
Jilin Fuel Alcohol Co., Ltd.	Jilin City, Jilin Province	760	634	Corn	2003	DDGS[3], corn oil, ethyl acetate	CNPC	www.cnpc.com.cn/jfa/
Henan Tianguan Group	Nanyang, Henan Province	646 1) Wheat 380 2) Cassava 253 3) Cellulosic 13	634	Wheat Cassava	2005	DDGS, liquid CO_2, Wheat bran and gluten	CNPC	www.tge.com.cn
Anhui BBCA Biochemical Co., Ltd.	Bengbu, Anhui Province	558	558	Corn	2005	DDGS, corn oil	COFCO	zlfysh.cn.gongchang.com
COFCO Bio-Energy (Zhaodong) Co., Ltd.	Zhaodong, Heilongjiang Province	355	317	Corn	2001	DDGS, corn oil	COFCO	www.cofcozd.com
Guangxi COFCO Bio-energy Co., Ltd	Nanning, Guangxi Province	253	253	Cassava	2007	NA	COFCO	www.cn-ferment.com/com/5555243053
Shandong Longlive Bio-technology Co. Ltd.	Yucheng, Shandong Province	63	NA[2]	Corncob	2012	Starch sugar, xylitol, xylose, lignin	Shaobo Cheng	www.longlive.cn
Total		2655	+2396					

Notes: 1.Capacity and production are rounded and converted from tonnes to million liters; 2. Operation just started in August 2012; 3.DDGS refers to Dried Distillers Grains with Solubles; 4.Companies websites are in Chinese.

Data and information of this table obtained from QIBBT (2010) and all the websites of the six com

2) Temporary expansion of conventional bioethanol

With the above-mentioned policy support, conventional bioethanol capacity was established and consequently expanded rapidly in 2005 and 2006 (Fig. 4.2). However, as this rapid growth in biofuel production resulted in a depletion of the state owned grain reserves, new harvests of corn and wheat were needed to maintain the same production levels. In 2007, 3.3 Mt of new harvested corn, equivalent to China's total imported corn from the US in the 2011-2012 marketing year, was used for ethanol production (QIBBT, 2010; Bi & Dobson, 2011). As a result, the Chinese government announced that no more approvals for new capacity for corn/wheat-based biofuels expansion should be granted (QIBBT, 2010). This limited the expansion of conventional biofuels development in China and resulted in the biofuels production levels of 2007 remaining the same as the previous year (Fig. 4.2). Additionally, the Chinese government gradually reduced the direct subsidies given to the four authorized ethanol plants from over US$31 million in 2004 to nearly US$19 million in 2020 (Global Subsidies Initiative of the International Institiute for Sustainable Development [GSI], 2008).

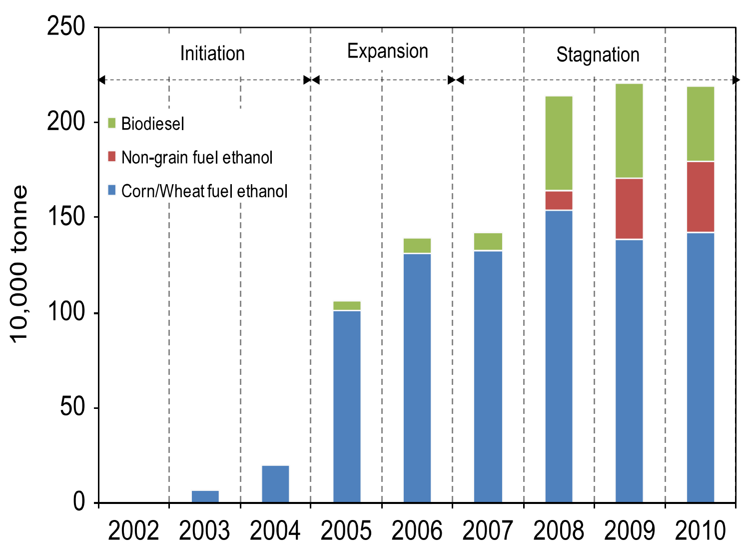

Figure 4.2 Biofuels production trends by feedstock, 2002-2010
Source: Chang et al., 2012

3) Stagnant stage with a little growth in non-grain biofuels

a). Non-grain bioethanol capacity

In 2008, new capacity for 1.5-generation bioethanol was built, but the increased capacity was not significant compared to existing first-generation biofuels production (Fig. 4.2). Only one cassava-based ethanol plant in Guangxi province was built with an annual capacity of 250 million liters (Table 4.2), which started operation in April 2008 (Fei, 2011). The production of cassava ethanol has supplied for provincial use of E10 in Guangxi and E10 had a transportation fuel market share of over 85% in 2008 (Fei, 2011). However, it decreased to 40% as the retail price of E10 has been the same as pure gasoline, making E10 unattractive to consumers (Fei, 2011). Part of the reason is that per liter E10 is equivalent to only 96% of one liter of pure gasoline's energy content. Consequently, the authorized ethanol plant had to stop production in March 2011 due to the facility running out of storage space for cassava-ethanol (Fei, 2011).

In addition to 1.5-generation biofuel, the first commercial scale cellulosic ethanol plant was built in Shandong province, which uses corncobs as feedstock. This government authorized plant, Longlive Bio-technology Co. Ltd., started operation in 2012 with a capacity of nearly 65 ML/yr (Table 4.2). The company uses biochemical conversion technologies for cellulosic ethanol production, which is a byproduct of xylitol production and other sugar products (Fig 4.3). Xylitol is manufactured using corncobs as raw materials through a pre-hydrolysis step (dilute acid), and the process residues are further used to produce cellulosic ethanol through SSF (Simultaneous Saccharification and Fermentation) (Cheng, 2004; Qu et al., 2006). However, it is not clear whether the facility can realize its claimed annual capacity of cellulosic ethanol.

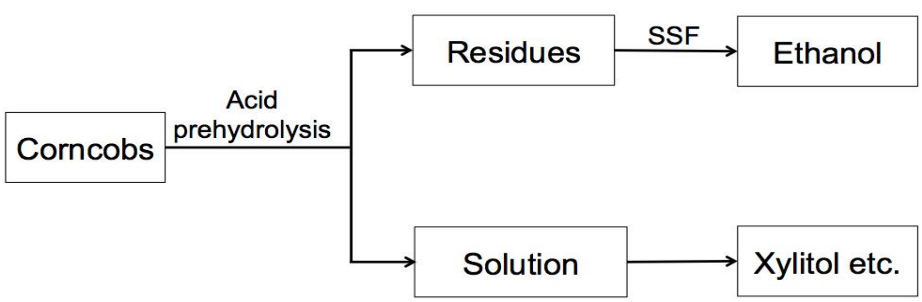

Figure 4.3 Corncobs ethanol production process

Note: the author consolidated patent information of Cheng (2004) and Qu et al. (2006)

b). Biodiesel capacity in China

Unlike the bioethanol industry, which is well regulated by the Chinese government, private owned companies are leading biodiesel development in China (GSI, 2008). Total biodiesel production increased to about 0.5 Mt/yr (0.58 GL/yr) in 2008 and 2009 but was reduced by 20% in 2010 (Fig. 4.2). Privately owned biodiesel plants have a total annual capacity ranging between 11-57 million liters using waste oil, such as used cooking oil, as feedstock (UCO) (ERI, 2010). However, due to lack of government regulations for quality, none of these products are mixed with diesel and used as transport fuel in China yet (ERI, 2010). Instead, it is used for power generation and off-road transportation in rural areas (GSI, 2008). It is estimated that the maximal availability of waste oil for biodiesel production is about 200 Mt/yr by 2020, which can hardly increase in a long-term, and it can produce approximately 1.5 GL/yr of biodiesel (ERI, 2010).

Besides private owned biodiesel companies, the Chinese government initiated projects to establish three biodiesel facilities using oil-bearing trees as feedstock (ERI, 2010). However, the progress is slower than the government expected. For example, only one of the three facilities is in operation in Hainan province, using industrial waste oil as feedstock.

4) Future trends of missing biofuels mandates by 2020

The Chinese government has total mandates of consuming 10 Mt (12.7 GL) of bioethanol and 2 Mt (2.3 GL) of biodiesel by 2020, which was 2 Mt and 0.2 Mt for 2010, respectively (NDRC, 2007, 2012). According to the government plan that 7 Mt (9 GL) of 2020 bioethanol mandate should be met by sweet sorghum derived ethanol and all biodiesel 2020 mandate should be derived from oil-bearing trees (Table 4.3). However, China has not built any capacity to grow or produce sweet sorghum-based ethanol or oil-bearing tree derived biodiesel (Table 4.3). As discussed in Chapter 3, although the country potentially has sufficient agricultural residues available for cellulosic ethanol production, it will be almost impossible to increase the capacity from one facility to 195 facilities in less than seven years. Therefore, China is very likely to miss its biofuels 2020 mandate.

Table 4.3 Government biofuels mandates and projections for 2020 vs. production for 2010 by feedstock types (GL)

	Bioethanol	**Biodiesel**
Mandates 2020	12.7[1]	2.3[1]
Gov. expectation 2020	9.0[1] (sweet sorghum)+2.1[1] (cassava)	5.2[3] (oil-bearing trees)
Production in 2010	1.9[2] (1st Gen.)+0.47[2] (cassava)	0.39[2] (UCO)

Source: 1. NDRC, 2007; 2. Chang et al., 2012; 3. SFA, 2013

4.2 Comparing biofuels with other types of renewable energy in China

4.2.1 The role of renewable energy in China's future energy matrix

Looking forward, the Chinese government has a goal of reducing emission intensity (tonnes of CO_2 emissions per dollar GDP) by 40-45% below its 2005 level by 2020 (ERI, 2010; NDRC, 2007). Renewable energy will play a key role in achieving the goal, particularly in replacing coal-fired power plants and in the industry sector. The Chinese government hopes that renewable energy will account for 15% of the country's total primary energy consumption by 2020 (NDRC, 2007). For example, *The White Book of China's Energy Policy, 2012* stated that non-fossil fuel energy sources should account for 30% of the total installed capacity for power generation during the 12th FYP (2011-2015) (National Energy Administration [NEA], 2012). These non-fossil fuel energy sources include hydroelectricity, wind power, solar energy, nuclear power and bioenergy (agricultural/forest residues direct combustion, landfill gas, biogas from animal manure) (NEA, 2012).

4.2.2 No increased 2020 mandates for biofuels in China

NDRC (2007) first announced specific mandates for each type of renewable energy source for 2010 and 2020 in *the Medium to Long-term Renewable Energy Plan of China 2007* (Table 4.4). Comparing 2010 mandates with actual achievements, the performance of biomass-based energy was not as outstanding as that of the other renewable energy sources such as wind and solar. All of the non-biomass based renewable energies have significantly exceeded their goals, whereas biomass-based energy has not only missed their goals, in the case of biogas and bioethanol they have not even come close! (Table 4.4). Although biodiesel exceeded its 2010 targets, the target was very easily achieved (Table 4.4). In addition, as the biodiesel was not used as transportation fuel it also failed to achieve its goal.

Table 4.4 Comparison of renewable energy in China, 2010 and 2020

	2010			2020	
	Target	Actual	Power generated (10^9 kWh)[d]	Original	Incremental
Hydroelectricity (10^6 kW)	190[a]	216[b]	686.7	300[a]	420[b]
Wind power (10^6 kW)	10[a]	31[b]	50	30[a]	200[b]
Solar power (10^6 kW)	0.3[a]	0.86[b]	0.86	1.8[a]	50[b]
Solar heating (10^6 m^2)	150[a]	168[c]	NA	300[c]	800[c]
Geothermal (10^6 tce)	4.0[a]	4.6[c]	0.15	12[c]	15**[c]
Bioenergy (power*) (10^6 kW)	5.5[a,b]		26.8	30[a,b]	
Pellets (Mt)	1[a]	3[c]	NA	50[c]	20[c]
Biogas (10^9 m^3)	15[a]	14[c]	NA	30[c]	50[c]
Bioethanol (GL)	2.5[a]	2.3[c]	NA	12.7[a,c]	
Biodiesel (GL)	0.2[a]	0.6[c]	NA	2.3[a,c]	

Notes:

*Electricity derived from biomass combustion and landfill gas;

** This is a 2015 target, while 2020 target is not available yet;

Sources: a.NDRC, 2007; b.NDRC, 2012; c. SCC, 2012b; d. Wang et al., 2012

Given the actual progress of renewable energy utilization in 2010, the Chinese government has readjusted the original 2020 mandates to meet revised targets in *the 12th Five-Year Plan for Renewable Energy Development* (NDRC, 2012). All of the non-biomass based renewable energy mandates have been increased, while the biomass-based energy has either remained at the same level, such as biofuels, or reduced (Table 4.4). For example, the government has reduced the 2020 mandate for pellets from 50/yr Mt to 20 Mt/yr (Table 4.4). It is evident that the Chinese government has concerns of biomass availability. However, using predominantly wind and solar, the country will continue to focus on developing renewable power/heat over the coming decade, likely accounting for 40% (310 GW) of the world's growth in renewable electricity during 2012-2018 (IEA, 2013).

Through the above comparison, the present study found that 1) biofuels ranked behind non-biomass-based renewable energy in China's renewable energy matrix; 2) it is possible that biogas and bioenergy plants will compete with cellulosic biofuels for agricultural residues as their feedstock. This will cast doubt on the assumption of the 15% of total agricultural residue being available for cellulosic biofuels production (As discussed earlier in Chapter 3).

4.2.3 Diversified energy sources in transportation

Coal consumption reduction is the first priority in China's renewable energy development plan, while the Chinese government has also realized the urgency of easing the reliance on imported oil driven by rapidly increasing passenger car sales. However, unlike the US and Brazil, biofuels are not the silver bullet for China, which doesn't have sufficient feedstock supply for conventional biofuels production and the progress of building capacity of advanced biofuels is too slow to satisfy its 2020 mandates. Therefore, the Chinese government has strategies of diversifying energy sources in the transportation sector, such as electrical vehicles (EVs), fuel cell, plug-in hybrid cars as well as tightening fuel economy. These solutions, together with biofuels, are expected to contribute to a slowdown the growth rate of petroleum demand in China's transportation sector. This section compares policies of these transport fuel related solutions to give an idea of the role biofuels will play in China's transport fuel matrix in the future.

The Chinese government aims to promote sales of energy saving vehicles and new energy vehicles until 2020. Energy saving vehicles are required to have higher fuel economy standards than non-energy saving vehicles manufactured in the same year, and new energy vehicles include pure electric vehicles (EVs), plug-in hybrid cars, and fuel cell vehicles (SCC, 2012a). According to China's *Energy Saving and New Energy*

Vehicles Industry Development Plan 2012-2020 total cumulative production and sales of new energy vehicles should reach 500,000 units by 2015 and 2,000,000 units by 2020 (SCC, 2012a). In 2009, the central government selected 13 cities (Beijing, Shanghai, Chongqing, Changchun, Dalian, Hangzhou, Jinan, Wuhan, Shenzhen, Hefei, Changsha, Kunming, and Nanchang) as pilot cities for promoting energy saving and new energy vehicles consumption in public transit, such as buses and taxies (Ministry of Finance [MoF] and Department of Science and Technology [DST], 2009).

However, compared to the total vehicle fleet of China, which is projected to be around 200-230 million units by 2020 as referenced in Chapter 2, the planned total of new energy vehicles would account for less than 1% of the total vehicles ownership. Some cities are using liquid natural gas (LNG), compressed natural gas (CNG), methanol, and DME (Dimethyl ether) at pilot scale in the public transit sector, although gasoline and diesel engines still form the bulk of China's vehicle fleets, accounting for about 80% of total vehicles (Wu, 2010). It appears that promoting energy saving vehicles to private car consumers can have a greater contribution in reducing the growth rate of transport fuel demand. From June 2010 and July 2013, subsidies totaling US$ 2.7 billion (RMB 16.6 billion) were provided to private energy saving vehicles consumers who bought 5.84 million units of energy saving vehicles (MoF, 2013).

Before discussing details about energy saving vehicles, it is worth noting that fuel economy standards for non-energy saving vehicles in China are higher than that of the US and Canada, with a further tightening projected standard through 2020 (Fig. 4.4). All carmakers in China are mandated to comply with this tightening fuel economy standard for new manufactured non-energy saving vehicles. This high fuel economy standard is likely a major reason that IEA's projection for China's total transportation fuel demand will not surpass that of the US by 2035.

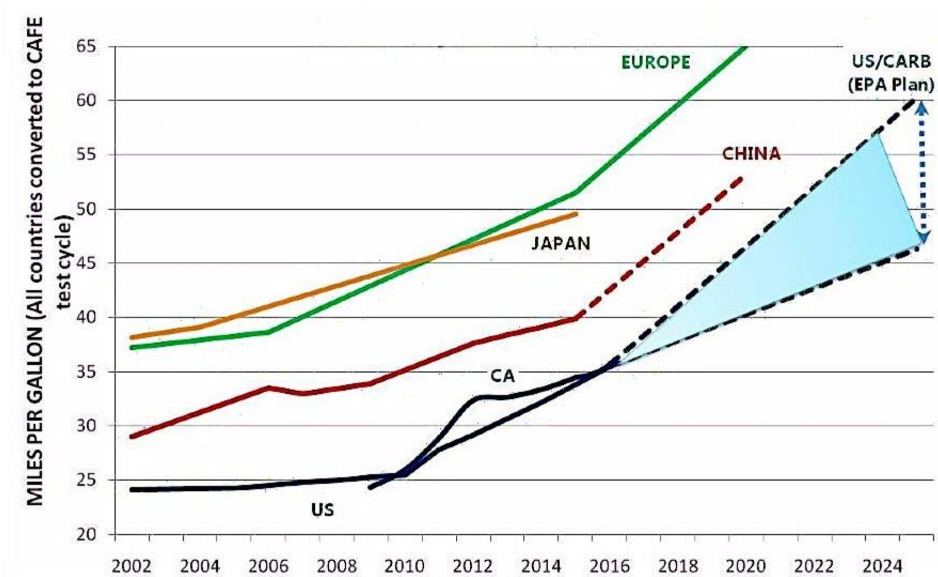

Figure 4.4 Comparison of fuel economy standards (mpg), 2002-2024
Source: An et al., 2011

The fuel economy standards of energy saving vehicles are stricter than non-energy saving cars manufactured in the same year (Table 4.5). The IEA (2012) reported that higher fuel economy standards would help China save about 9 Mtoe of transportation fuel, or 3% of total demand, by 2020, and 87 Mtoe, or 17%, by 2035. In the long term, improving fuel efficiency in the transportation sector may have a more significant contribution in reducing oil demand in China than increasing production and use of biofuels.

Table 4.5 Comparison of fuel economy standards (liter per 100 km)

Manufacturing year	2006[1]	2015[2]	2020[2]
Non-energy saving passenger car	8.0	6.9	5.0
Energy saving passenger car	NA	5.9	4.5

Source: 1. Wu, 2010 2.SCC, 2012a

All the above-mentioned solutions are currently being used in China to reduce the growth rate of oil demand. However, oil will remain the primary energy source, accounting for nearly 90% of total demand compared to biofuels and electricity that will account for 4% by 2035 (Fig. 4.5). In comparison, biofuels in the US will play a significant role, accounting for 16% of total transport fuel demand by 2035 (IEA, 2012). Biofuels in China are likely to only play a minor role in the energy matrix of the country's transportation sector by 2020, and it is unlikely to be significant through 2035 either.

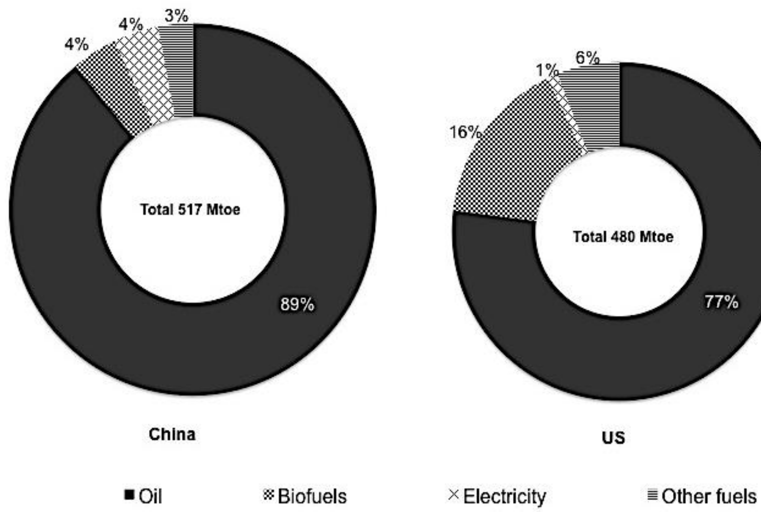

Figure 4.5 Comparison of transportation energy share by fuel, 2035
Data obtained from IEA (2012)

4.3 Discussion

Reviewing the history of biofuels in the US and Brazil, the present study identified that oil security issues were the main driving force for the two countries to develop biofuels in the first place. In addition, policies played a very important role in accelerating the development of biofuels industry in both counties'. The US implemented its original Renewable Fuel Standard in 2005. Although this was only two to three years later than the Chinese government initiated biofuels utilization, China's biofuel production is far behind that of the US. As for the success of sugarcane ethanol in Brazil, it cannot simply be attributed to a climate favorable for sugarcane cultivation. The Brazilian government developed and implemented a series of innovative policies to help biofuels commercialization.

Policies established in these two countries have four key factors in common, which include: 1) increasing biofuels consumption capacity through strong biofuels mandates, (RFS2 in the US and a minimal ethanol blending ratio of 25% in Brazil); 2) enhancing strong biofuels consumption capacity, (the US has the world's largest vehicle fleets and Brazil has FFVs that increase the overall ethanol blending ratio); 3) ensuring a sufficient feedstock supply for conventional biofuels production, (corn in the US and sugarcane in Brazil); and 4) reducing production costs (conversion technologies of corn/sugarcane ethanol are cost competitive, which can be profitable without government subsides).

In contrast, China does not have any of these four essential factors and the Chinese government is not currently facilitating the development of the biofuels industry by developing these types of policies. First, China's biofuels mandates for 2020 is much less than the US and Brazil (as discussed in Chapter 2). Secondly, biofuels demand, particularly bioethanol, is lower than that of the US and Brazil because China's growing vehicle fleet, which started from a very small base, will not surpass that of the US in the current decade. Thirdly, China does not have sufficient land to grow feedstock for conventional biofuels because arable land is prioritized for food/feed production and marginal land is low in productivity. Last but not least, the Chinese government is still subsidizing all the authorized ethanol plants, which cannot even run as "break-even" facilities.

It is found that China's policy for the biofuels industry was not based on long-term goals, which resulted in the biofuels industry becoming stagnant since 2008. The reason behind the initiatives for China to develop biofuels in the early 2000's was not based on achieving oil security, but to use the state grain reserves, which were stored for many years. Since 2007, no further expansion of first-generation biofuels capacity or production is allowed in China. Very little progress has been made with 1.5-generation biofuels in 2008 or advanced biofuels in 2012. Except for biofuels mandates for 2020 and some subsidies provided to existing biofuels producers, a sufficient and specific policy is not available to lead the country to achieve the biofuels mandates for 2020. In contrast, the pricing policy of selling E10 at the same prices as pure gasoline is decreasing people's willingness to buy because per gallon driving distance of E10 is 3% less than that of per gallon gasoline.

In general, the original motivation for China to produce biofuel was not oil security. Consequently, the government did not establish a long-term, sustainable plan for biofuels development. In particular they overestimated the potential for conventional biofuels in the country, failing to take into account the limited land resources that are available for conventional feedstock plantations. At the same time, policy support for accelerating the development of advanced biofuels is lacking. The currently policies have not established a roadmap for biofuels development, but rather use biofuels more as a symbol for renewable energy in China.

Drawing on lessons from the US and Brazil, China should realize that advanced biofuels are more suitable for the country than conventional biofuels. Policy support is needed to both ensure food production while increasing the harvest ratio of crop residues so that sufficient feedstock can be available. Meanwhile, advanced biofuels production cost need to be reduced as well. The Chinese government should assess both feedstock potential and biofuels demand in order to set a reasonable and realistic biofuels mandates. In terms of biofuel use, FFVs should be increasingly introduced during the motorization process of the country so that China can have the flexibility of using biofuels with a higher blending ratio and avoid the “blend wall” issue. Currently, China’s biofuels production capacity is far from reaching a “blend wall”, but once the motorization process is complete, it would be very difficult to increase the share of FFVs in the whole vehicle fleet.

Comparing biofuels policy to other types of renewable energy policies reveals that biofuels are not prioritized in the country’s development plan for renewable energy by 2020. The Chinese government increased 2020 mandates of all non-biomass based renewable energy types, such as hydroelectricity, wind power and solar energy, while biofuels mandates for 2020 remained at the same level. Renewable power has the highest priority, followed by renewable heat, as this would reduce coal consumption, as well as GHG emissions, significantly. In contrast, the transportation sector has much less potential to contribute to reduction of CO_2 emissions than the power sector and the industrial sector.

Although the growing transport fuel demand does have an impact on decreasing the country's oil security, biofuels are not the major solutions to China's future transport needs. Other solutions will likely play a larger role than biofuels in decreasing the growth for oil demand, such as increased buying of foreign oil resources, implementing stricter fuel economy standards (higher than that of the US), and promoting new energy cars (EVs, plug-in hybrid cars, and fuel cell cars) and energy saving cars (having higher fuel economy standards than normal cars) through subsidies. Comparing all these solutions together, including biofuels, it is likely that stricter fuel economy standards as well as energy saving cars may play the most important role in the future.

In China, neither GHG emissions reduction nor oil security issue has encouraged the development of biofuels. Thus there has been little policy support for planting feedstock or building production capacity for making advanced biofuels.

5 Conclusions and Recommendations

Compared to OECD countries, which took a period of more than a hundred years to complete the process of industrialization, China has experienced a more compressed process of industrialization over the last two-to-three decades. Since 2000, when heavy industry took over and became the driving force for the country's industrialization, total primary energy consumption and GDP growth dramatically increased and resulted in China being the world's largest energy user and the world's second largest economy.

For example, China's industrial sector is responsible for nearly half of the country's GDP, mostly from heavy industry, such as the manufacturing sector, as well as the steel and cement industry. Consequently, the industrial sector and power sector became the two largest energy users, consuming 43% and 42% of the country's total primary energy in 2009, respectively. China is rich in coal but scarce in oil and natural gas resources, and the country has relied heavily on coal for around 70% of total primary energy use since the late 1990's, followed by oil accounting for about 20%.

However, China ranks as the world's second largest oil user and the oil self-sufficiency of the country is already well below 50%, and it is predicted to further decrease to one-third by 2020 and one-fifth by 2035. This rapid decrease in oil security is mainly due to two reasons. China's dramatically increased "motorization" process and China's economic restructuring. Over the last decade, China started its motorization process, which is still, in many ways, in its infancy. It has been primarily driven by private passenger car sales (running on gasoline) due to people's increased incomes. As the world economy is still not fully recovered after the economic crisis in 2008, the world's goods consumption demand remains weak. As it has functioned as the "world's factory", China's goods export contribution to the GDP growth is decreasing. In addition, the appreciation of Chinese currency (RMB) and increased labour costs resulted in the economic driving force shifting from the export of goods to domestic consumption. Consequently, domestic goods transportation will require an increase in the use of petroleum/diesel in the future, particularly diesel, which is already a favored transport fuel in China's transportation sector.

The price of accelerated development is not just limited to energy security issues for China, but also its GHG emissions from fuel combustion that surpassed the US emissions in 2007. What is more, air pollution from fossil fuel combustion causes severe public health concerns, particularly from transportation fuel combustion in urban areas. The process of industrialization and urbanization decreased and contaminated China's scarce arable land resources in terms of both quality and quantity. As the world's most populous country with 1.3 billion, ensuring food security is another critical challenge as the country is already a net food importer.

Looking to the future, the domestic supply and demand conflict for fossil fuels and land resources will intensify in China with an increasing negative impact on the environment caused by industrialization, motorization and urbanization. Coal will remain the largest energy source and oil security issue will become more severe, which will lead to increased carbon emissions and pollution in China. Meanwhile, people's lifestyle will be further upgraded so that more and more natural resources, especially land resources, will be required for food production as well as construction.

Renewable energy is an attractive alternative to reduce coal and oil consumption. For example, hydroelectricity, wind power, solar energy and bioenergy can reduce coal consumption for power and heat generation, while only biofuels can serve as an alternative for transport fuels. China is the world's leader in the development of hydroelectricity, wind power and solar heat utilization. However, China's total renewable energy use only accounted for less than 9% of its total primary energy consumption in 2010, and only 0.8% of this renewable energy total was from biofuels. Compared to the world's leading conventional biofuels producers, such as the US and Brazil, China's biofuels production accounted for only 2% of the world's total in 2011. Although the Chinese government has set a target of increasing the percentage of renewable energy to 15% by 2020, the focus remains on renewable power and heat generation. Recently, the Chinese government increased all the non-biomass based renewable energy mandates for 2020, while the biofuels mandates for 2020 remained at the same volume as they were first announced in 2007 (12.7 GL of bioethanol and 2.3 GL of biodiesel). This indicates that biofuels are not a priority for China's future renewable energy development plans.

It is apparent that being the world's largest new car market, particularly leading in passenger car sales, does not directly result in a rapid growth in biofuels demand. It is projected that 14.3 GL of bioethanol and 14.5 GL of biodiesel would be needed in China's transport sector by 2020 if every drop of pure gasoline and diesel is to be supplemented with E10 and B5, respectively. This indicates that China's biodiesel mandate for 2020 is much lower than the country's consumption capacity, but the bioethanol mandate for 2020 is likely to be close to the country's needs.

In terms of total volume, China's biofuels demand/mandates is much less than that of the US and Brazil, especially for bioethanol. As China's rapid motorization started from a very small base, the country's vehicle fleets are not likely to surpass that of the US by 2020. Unlike Brazil, FFVs are not sold in China, which will limit the volume of bioethanol demand due to the use of bioethanol is limited in the form of E10. In addition, the Chinese government will likely use other solutions, such as implementing stricter fuel economy standards, promoting new energy cars and energy saving cars, to slow down the growing demand for transportation fuels. This can also directly slow down the increase of biofuels consumption capacity.

In addition, other factors will also have an impact on transport fuel demand. For example, China's economic growth is slowing down, while prices of gasoline and biodiesel may further increase. Private car users mainly use their cars for commuting to work and for some short-to-medium distance travelling. Trains and airplanes still play a larger role than vehicles in long distance travelling. What is more, an increasing number of local governments in China are implementing regulations to curb car use in order to reduce air pollution and traffic congestion in urban areas. With all these factors in mind, it is foreseeable that China's demand and/or capacity for biofuels is unlikely to grow rapidly to the level of that in the US and Brazil by 2020 and even further into the future.

Although China's needs for biofuels are relatively small, the country will very likely miss the mandates for 2020 due to the fact that: 1) sufficient feedstocks are not available for conventional biofuels production; and 2) sufficient capacity cannot be built in time for advanced biofuels production by 2020:

- Due to the fact that land resources, particularly arable lands, are very scarce in China, the government no longer grants the expansion of first-generation biofuels capacity since 2007. The Chinese government expects to increase biofuels production from 1.5-generation feedstocks, including cassava, sweet sorghum and oil-bearing trees, with these crops/trees grown on marginal land. The government has therefore expected to produce about 2 GL of cassava-ethanol, 9 GL of sweet sorghum-ethanol and 5 GL of biodiesel derived from oil-bearing trees by 2020. However, according to the most conservative scenarios of the present study, it is projected that China may potentially produce 0.4 GL of cassava-ethanol, 2.5 GL of sweet sorghum-ethanol, and derive 2.5-6.7GL of biodiesel by 2020. Given the fact that the country currently only has an operational cassava-ethanol capacity of 0.5 GL/yr, and very little plantation of sweet sorghum-ethanol or oil-bearing trees-biodiesel have been established on low productivity marginal land, China is very unlikely to meet its biofuels mandates for 2020 by increasing 1.5-generation biofuels production.
- It is worth noting that China may have sufficient agricultural residues to produce 29 GL of cellulosic ethanol if crop growth rates can remain at the same levels as they were during the last decade and 15% of the 1150 million dry tonnes of crop residues were available for harvesting by 2020, which would be sufficient to meet

its 2020 bioethanol mandate and the projected demand already. However, China is unlikely to have enough facilities for cellulosic ethanol production. It will be very challenging to increase cellulosic ethanol capacity from the current level of a few plants making 65 ML/yr, to the 195 facilities that would be required, assuming they have the same scale as the existing one.

- Other potential risks include the process of urbanization and industrialization decreasing arable land resources. Biogas and bioenergy, which are priorities of biomass-based renewable energy in China, may compete with cellulosic biofuels production for agriculture residues. Production costs and feedstock costs are not considered as parameters in the calculation of crop residues availability in the present study as advanced biofuels may not be economicly viable by 2020.
- Compared to agricultural residues, China may potentially have nearly 22 million dry tonnes of forest residues, which are residues from wood processing and logging, to produce 2.7-5.6 GL of cellulosic ethanol. However, these forest residues will be used for bioenergy production instead of biofuels according to a recently announced development plan for forest biomass utilization from 2011 to 2020.

For all of these reasons, biofuels will likely to play a minor role in China's future transport needs. As biofuels are not the priority to the Chinese government, specific and executable policy support have not been developed for the whole supply chain of the biofuels industry, such as: 1) establishing commercial scale feedstock plantations; 2) reducing production costs and increasing biofuels productivity, 3) increasing biofuels consumption/production capacity; as well as 4) people's willingness to buy biofuel products. The government mandates for biofuels are insufficient to facilitate its realization when compared to the successful biofuel development strategies used in the US and Brazil.

To try to encourage the development of biofuels, China should utilize the existing grain-based biofuels infrastructures to build advanced biofuels capacity and implement a higher blending ratio of bioethanol in certain regions of the country, such as the east coastal areas, instead of widely spreading E10 in some regions that barely have any local feedstock supply. Most oil demand is in provinces located in the east coastal areas. Current authorized biofuels facilities are located in or close to the east coastal areas, which have local or close access to major crop production areas. These facilities have the advantage of establishing capacity for advanced biofuels by leveraging some of the already existing infrastructure and logistics channels. In parallel, FFVs could be promoted in the east coastal areas where a higher bioethanol-blending ratio could be implemented. As the country's motorization process is just in its infancy, the government could seize the opportunity to increase the FFVs' share of the national vehicle fleet, which is more difficult for a country to achieve when its motorization process is mature. For example, the US currently has 8 million units of FFVs in the country accounting for 3% of total vehicles fleet and the share of FFVs is not expected to increase rapidly in the near future (DOE, 2013).

Other supportive policies are required to achieve the proposed higher blending ratio of bioethanol in the east coastal areas of China. First, the government needs to protect its arable land resources (both quantity and quality), which can increase/retain both crop yields and residue yields. Secondly, incentives should be provided to farmers to grow energy crop/trees on marginal land. Although 1.5-generation biofuels are not the majority of feedstock supply for biofuels production in China they could be a supplemental feedstock supply for conventional biofuels production. Third, subsidies and incentives are also needed for research in areas that can reduce production cost, increase crops yields, and improve conversion technologies. Last but not least, a reduction in the retail price of biofuels-blended petroleum could be implemented to increase people's willingness to buy these products, especially for the higher blending ratios of biofuels.

As for biodiesel, it is proposed that, first the Chinese government should provide incentives to biodiesel companies to upgrade their biodiesel quality so that it can be used for road transportation. Second, the State Forestry Administration of China should support local government to improve marginal land productivity that has the potential to grow oil-bearing trees. Third, increased research on improving of increasing fruit yields of oil-bearing trees should be supported. Perhaps policies supportive of increasing land and tree productivities will not have an significant impact on increasing biodiesel production in a short term, but these policies will benefit the country by increasing the forest area and residue yields in the forest sector for bioenergy production. In addition, China can establish oil-bearing trees plantation in other countries, such as in neighboring Southeast Asia countries. This will not only increase forest areas in these countries, but also increase feedstock supplies.

In summary, the proposed strategy for China to develop biofuels is unlike the US and Brazil. Biofuels utilization in China should be more regional rather than countrywide, more flexible rather than fixed. For example, if FFVs were widely sold in China then imported biofuels could become an option to achieve its bioethanol mandates for 2020. All of the above-mentioned suggestions may not result in biofuels playing a significant role in the whole country, but at least they have the potential to become regionally important in some provinces and cities in China.

Bibliography

74 Chinese cities to publish daily PM2.5 reports: ministry. (2012, May 25). *Xinhua.* Retrieved October 20, 2012, from http://www.xinhuanet.com/english/

An, F., Earley, R. & Green-Weiskel, L. (2011). *Global Overview on Fuel Efficiency and Motor Vehicle Emission Standards: Policy Options and Perspectives for International Cooperation* [Report No. 3CSD19/2011/BP3]. Retrieved September 10, 2012, from United Nations Department of Economic and Social Affairs website: http://www.un.org/esa/dsd/resources/res_pdfs/csd-19/Background-paper3-transport.pdf

Atsmon, Y., Ducarme, D., Magni, M., & Wu, C. (2012). *McKinsey Consumer & Shopper Insights: Luxury Without Borders: China's New Class of Shoppers Take on the World*. Retrieved January 5, 2013, from McKinsey&Company website http://www.mckinseychina.com/wp-content/uploads/2012/12/the-mckinsey-chinese-luxury-consumer-survey-2012-12.pdf

Autohome. (2011, April 16). *中国乘用车历年销量数据 (2001 年-2010 年)* [Passenger car annual sales in China (2001-2010)]. Retrieved June 15, 2012, from http://club.autohome.com.cn/bbs/thread-a-100002-8753794-1.html

Bacovsky, D., Barclay, J., Bockey, D., Dornelles, R., Edye, L., Foust, T., . . . van Zyl, W. (2009). *Update on implementation agendas 2009 - A review of key biofuel producing countires* (Report No. T39-PR1). In Mabee, W.E., Neeft, J., and van Keulen, B. (Ed.). Retrieved February 6, 2012, from IEA Bioenergy website: http://www.biofuelstp.eu/downloads/A_RS_38_Biofuel_Implementation_2009.pdf

Barros, S. (2012). *Brazil Biofuels Annual Report 2012* (Report No. BR12013). Retrieved January 8, 2013, from Sao Paulo Agricultural Trade Office website: http://www.unece.lsu.edu/biofuels/documents/2013Mar/bf13_16.pdf

Bauen, A., Berndes, G., Junginger, M., Londo, M., Ball, R., Bole, T., . . . Mozaffarian, H. (2009). *Bioenergy - A Sustainable and Reliable Energy Source (Main Report)*. Retrieved February 7, 2013, from IEA Bioenergy website: http://www.globalbioenergy.org/uploads/media/0912_IEA_Bioenergy_-_MAIN_REPORT_-_Bioenergy_-_a_sustainable_and_reliable_energy_source._A_review_of_status_and_prospects.pdf

Boston Consulting Group. (2012). *More than a third of large manufacturers are considering reshoring from China to the US*. Retrieved August 12, 2012, from http://www.bcg.com/media/PressReleaseDetails.aspx?id=tcm:12-104216

Bi, W., & Dobson, R. (2011, December 29). Corn demand for industrial use in China may slow down in 2012 as economy cools. *Bloomberg.* Retrieved August 20, 2012, from http://www.bloomberg.com

Bi, Y., Wang, H., Wang, D., Gao, C., & Wang, Y. (2011). 中国稻草资源量估算及其开发利用 [Estimation and utilization of rice straw resources in China]. *中国农学通报, 27*(15), 137-143.

Boeing. (2012). *Current Market Outlook 2012-2013.* Retrieved August 28, 2012, from http://www.boeing.com/assets/pdf/commercial/cmo/pdf/Boeing_Current_Market_Outlook_2013.pdf

British Petroleum. (2004). *BP Statistical Review of World Energy June 2004*. Retrieved September 24, 2011, from http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/S/statistical_review_of_world_energy_full_report_2004.pdf

British Petroleum. (2011). *BP Statistical Review of World Energy June 2011*. Retrieved September 23, 2012, from http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2011.pdf

British Petroleum. (2012). *BP Statistical Review of World Energy June 2012*. Retrieved February 20, 2013, from http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2012.pdf

Canada OKs China's largest overseas energy acquisition. (2012, December 7). *CBSNews*. Retrieved January 6, 2013, from http://www.cbsnews.com

Central Intelligence Agency. (2013). *The World Factbook*. Retrieved May 17, 2013, from https://www.cia.gov/library/publications/the-world-factbook/index.html

Chang, S., Zhao, L., Timilsina, G. R., & Zhang, X. (2012). Biofuels development in China: Technology options and policies needed to meet the 2020 target. *Energy Policy, 51,* 64-79. doi:10.1016/j.enpol.2012.05.084

Chen, L., Xing, L., & Han, L. (2009). Renewable energy from agro-residues in China: solid biofuels and biomass briquetting technology. *Renewable and Sustainable Energy Reviews, 13*(9), 2689-2695. doi:10.1016/j.rser.2009.06.025

Cheng, S. (2004). *低聚木糖的制备方法* [Method of producing xylo-oligosaccharides] (Patent No. CN200410023875). Retrieved July 10, 2013, from State Intellectual Property Office of P.R.C website: http://211.157.104.87:8080/sipo/zljs/hyjs-yx-new.jsp?recid=CN200410023875.X&leixin=fmzl&title=%B5%CD%BE%DB%C4%BE%CC%C7%B5%C4%D6%C6%B1%B8%B7%BD%B7%A8&ipc=C07H3/06

China Association of Automobile Manufacturers. (2012, January 12). *2011 年 12 月汽车工业产销情况简析* [Briefing of China's Auto Industry in Dec 2011]. Retrieved June 15, 2012, from http://www.caam.org.cn/zhengche/20120112/1605066964.html

China Foreign Exchange Trade System. (2011). *人民币汇率中间价(历史数据)* [CNY Central Parity (Historical Data)]. Retrieved July 19, 2012, from http://www.chinamoney.com.cn/fe/Channel/17383

China's motor vehicles top 233 mln. (2012, July 17). *Xinhua*. Retrieved December 10, 2012, from http://news.xinhuanet.com/english/

Collins, G., & Erickson, A. (2012, January 2). China's growing meat consumption is driving corn imports and creating a new strategic dependency. *China SignPost*. Retrieved March 27, 2012, from http://www.chinasignpost.com

Cruz, C. H. B. (2011, May 4). Brazil's biofuel revolution. *Allianz Knowledge.* Retrieved June 9, 2012, from http://knowledge.allianz.com

Daily chart: Choked. (2013, January 16). *The Economist.* Retrieved May 24, 2013, from http://www.economist.com

Dargay, J., Gately, D., & Sommer, M. (2007). Vehicle Ownership and Income Growth, Worldwide: 1960-2030. *The Energy Journal (Cambridge, Mass.), 28*(4), 143-170.

Dong, P., Man, Y., Liang, Y., & Huang, X. (2008). *21 世纪我国石油安全的战略对策* [Strategy For China's Petroleum Guarantee in The 21st Century]. *资源与产业,10*(1), 12-15. doi:10.3969/j.issn.1673-2464.2008.01.004

Du, Y. (2010, August 18). 吴坚：我国已有五处生物质柴油原料林基地备选点[Wu Jian: Five biodiesel feedstock plantation bases had been selected]. *People*. Retrieved January 27, 2012, from http://people.com.cn

Energy Policy Act, Pub. L. 109-58 (2005). Retrieved April 4, 2012, from US Government Printing Office website: http://www.gpo.gov/fdsys/pkg/PLAW-109publ58/pdf/PLAW-109publ58.pdf

Energy Research Institute of National Development and Reform Commission. (2010). *中国生物质能技术路线图研究* [Research on Biomass Energy Technology Roadmap in China]. Retrieved November 25, 2011, from http://www.efchina.org/csepupfiles/report/201112444831414.5005357654043.pdf/%E4%B8%AD%E5%9B%BD%E7%94%9F%E7%89%A9%E8%B4%A8%E8%83%BD%E8%B7%AF%E7%BA%BF%E5%9B%BE%E7%A0%94%E7%A9%B6%E6%8A%A5%E5%91%8A.pdf

Food and Agriculture Organization of the United Nations. (2011). *Food and Agricultural Commodities Production*. RetrievedApril 8, 2012, from faostat.fao.org/site/339/default.aspx

Food and Agriculture Organization of the United Nations. (n.a.). *Definition and Classification of Commodities: 3. Sugar crops and sweeteners and derived products*. Retrieved April 8, 2012, from http://www.fao.org/es/faodef/fdef03e.htm

Fei, L. (2011, May 20). 世界最大非粮燃料乙醇企业被迫停产 [The world's largest non-grain ethanol plant is compelled to stop production]. *ChinaNews*. Retrieved October 14, 2011, from http://www.chinanews.com

Furtado, A. T., Scandiffio, M. I. G., & Cortez, L. A. B. (2011). The Brazilian sugarcane innovation system. *Energy Policy, 39*(1), 156-166.dio:10.1016/j.enpol.2010.09.023

Gale, H.F., Tuan, F., Wang, X.H., & Cao, Z. (2009). *China is using more corn for industrial products* (Report No. FDS-09K-01). Retrieved July 6, 2013, from United States Department of Agriculture website: http://www.ers.usda.gov/media/153522/fds09k01.pdf

Goldemberg, J., Coelho, S. T., Nastari, P. M., & Lucon, O. (2004). Ethanol learning curve-the Brazilian experience. *Biomass and Bioenergy, 26*(3), 301-304. doi:10.1016/S0961-9534(03)00125-9

Goswami, G., & Tasukimori, O. (2013, January 31). Asia to deepen Iran oil import cuts in 2013 as sanctions bite. *REUTERS*. Retrieved March 17, 2013, from http://www.reuters.com

Government of Hainan Province. (2009, April 2). *海南省人民政府办公厅关于引发海南省生物柴油市场推广使用工作方案的通知* [Notice of promoting and expanding biodiesel use as transportatio fuel in Hainan province]. *The People's Government of Hainan Province*. Retrieved June 9, 2013, from http://www.hainan.gov.cn/data/hnzb/2009/05/1653/

Government of Hainan Province. (2010, January 20). *中海油 6 万吨生物柴油项目投产* [CNOOC's biodiesel project started operation with targeted capacity of 60,000 tonnes per year]. *The People's Government of Hainan Province*. Retrieved June 9, 2013, from http://www.hainan.gov.cn/data/news/2010/01/94183/

Global Subsidies Initiative of the International Institiute for Sustainable Development. (2008). *Biofuels-At What Cost ? Government support for ethanol and biodiesel in China*. Retrieved September 10, 2011, from http://www.iisd.org/gsi/sites/default/files/china_biofuels_subsidies.pdf

Global Wind Energy Council. (2013). *Global Wind Statistics 2012.* Retrieved June 8, 2013, from http://www.gwec.net/wp-content/uploads/2013/02/GWEC-PRstats-2012_english.pdf

Hainan Daily. (2010, November 21). *海南试用生物柴油 已在 12 家中石化加油站试销售*

[Twelve gas stations of Sinopec started selling biodiesel in Hainan]. *Xinhua.* Retrieved November 22, 2012, from http://news.xinhuanet.com

Hennock, M. (2002, November 11). China: the world's factory floor. *BBC*. Retrieved December 14, 2012, from http://www.bbc.co.uk

Hermele, K. (2011). *Regulating Sugarcane Cultivation in Brazil*. Retrieved January 9, 2012, from Lund University of Sweden website: http://www4.lu.se/upload/Humanekologi/Hermele.Regulating.Sugarcane.Cultivation.in.Brazil.pdf

Hu, C. (2009). *胡存智：中国耕地质量等级调查与评定工作情况及主要成果* [Hu Cunzhi: major results of evaluating and grading China's arable land by quality]. *Ministry of Land and Resource of China*. Retrieved May 5, 2013, from weMhttp://www.mlr.gov.cn/wszb/2009/20090612qmpxxxgtzygb_1_2_1/zhibozhaiyao/200912/t20091224_700738.htm

Hu, L. (2010). *我国利用边际性土地生产能源作物的潜力和区域分布特点* [The potential of growing energy crops on marginal land in China and the features of marginal land distribution] [PowerPoint slides]. Retrieved November 29, 2012, from http://www.biogas-china.org/index.php?id=156&cid=170&fid=23&task=download&option=com_flexicontent&Itemid=19&lang=zh

Hu, X. (2011). 纤维素乙醇研究开发进展 [Progress of cellulose ethanol research & development]. *化工进展, 30*(1), 137-143.

Huang, H. (2012). 林业生物质能源迎机遇 共生共赢谋发展 [Opportunities for forest bioenergy, a win-win solution for development], *中国高科技产业导报*. Retrieved April 23, 2012, from http://paper.chinahightech.com

International Energy Agency. (2009). *Transport, Energy and CO_2: Moving Toward Sustainability*. (Report No. 61 2009 25 1 P1). Retrieved July 26, 2012, from http://www.iea.org/textbase/nppdf/free/2009/transport2009.pdf

International Energy Agency. (2011a). *CO_2 Emissions from Fuel Combustion Highlights* (2011 ed.). Retrieved February 16, 2012, from http://www.iea.org/media/statistics/CO2highlights.pdf

International Energy Agency. (2011b). *Technology Roadmap-Biofuels for Transport*. Retrieved February 12, 2012, from http://www.globalbioenergy.org/uploads/media/0912_IEA_Bioenergy_-_MAIN_REPORT_-_Bioenergy_-_a_sustainable_and_reliable_energy_source._A_review_of_status_and_prospects.pdf

International Energy Agency. (2012). *World Energy Outlook 2012*. Paris, France: IEA Publication.

International Energy Agency. (2013). *Medium-Term Renewable Energy Market Report*

2013 (Executive Summary): Market Trends and Projection to 2018. Retrieved August 25, 2013, from http://www.iea.org/Textbase/npsum/MTrenew2013SUM.pdf

International Monetary Fund. (2012). *China Economic Outlook*. Retrieved February 17, 2013, from http://www.imf.org/external/country/CHN/rr/2012/020612.pdf

Intergovernment Panel on Climate Change. (2007). *Climate Change 2007:Synthesis Report*. Retrieved May 6, 2011, from IPCC website: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

Iowa State University Extention and Outreach. (2008). *Liquid Fuel Measurements and Conversions (File C6-87)*. Retrieved December 9, 2011, from http://www.extension.iastate.edu/agdm/wholefarm/pdf/c6-87.pdf

Jank, M. S. (2011). *Biofuel Industry: A local and Global View* [PowerPoint slides]. Retrieved January 26, 2012, from http://www.bbest.org.br/2011/images/palestras/marcos_jank

Jia, X. & Zhao, Y. (2009). *Policy Forum 09-016: The Chinese Economic Stimulus Package and its Impact on Environmental Protection Organization*. Retrieved February 12, 2011, from Nautilus Institute for Security and Sustainability website: http://nautilus.org/publications/essays/napsnet/forum/2009-2010/09016XijinYusi.html

Jiang, J. & Sinton, J. (2011). *Overseas Investments by Chinese National Oil Companies-Assessing the drivers and impact*. Retrieved February 7, 2013, from International Energy Agencty website: http://www.iea.org/publications/freepublications/publication/overseas_china.pdf

Kharas, H. (2010). *Working Paper No. 285 The Emerging Middle Class in Developing Countries*. (Report No. DEV/DOC(2012)2). Retrieved January 10, 2012, from OECD Development Centre website: http://www.oecd.org/social/poverty/44457738.pdf

Lane, J. (2013, July 22). 12 Bellwether Biofuels Projects-where do they stand? *BiofuelsDigest*. Retrieved October 11, 2013, from http://www.biofuelsdigest.com

Li, L., Karatzos, S., & Saddler, J. (2012). The potential of forest-derived bioenergy to contribute to China's future energy and transportation fuel requirements. In R. Ayling (Eds.), *Proceeding of Future Forestry Leaders Symposium: The Forestry Chronicle (pp* 547-552). Mattawa, ON: The Canadian Institute of Forestry.

Li, S., & Chan-Halbrendt, C. (2009). Ethanol production in (the) People's Republic of China: Potential and Technologies. *Applied Energy, 86 (Supplement 1)*, S162-S169.

Liang, M. & Guo, Y. (2012, June 14). *GDP 三年来首次破八 经济探底迹象显现* [GDP growth rate decreased below 8% for the first time in the past three years, a sign of the Chinese economy is approaching bottom]. Retrieved December 7, 2012, from http://finance.ifeng.com/news/special/data201206/20120714/6760203.shtml

Liu, J. (2013, March 5). China to scale of megacities in urbanization drive: Wen. *Xinhua*. Retrieved April 20, 2013, from http://news.xinhuanet.com/english/

Liu, Z., Wang, X., & Lei, M. (2012, July 13). *经济增速"破八" 稳增长如何发力?* [How does steady growth help when GDP growth rate is under 8%?]. *China Finance Corperation*. Retrieved September 4, 2013, from http://news.xinhua08.com

Longlive. (2012a, October 8). *龙力生物2 代纤维燃料乙醇供货石油系统* [Longlive starts providing 2nd-generation cellulosic fuel ethanol to the provincial petroleum supply system]. Retrieved February 10, 2013, from http://www.longlive.cn/news_detail/newsId=4a2fa12d-93f1-4025-8e46-5f5c09c387b8.html

Longlive. (2012b, May 14). *燃料乙醇* [Fuel ethanol]. Retrieved July 16, 2012, from http://www.longlive.cn/cptyy/&FrontComContent_list01-1344825016041CurrentIds=04329c29-f01e-4fdc-8609-cd0b4bd5b062__c9deb71b-1ca1-4170-8e29-a92a03572aa0&comContentId=c9deb71b-1ca1-4170-8e29-a92a03572aa0.html

MetOffice. (n.a.). *The Great Smog of 1952*. Retrieved February 5, 2013, from http://www.metoffice.gov.uk/education/teens/case-studies/great-smog

Meyer, D., Myelka, L., Press, R., Dall'Oglio, E. L., de Sousa Jr, P. T., & Grubler, A. (2012). *Historical Case Studies of Energy Technology Innovation: Brazilian Ethanol: Unpacking a Success Story of Energy Technology Innovation.* Retrieved March 8, 2013, from the International Institute for Applied Systems Analysis website: http://www.iiasa.ac.at/web/home/research/researchPrograms/TransitionstoNewTechnologies/13_Meyer_Brazil_Ethanol_WEB.pdf

Ministry of Commerce of China. (2011). *2020 年前中国石油需求增速将明显下降* [Growth rate of oil demand in China will significantly decrease by 2020]. Retrieved January 28, 2012, from http://www.mofcom.gov.cn/aarticle/hyxx/fuwu/201112/20111207888586.html

Ministry of Energy Protection. (2010). *中国机动车污染防治年报* [China Vehicle Emission Control Annual Report]. Rretrieved May 27, 2013, from Ministry of Enviromental Protecton of China website: http://wfs.mep.gov.cn/dq/jdc/zh/201011/P020101110336607260005.pdf

Ministry of Finance of China. (2013). "节能产品惠民工程"取得显著成效 [Remarkable effect of promoting energy saving products and benefiting people]. Retrieved from August 29, 2013, jjs.mof.gov.cn/zhengwuxinxi/diaochayanjiu/201307/t20130711_960347.html

Ministry of Finance & the Department of Science and Technologies of China. (2009). *财政部科技部下发通知补助使用节能与新能源汽车* [Ministry of Finance and Department of Science abd Technologies notify to provide subsidies to energy saving vehicles and new energy vehicles]. Retrieved February 25, 2011, from the Central People's Gvoernment of the People's Republic of China website: http://www.gov.cn/jrzg/2009-04/28/content_1298588.htm

Ministry of Industry and Information Technology of China. (2012). *制糖行业"十二五"发展规划* [The 12th Five Year Plan for Sugar Manufacturing Industry]. Retrieved June 16, 2013, from http://www.miit.gov.cn/n11293472/n11293877/n13434815/n13434832/n14445072.files/n14439675.pdf

Ministry of Land and Resources of China. (2013). *资源概况: 土地资源* [Briefing of land resources]. Retrieved May 12, 2013, from http://www.mlr.gov.cn/zygk/

More Chinese cities consider limiting car consumption. (2013, June 25). *ChinaAuto Web*. Retrieved August 19, 2013, from http://chinaautoweb.com/2013/06/more-chinese-cities-consider-limiting-car-consumption/

Moreira, A. (2011, February 13). Frota de veículos cresce 119% em dez anos no Brasil, aponta Denatran [The number of vehicles in Brazil grew 119% in the past ten years, says Denatran]. *Auto Esporte*. Retrieved October 7, 2013, from http://g1.globo.com

National Bureau of Statistics. (1996). *中国统计年鉴 1996* [China Statistical Yearbook 1996]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (1997). *中国统计年鉴 1997* [China Statistical Yearbook 1997]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (1998). *中国统计年鉴 1998* [China Statistical Yearbook 1998]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics (1999). *中国统计年鉴 1999* [China Statistical Yearbook 1999]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2000). *中国统计年鉴 2000* [China Statistical Yearbook 2000]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2001). *中国统计年鉴 2001* [China Statistical Yearbook 2001]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2002). *中国统计年鉴 2002* [China Statistical Yearbook 2002]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2003). *中国统计年鉴 2003* [China Statistical Yearbook

2003]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2004). *中国统计年鉴 2004* [China Statistical Yearbook 2004]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2005). *中国统计年鉴 2005* [China Statistical Yearbook 2005]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2006). *中国统计年鉴 2006* [China Statistical Yearbook 2006]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2007). *中国统计年鉴 2007* [China Statistical Yearbook 2007]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2008). *中国统计年鉴 2008* [China Statistical Yearbook 2008]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2009). *中国统计年鉴 2009* [China Statistical Yearbook 2009]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2010). *中国统计年鉴 2010* [China Statistical Yearbook 2010]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2011). *中国统计年鉴 2011* [China Statistical Yearbook 2011]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2012a). *中国统计年鉴 2012* [China Statistical Yearbook 2012]. Beijing: National Bureau of Statistics of China.

National Bureau of Statistics. (2012b, February 22). *中华人民共和国 2011 年国民经济和社会发展统计公报* [Statistics bulletin of national economy and social development in 2011]. *National Bureau of Statistics of China*. Retrieved May 17, 2012, from http://www.stats.gov.cn/tjgb/ndtjgb/qgndtjgb/t20120222_402786440.htm

National Bureau of Statistics. (2013, February 22). *中华人民共和国 2012 年国民经济和社会发展统计公报* [Statistics bulletin of national economy and social development in 2012]. *National Bureau of Statistics of China*. Retrieved May 17, 2013, from http://www.stats.gov.cn/tjgb/ndtjgb/qgndtjgb/t20130221_402874525.htm

National Development and Reform Commission of China. (2006). *中华人民共和国国民经济和社会发展第十一个五年规划纲要* [The 11th Five Year Plan of National Economic and Social Development of People's Republic of China]. Retrieved December 17, 2011, from http://news.xinhuanet.com/misc/2006-03/16/content_4309517.htm

National Development and Reform Commission of China. (2007). *可再生能源中长期发展规划* [Medium and Long-Term Development Plan for Renewable Energy in China]. Retrieved June 26, 2011, from http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/2007/20079583745145.pdf

National Development and Reform Commission of Chin. (2011). "*十二五"农作物秸秆综合利用实施方案* [The 12th Five Year Plan for a Comprehensive Utilization of Agricultural Residuse]. Retrieved February 11, 2012, from http://www.ndrc.gov.cn/zcfb/zcfbtz/2011tz/W020111219503630433351.pdf

National Development and Reform Commission of China. (2012). *可再生能源发展"十二五"规划* [The 12th Five Year Plan for Renewable Energy Development]. Retrieved February 15, 2013, from http://www.enpowertech.com/HtmlEdit/uploadfile/20121029144905686.pdf

National Development and Reform Commission of China. (n.a.). *Main Functions of the National Development and Reform Commission*. Retrieved August 11, 2013, from http://en.ndrc.gov.cn/mfndrc/default.htm

National Development and Reform Commission of China, Ministry of Public Security of China, Ministry of Finance of China, Ministry of Commerce of China, State Administration of Taxation of China, Ministry of Energy Protection, . . . General Administration of Quality Supervison, Inspection and Quarantine. (2004).*关于印发《车用乙醇汽油扩大试点方案》和《车用乙醇汽油扩大试点工作实施细则》的通知* [Printing and distributing notifications for "Pilot plan for the extension of using ethanol mixed gasoline as transportation fuels" and "Detailed rules to expand pilot work of using ethanol mixed gasoline]. Retrieved April 24, 2011, from State Administration of Taxation of China website: http://www.chinatax.gov.cn/n8136506/n8136563/n8193451/n8193556/n8194613/8250920.html

National Energy Administration. (2012).《中国的能源政策(２０１２)》白皮书 [The White Book of China's Energy Policy, 2012]. Retrieved March 7, 2013, from http://www.nea.gov.cn/2012-10/24/c_131927804.htm

Novozymes. (2010). *Biofuels improve energy securtiy* [Customer Communication]. Retieved June 23, 2013, from http://bioenergy.novozymes.com/en/the-basics/advantages/Documents/Info_2008-22370-04_200dpi.pdf

Organisation for Economic Co-operation and Development. (2005). *China in the Global Economy-Governance in China*. Retrieved May 29, 2011, from http://www.oecd-ilibrary.org/governance-in-china_5lh1rn41pckl.pdf?contentType=/ns/Book&itemId=/content/book/9789264008441-en&containerItemId=/content/serial/19900457&accessItemIds=&mimeType=application/pdf

Organisation for Economic Co-operation and Development. (2007). *OECD Environmental Performance Reviews: China*. Retrieved September 17, 2012, from http://www.oecd-ilibrary.org/docserver/download/9707051e.pdf?expires=1381871

892&id=id&accname=ocid194914a&checksum=85B5912F4D61EB9EDB61758A0242A6A7

Ou, X., Zhang, X., Chang, S., & Guo, Q. (2009). Energy consumption and GHG emissions of six biofuel pathway by LCA in (the) People's Republic of China. *Applied Energy, 86*(2009), S197-S208. doi:10.1016/j.apenergy.2009.04.045

Pan, X., Li, G., & Gao, T. (2012). *危险的呼吸: PM2.5 的健康危害和经济损失评估研究* [Dangerous Breath-an assessment of PM 2.5 impact on health and economic loss]. (1st ed.). Retrieved February 4, 2013, from GreenPeace website: http://www.greenpeace.org/china/Global/china/publications/campaigns/climate-energy/2012/dangerous-breath.pdf

Pear, R. (2012, January 1). After three decades, tax credit for ethanol expires. *The Ney York Times*. Retrieved March 20, 2013, from http://www.nytimes.com

Phoenix New Media. (2012, February 6). *人民币升值趋势延续 未来一年兑美元料至 6.13* [Continued appreciation of the RMB, projected ￥/$ ratio to achieve 6.13 in the next year]. Retieved July 10, 2012, from http://finance.ifeng.com/forex/rmb/20120206/5536980.shtml

Qingdao Institute of Bioenergy and Bioprocess Technology of Chinese Academy of Science. (2010). *中国生物能源发展现状与技术预见* [Development status and technologies prediction of bioenergy in China]. Retrieved March 19, 2011, from http://www.qibebt.cas.cn/xscbw/xxcp/ztbg/201110/P020111026499140612013.pdf

Qiu, H., Huang, J., Yang, J., Rozelle, S., Zhang, Y. [Yuhua]., Zhang, Y. [Yahui], & Zhang, Y.[Yanli] (2010). Bioethanol development in China and the potential impacts on its agricultural economy. *Applied Energy, 87*(1), 76-83. doi: 10.1016/j.apenergy.2009.07.015

Qiu, H., Sun, L., Huang, J. & Rozelle, S. (2012). Liquid biofuels in China: Current status, government policies, and future opportunities and challenges. *Renewable and Sustainable Energy Reviews*, 16(5), 3095-3104. doi:10.1016/j.rser.2012.02.036

Qu, Y., Zhu, M., Cheng, S., Lin, X., Bao, X., & Lin, J. (2006). *利用玉米芯加工残渣发酵生产纤维素酒精的方法* [Method of producing cellulosic ethanol from corncob residues] (Patent No. CN200610131965). Retrieved September 16, 2013, from State Intellectual Property Office of P.R.C website: http://211.157.104.87:8080/sipo/zljs/hyjs-yx-new.jsp?recid=CN200610131965.X&leixin=fmzl&title=%C0%FB%D3%C3%D3%F1%C3%D7%D0%BE%BC%D3%B9%A4%B2%D0%D4%FC%B7%A2%BD%CD%C9%FA%B2%FA%CF%CB%CE%AC%CB%D8%BE%C6%BE%AB%B5%C4%B7%BD%B7%A8&ipc=C12P7/10%282006.01%29I

Rabinovitch, S. (2011, October 25). China labour costs soar as wages rise 22%. *Financial*

Times. Retrieved January 9, 2012, from http://www.ft.com

Renewable Energy Development Center of National Development and Reform Commission. (2008). *中国生物液体燃料规模化发展研究(总报告)* [A Study of Large-scale Biofuels Development in China (General Report)]. Retrieved June 5, 2011, from The China Sustainable energy Program website: http://www.efchina.org/csepupfiles/report/20111253511476.3956112152238.pdf/中国生物液体燃料规模化发展研究.pdf

Rosenberg, J. (n.a.). *The Great Smog of 1952*. Retrieved February 7, 2013, from http://history1900s.about.com/od/1950s/qt/greatsmog.htm

Shi, J. (2012). *中国汽车工业发展情况介绍* [Introduction of Chinese Auto Industry Development] [PowerPoint slides]. Retrieved March 15, 2013, from *Automotive News* website: http://www.autonews.com/Assets/html/12_ancc/pdf/pres_jianhua_zh.pdf

Shi, Y. (2011). 中国生物质原料资源 [China's resources of biomass feedstock]. *中国工程科学, 13*(2), 16-23. doi:1009-1742(2011)02-0016-08

Sims, R., Taylor, M., Saddler, J., & Mabee, W. (2008). *From 1st-to-2nd-Generation Biofuel Technologies: An overview of current industry and RD&D activities (Extended Executive Summary)*. Retrieved December 6, 2010, from International Energy Agency website: http://www.iea.org/publications/freepublications/publication/2nd_Biofuel_Gen_Exec_Sum.pdf

State Council of China. (2009). *汽车产业调整和振兴规划* [Adjustment and Prosperity Plan for Auto Industry]. Retrieved October 26, 2012, from the Central People's Government of the People's Republic of China website http://www.gov.cn/zwgk/2009-03/20/content_1264324.htm

State Council of China. (2012a). *节能与新能源汽车产业发展规划（2012－2020 年）* [Automobile industry development plan of energy saving and new energy vehicles (2012-2020)]. Retrieved February 4, 2013, from the Central People's Government of the People's Republic of China website: http://www.gov.cn/zwgk/2012-07/09/content_2179032.htm

State Council of China. (2012b). *"十二"五国家战略性新兴产业发展规划* [The 12th Five Year Plan of national strategical emerging industries development plan]. Retrieved March 22, 2013, from the Central People's Government of People's Republic of China website: http://www.gov.cn/zwgk/2012-07/20/content_2187770.htm

State Council of China. (2013). *能源发展"十二五"规划 [*The 12th Five Year Plan of Energy Development]. Retrieved September 17, 2013, from the Central People's

Government of the People's Republic of China website: http://www.gov.cn/zwgk/2013-01/23/content_2318554.htm

Schnepf, R. & Yacobucci, B. D. (2013). *Renewable Fuel Standard (RFS): Overview and Issues*. Retrieved September 30, 2013, from Congress Research Service website: http://www.fas.org/sgp/crs/misc/R40155.pdf

State Forestry Administration of China. (2004). *中国林业统计年鉴 2003* [China Forestry Statistical Yearbook 2003]. 北京: 中国林业出版社

State Forestry Administration of China. (2005). *中国林业统计年鉴 2004* [China Forestry Statistical Yearbook 2004]. 北京: 中国林业出版社

State Forestry Administration of China. (2006). *中国林业统计年鉴 2005* [China Forestry Statistical Yearbook 2005]. 北京: 中国林业出版社

State Forestry Administration of China. (2007). *中国林业统计年鉴 2006* [China Forestry Statistical Yearbook 2006]. 北京: 中国林业出版社

State Forestry Administration of China. (2008). *中国林业统计年鉴 2007* [China Forestry Statistical Yearbook 2007]. 北京: 中国林业出版社

State Forestry Administration of China. (2009). *中国林业统计年鉴 2008* [China Forestry Statistical Yearbook 2008]. 北京: 中国林业出版社

State Forestry Administration of China. (2010a). *中国林业统计年鉴 2009* [China Forestry Statistical Yearbook 2009]. 北京: 中国林业出版社

State Forestry Administration of China. (2010b). *第七次全国森林资源清查主要结果 (2004-2008 年)* [Key results for the 7th assessment of domestic forest resource]. *State Forestry Administration of China.* Retrieved April 13, 2011, from http://www.forestry.gov.cn/portal/main/s/65/content-326341.html

State Forestry Administration of China. (2011a). *中国林业统计年鉴 2010* [China Forestry Statistical Yearbook 2010]. 北京: 中国林业出版社

State Forestry Administration of China. (2011b). *林业局印发林业生物能源原料基地检查验收办法*[The State of Forestry Admininstration of China prints and distributes the inspect for acceptance guidelines of forest bioenergy feedstock base]. Retrieved April 5, 2012, from the Central People's Government of the People's Republic of China website: http://www.gov.cn/gzdt/2011-05/26/content_1871324.htm

State Forestry Administration of China. (2012). *2011 年全国林业统计年报分析报告* [Analysis Report of 2011 Nationwide Forestry Statistics Annual Report]. Retrieved January 10, 2013, from http://www.forestry.gov.cn/uploadfile/main/2012-5/file/2012-5-15-374ecfc1461842f685d6db6b9d47fea1.pdf

State Forestry Administration of China. (2013). *全国林业生物质能发展规划(2011-2020 年)*

[National Forestry Biomass Energy Development Plan (2011-2020)]. Retieved October 6, 2013, from http://www.forestry.gov.cn/uploadfile/main/2013-6/file/2013-6-13-849baa6325bb40a59e559641beaa9ee0.pdf

Stephen, J. D., Mabee, W. E., & Saddler, J. N. (2010). Biomass logistics as a determinant of second-generation biofuel facility scale, location and technology selection. *Biofuels, Bioproducts and Biorefining, 4*(5), 503-518. doi:10.1002/bbb.239

Stephen, J. D., Mabee, W. E., & Saddler, J. N. (2011). Will second-generation ethanol be able to compete with first-generation ethanol? Opportunities for cost reduction. *Biofuels, Bioproducts and Biorefining, 6*(2), 159-176. doi:10.1002/bbb.331

Sugarcane Industry Association of Brazil (UNICA) (2008). *Sugarcane producing regions in Brazil*. Retrieved June 12, 2013, from http://www4.lu.se/upload/Humanekologi/Hermele.Regulating.Sugarcane.Cultivation.in.Brazil.pdf

Tao, J., Yu, S., & Wu, T. (2011). Review of China's bioethanol development and a case study of fuel supply, demand and distribution of bioethanol expansion by national application of E10. *Biomass and Bioenergy, 35*(9), 3810-3829.dio: 10.1016/j.biombioe.2011.06.039

The Climate Institute. (2007). *China's Greenhouse Pollution*. Retrieved August 11, 2011, from http://www.climateinstitute.org.au/verve/_resources/chinareport.pdf

Tian, Y. (2010). 中国第二代生物燃料资源 发展潜力分析 [Analysis of biomass resource potential for the development of 2nd generation biofuels in China]. *中国能源, 32*(7), 17-20. doi :10.3969/j.issn.1003·2355.2010.07.003

Tian, Y., Zhao, L., Meng, H., Sun, L., & Yan, J. (2009). Estimation of un-used land potential for biofuels development in (the) People's Republic of China. *Applied Energy, 86 (Supplement 1)*, S77-S85.

Tyner, W.E., & Viteri, D. (2010). Implications of blending limits on the US ethanol and biofuels markets. *Biofuels, 1*(2), 251-253.

UNHabitat. (2011). *Cities and Climate Change: Global Report on Human Settlements 2011* (2011 ed.). Rretrieved July 10, 2012, from http://www.unhabitat.org/downloads/docs/GRHS2011_Full.pdf

US Department of Energy. (2011). *US Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industr* (Report No. ORNL/TM-2011/224y). Retrieved February 9, 2013, from Office of Energy Efficiency & Renewable Energy of USDA website: http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf

US Department of Energy. (2013). Flexible Fuel Vehicles. Retrieved October 12, 2013, from http://www.afdc.energy.gov/vehicles/flexible_fuel.html

US Department of Transportation. (2011). Table 1-11: Number of US Aircraft, Vehicles, Vessels, and Other Conveyances. Retrieved May 10, 2013, from http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html

US Energy Information Administration. (2010). *Annual Energy Review 2009*. (Report No. DOE/EIA-0384(2009)). Retrieved July 16, 2011, from ftp://ftp.eia.doe.gov/multifuel/038409.pdf

US Energy Information Administration. (2011). *History of energy consumption in the United States, 1775–2009*. Retrieved July 26, 2012, from http://www.eia.gov/todayinenergy/detail.cfm?id=10

US Energy Protection Agency. (2013, March 18). Particulate Matter (PM). Retrieved April 10, 2013, from http://www.epa.gov/pm/

Wagner, D. V., An, F., & Wang, C. (2009). Structure and impacts of fuel economy standards for passenger cars in China. *Energy Policy, 37*(10), 3803-3811.

Waldmeir, P. (2013, April 11). Urban middle class boosts China car sales. *Financial Times*. Retrieved July 16, 2013, from http://www.ft.com

Wang, J. (2004). 中国石油安全与地缘政治. [China Petroleum Security and Geography Politics]. *资源·产业, 6*(1), 3-7. doi:10.3969/j.issn.1673-2464.2004.01.001

Wang, L. (2008). 改革开放以来我国能源消费的影响因素以及面临的问题. [Attribution Factors and Problems of Energy Consumption since the Reform and Open-up in China]. *教学与研究, 2008*(10), 29-36. doi:10.3969/j.issn.0257-2826.2008.10.004

Wang, X., Yang, L., Steinberger, Y., Liu, Z., Liao, S., & Xie, G. (2013). Field crop residue estimate and availability for biofuel production in China. *Renewable and Sustainable Energy Reviews*. 27, 864-875. doi:10.1016/j.rser.2013.07.005

Wang, Z., Huang, H., Fan, L.J., Wang, W., Sun, P., Liu, J., … Zheng, K. (2012). *The Renewable Industry Development Report 2011 (Chinese-English)* (1st ed.). Retrieved August 9, 2013, from China Renewable Energy Information Portal website: http://www.cnrec.info/go/AttachmentDownload.aspx?id={e5111e6c-6b45-4cf7-916e-659ae1eccea3}

WardsAuto. (2013). *U.S. Car and Truck Sales, 1931-2012*. Retrieved October 6, 2013, from http://wardsauto.com/keydata/historical/UsaSa01summary

Weiss, W., & Mauthner, F. (2012). *Solar Heat Worldwide--Markets and Contribution to the Energy Supply 2010 (Ed. 2012)*. Retrieved January 17, 2013, from AEE-Institute for Sustainable Technologies website: http://www.iea-shc.org/Data/Sites/1/publications/Solar_Heat_Worldwide-2012.pdf

World Health Organizaton. (n.a.). *Public Health and Environment (PHE)-Database: outdoor air pollution in cities.* Retrieved February 26, 2013, from http://www.who.int/phe/health_topics/outdoorair/databases/en/

World Bank. (2012a). *Agriculture, value added (% of GDP)*. Retrieved July 18, 2013, from http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

World Bank. (2012b). *Forest area (% of land area)*. Retrieved July 18, 2013, from http://data.worldbank.org/indicator/AG.LND.FRST.ZS/countries

World Bank. (2012c). *Industry, value added (% of GDP)*. Retrieved July 18, 2013, from http://data.worldbank.org/indicator/NV.IND.TOTL.ZS

World Bank. (2012d). *Services, etc., value added (% of GDP)*. Retrieved July 18, 2013, from http://data.worldbank.org/indicator/NV.SRV.TETC.ZS

World Bank. (2013a). *GDP (current US$)*. Retrieved July 18, 2013, from http://data.worldbank.org/indicator/NY.GDP.MKTP.CD

World Bank. (2013b). *GDP growth (annual %)*. Retrieved July 18, 2013, from http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG

Wu, Q. (2010, August 30). 《节能与新能源汽车发展规划(2011 年至 2020 年)》征求意见稿述评[Assessing the draft of "*Automobile industry development plan of energy saving and new energy vehicles (2012-2020)*"]. *OAUTO*. Retrieved April 8, 2012, from http://mag.oauto.com

Xie, G., Wang, X., & Ren, L. (2010). 中国作物秸秆资源评估研究现状 [China's crop residues resources evaluation]. *生物工程学报, 26*(7), 855-863.

Xu, X., Wang, X., Jin, M., & Wu, X. (2008) 甜高粱生产燃料乙醇的研究进展 [Researh progress of using sweet sorghum for ethanol production]. *现代化工*, 28(3), 17-21.

Yan, Z., Zhang, L., Wang, S., & Hu, L. (2008). 中国能源作物生产生物乙醇的潜力及分布特点 [Potential yields of bio-ethanol from energy crops and their regional distribution in China]. *农业工程学报, 24*(5), 213-216. doi: 1002-6819(2008)-5-0213-04

Yang, J. (2013, November 1st). China's auto market likel to maintain steady growth despited challenges. *Automotive News China*. Retrieved November 5, 2013, from http://www.autonewschina.com

Yuan, M. & Zhuang, Z. (2009). The impact and countermeasures of RMB appreciation of export-based enterprises in China. *International Journal of Marketing Studies, 1*(1), 85-89.

Zhang, C., Xie, G., Li, S., Gai, L., & Qi, Y. (2010). 中国能源作物甜高粱的空间适宜分布及乙醇生产潜力[Spatial suitability and its bio-ethanol potential of sweet sorghum in China]. *生态学报, 30*(17), 4765-4770.

Zhang, P., Yang, Y., Tian, Y., Yang, X., Zhang, Y., Zheng, Y., & Wang, L. (2009). Bioenergy industries development in China: Dilemma and Solution. *Renewable and Sustainable Energy Reviews, 13*(9), 2571-2579. doi:10.1016/j.rser.2009.06.016

Zhang, Y. (2011). 张永利在全国林业生物质成型燃料现场会上的讲话 [The speech of Yongli Zhang, Deputy Director of the State Forestry Administration of China, on the national conference of forestry biomass derived pellets and briquettes]. Retrieved December 7, 2012, from http://www.forestry.gov.cn/portal/main/s/2672/content-522667.html