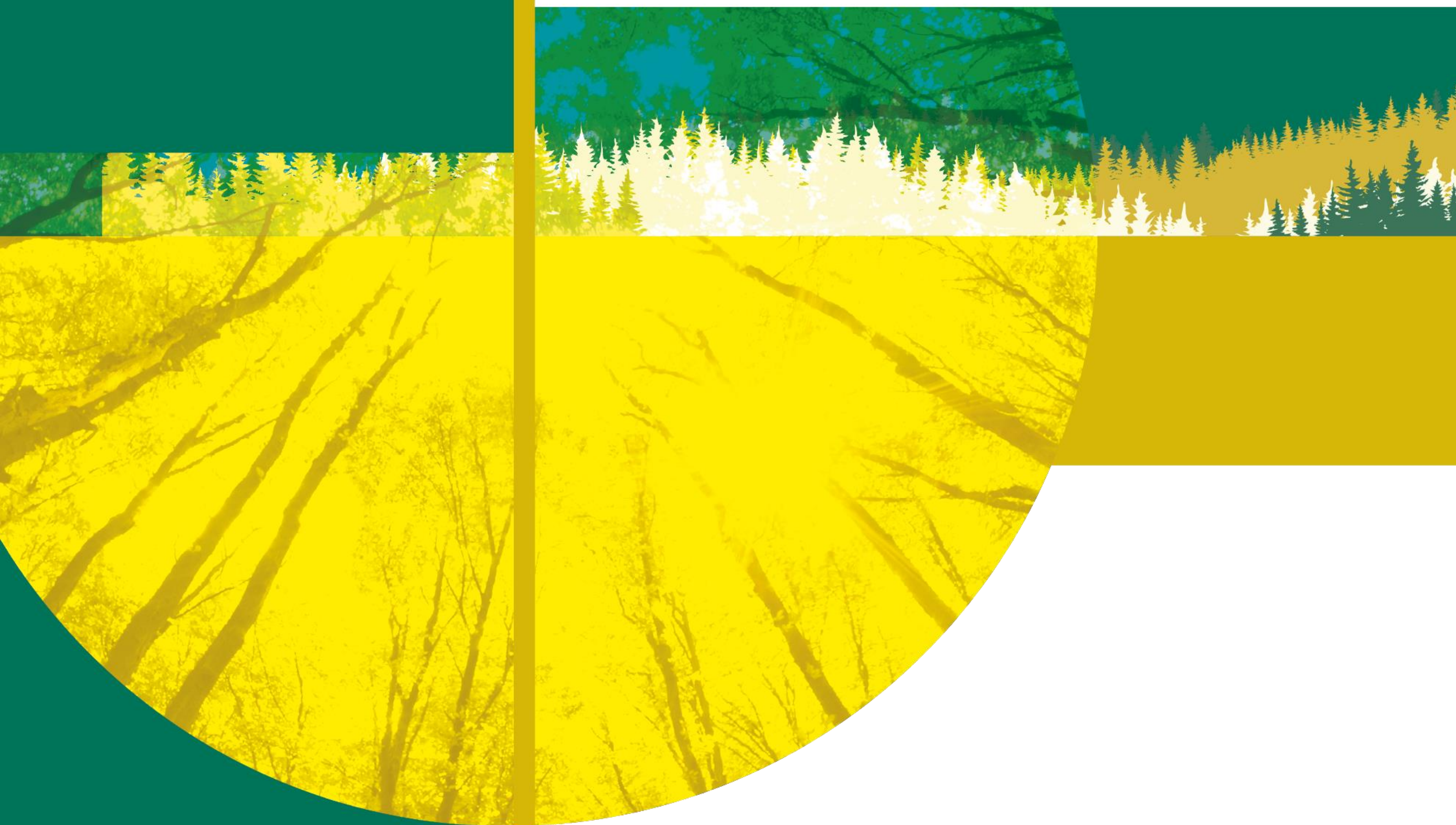
The Potential of Biofuels in China



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The Potential of Biofuels in China

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Executive summary

China now has the largest economy in the world. As a result, it will face an ever-increasing energy demand for the foreseeable future. In 2013, China surpassed the USA as the largest net importer of petroleum and other oil based liquids. It also accounted for more than a quarter of the world's growth in oil consumption. Oil demand is primarily driven by a growing economy with one indication being China's current status as the world's biggest car market with sales of new vehicles expanding due to the country's growing middle class. However, this increasing demand for fossil fuels has also contributed to the country's increasing energy security concerns. As a result, China has taken steps to secure energy supply through various strategies such as intensive domestic exploration, investment in overseas oil companies, securing long-term contracts with suppliers of fossil fuels, such as natural gas from Russia and investing heavily in renewable forms of energy.

At the same time as China's economy has rapidly grown it has also become the world's largest CO_2 emitter and faces growing concerns over air pollution. Thus, climate change mitigation and pollution abatement, particularly in its cities, have also become important policy drivers for the country. This is indicated by China's signing of the recent UNFCCC COP21 agreement and the country's 13th five-year plan that was released in March 2016. This most recent five-year plan described a large number of binding commitments to aid in environmental reform.

Since the oil crisis of the 1970's energy security and climate change mitigation requirements have been the main motivators behind most countries' desire to develop biofuels. Although climate change and energy security are also of concern to China, it is not clear which of these drivers has been the primary motivator for biofuels development. However, the policies that China has implemented so far to help develop biofuels have resulted in the country becoming the world's third largest ethanol producer. The country currently produces about 3 billion litres of ethanol and about 1.14 billion litres of biodiesel per year. Although the Chinese government has set ambitious targets to increase annual biofuels production to12.7 billion litres of ethanol and 2.3 billion litres of biodiesel by 2020, it is highly unlikely that these targets will be met. It is worth noting that biofuels development and use received little attention in the country's recently released 13th five-year plan. Unlike other forms of renewable energy, no exact output targets were given for biofuels.

Unlike stationary power, which can be derived from multiple sources including solar, hydro and wind, transportation has limited options available for decarbonisation. Although biofuels can potentially alleviate energy security concerns and make an important contribution to reducing transportation emissions and air pollution, it seems that the most recent central government policies have primarily focussed on the development of "new energy vehicles" (electric and hybrid vehicles). However, it is worth noting that electric vehicle expansion based on coal-derived electricity will have a limited impact on emissions.

China's biofuels policies have mainly focused on ethanol production with about 99% of the ethanol produced in China based on conventional starch-based feedstocks. Current ethanol production has been developed within a highly regulated environment as no facilities can be built unless government approval is obtained. All ethanol production and distribution is controlled by state-owned oil companies and only state approved companies can carry out blending and receive incentives and subsidies. Although an E10 mandate is in place in four provinces and 27 cities, no blending can take place outside of these areas. The price of the ethanol that blenders have to pay producers is fixed at 91.1% of the price of gasoline. As a result, there are no incentives in place for consumers to preferentially purchase ethanol containing fuels as the blended fuel costs the same price as the unblended fuel.

After the initial development of ethanol production facilities based on stale grain reserves in 2007, the government banned further bioethanol development based on grains. Instead they encouraged the production of so-called 1.5 generation feedstocks such as cassava, sweet potato and sweet sorghum. A further two ethanol facilities were supposed to be developed based on cassava and one based on sweet sorghum. These 1.5 generation crops were supposed to be predominantly grown on marginal lands. However, this approach has had limited success, with land and water availability proving to be significant challenges while these supposed biofuels feedstocks still compete with food production.

The commercial development of so-called second generation/advanced biofuels based on cellulosic feedstocks has been limited to small volumes. Currently there is only one demonstration/commercial scale facility using corn cobs as the feedstock. However, it appears that there is considerable potential for further cellulosic ethanol production based on a range of agricultural residue feedstocks. Preliminary assessments of agriculture residue availability indicate that there should be significant quantities available for ethanol production, even based on conservative estimates. However, far more detailed studies need to be carried out to determine realistic availability within an economically viable radius. At the same time, a detailed assessment of the likely supply chain challenges that might be encountered in China needs to be carried out. (i.e. small-scale farming versus large-scale commercial farming; manual harvesting versus mechanical harvesting; topographical factors such as terrace farming; and the viability of large-scale collection of rice straw). These further analyses will be better able to distinguish between the theoretical and actual potential of making advanced/second generation bioethanol in specific locations.

Although several international companies such as DuPont, Beta Renewables and Novozymes have announced plans for construction of commercial scale cellulosic ethanol facilities in China, in partnership with existing ethanol producers, the current low price of oil has delayed these developments. Thus, it is unlikely that the commercial development of cellulosic ethanol will occur in time to meet the government’s ethanol targets for 2020. However, this conversion technology is probably the best opportunity for the country to expand ethanol production, in addition to achieving its climate change mitigation and emission reduction targets for transport.

Unlike the ethanol industry the biodiesel industry has developed slowly, is dominated by small-scale private businesses and is largely unregulated. No mandate for biodiesel blending exists, except for a small trial in two counties in Hainan province. There are also limited incentives to carry out biodiesel blending. The vast majority of the biodiesel that is produced is used by industry, with only about 30% used for transport. Market penetration for biodiesel has been very limited as state-owned oil companies own 90% of the gas stations and they have not encouraged biodiesel use.

Virtually all of the biodiesel that is produced is based on used cooking oil as the feedstocks. Although large volumes of so-called "gutter oil" are produced in China, competition from illegal re-use in food applications has resulted in supply availability challenges. The central government's strategy of developing 1.5 generation oilseed-bearing trees and crops such as *Jatropha* as the feedstocks has had limited success to date. Although biodiesel production targets are modest and could possibly be achieved, further expansion is likely to be limited. Although there is approximately equal demand for gasoline and diesel in China's transportation supply chain, biodiesel market penetration and production targets have been very low compared to ethanol. Early indications are that compressed natural gas vehicles, particularly for haulage, may be preferentially developed ahead of biodiesel. Although imported biofuels could potentially be used to meet government targets this is likely to remain limited as current regulations do not allow any imported ethanol to be used for transport.

The experience in other jurisdictions such as Brazil, the EU and the US has shown the essential role the supporting policies play in creating demand, stimulating production and facilitating research, development and commercialisation of biofuels. Although the Chinese government has implemented some policy support for biofuels, these policies have primarily focused on ethanol, have lacked integration and have had a limited impact on the development of biofuels. For example, the most recent 13th Five-year Plan makes limited mention of biofuels implying that biofuels will likely play only a minor role in China's decarbonisation of its transport sector.

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1. Introduction

China is a global superpower which already has, or soon will have, the largest economy in the world. Although China has been a major player in the investment and promotion of renewable energy, through its interest in developing hydro, solar and wind, bioenergy and biofuels in particular have constituted a much smaller component. China has set a target of having15% renewables within its energy mix by 2020. The country's climate action plans, as submitted to the UNFCCC COP21 climate summit meeting in Paris and as recently published in China's13th Five-year plan, describe clear goals with respect to emissions reductions. China is the world's biggest importer of oil and, with the severe air pollution that is regularly encountered in its cities, it might be expected that biofuels development would form an important part of the government strategy to address these issues.

China has promoted biofuels production and consumption since early 2000s and it is currently the third largest bioethanol producer worldwide. However, production volumes are still relatively small, with an estimated 3.08 billion litres of ethanol and 1.14 billion litres of biodiesel produced in 2015 (USDA, 2015). Although ethanol production is projected to grow by 2.6% in 2016, and biodiesel production is expected to remain the same, the government has set 2020 production targets of 10 Mt ethanol (12.7 billion litres) and 2 Mt (2.3 billion litres) of biodiesel. It is very unlikely that these goals, and the ethanol target in particular, will be reached.

While most indications are that biofuel expansion will be very limited some Chinese reports are very optimistic, with Chen et al (2016) describing a potential capacity of non-food biofuels from 2015-2030 of 75.6-152.13 million metric tonnes (based on a feedstock availability analysis).

1.1 ENERGY SUPPLY AND DEMAND

China has experienced a compressed industrialization process over the past two decades, resulting in rapid economic development and rapid growth in energy consumption. China became the second largest economy in the world in the early 2000s and it has been the world's largest energy consumer since 2010 (IEA, 2010; EIA, 2014a). The increase in China's share in the global economy leaped from less than 4% in 1990 to 10% by 2006 and it is projected to be over 18% by 2019 (IMF, 2014).

Over this time the Chinese consumption patterns have also changed significantly with the increased disposable income of the country's growing middle class leading to even higher levels of energy demand from both manufacturing of consumer goods and powering household items such as refrigerators, televisions, computers, etc. The growth in Chinese GDP per capita has grown from less than US$800 in 1990 to roughly US$7,500 in 2010 (Figure 1). It is expected to double to close to US$15,000 by 2018 (IMF, 2014).

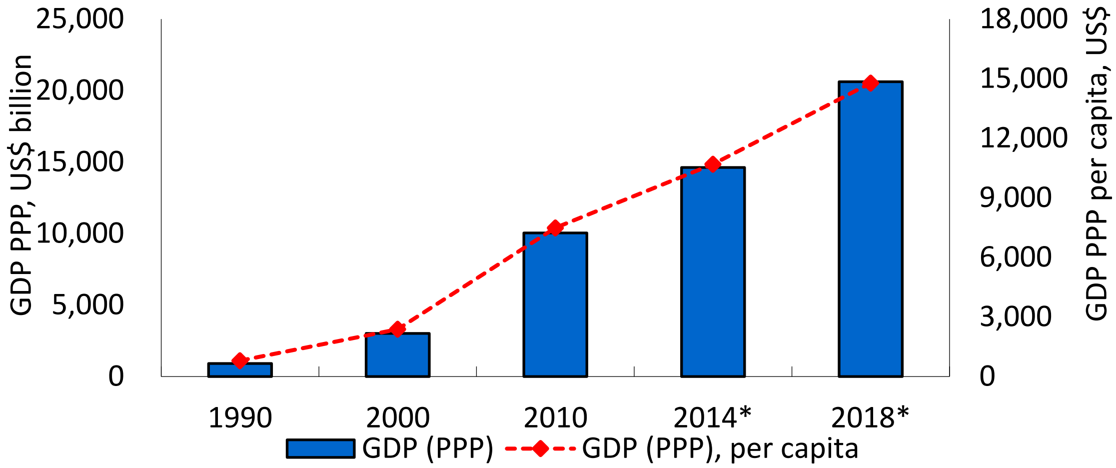

*Figure 1. China's GDP (PPP) and GDP (PPP) per capita (selected years); source: IMF (2014), *IMF estimate.*

The IEA projects that China's total primary energy demand will grow from 2,909 Mtoe in 2012 (≈ 121.8 EJ) to 4,185 Mtoe (≈ 175.2 EJ) by 2040 (IEA, 2014f). Although China had been energy self-sufficient until the 1990's, by 2000 net energy imports represented 2.7% of the country's energy use and by 2011 this number had grown to 10.8% (World Bank).

Most of China's energy is derived from non-renewable sources with coal (66.2%), oil (18.8%), and natural gas (5.4%) supplying approximately 90% of all energy in 2012 (Figure 2, China, 2013). China is the world's biggest producer, importer, and consumer of coal (IEA, 2014b). Although China was the 4th largest oil producer in 2012, it has been a net crude oil importer since 1996 (IEA, 2014b).

China's natural gas consumption has grown since the 2000s with its contribution to energy demand doubling from 2.6% in 2005 to 5.2% in 2012. To try to ensure security of supply, in 2014 China signed two major agreements with Russia for it to supply natural gas over a 30-year period (Martin, 2014; Paton & Guo, 2014). Hydropower currently constitutes 7.8% of China's energy mix, wind 1.1% and biofuels about 0.1%.

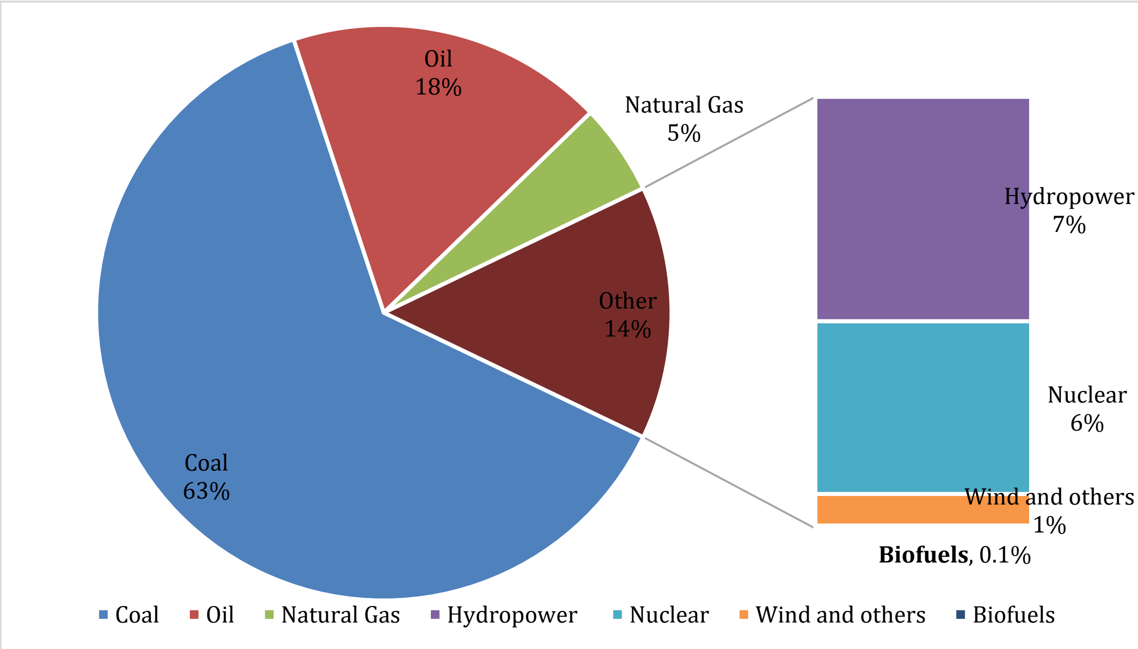

Figure 2. China's total primary energy consumption in 2012; source: based on data from CNREC (2014).

The predominance of fossil-based energy sources (particularly coal) used in China has resulted in high levels of GHG emissions and air pollution. China released 9680 million tons CO2 in 2014 (Global Carbon Atlas, 2014) and in 2012 it was estimated that less than 1% of China's 500 largest cities met the air quality standards recommended by the World Health Organization. Seven Chinese cities were ranked among the 10 most polluted cities in the world (Zhang & Crooks, 2012). It is estimated that the economic cost of the health impacts from outdoor pollution in China was about USD 1.4 trillion in 2010 and close to 1.3 million deaths in the same year were attributable to ambient air pollution (OECD, 2014).

Since the mid-2000s the Chinese government has actively sought to address the country's high dependence on fossil fuels by encouraging the development of renewable and non-fossil energy sources. This has resulted in significant growth in the contribution that renewable energies now make to China's overall energy consumption (Figure 3).

Hydropower is the biggest source of renewable energy, contributing 81% of all renewable energy (CNREC, 2014). China was the world's largest investor in hydropower, wind, solar, solar PV, and solar water heating capacities in 2013, with China investing more in renewable energy than all of Europe combined. It also invested more in renewable power capacity than it did in fossil fuels (REN21, 2014). Since the middle of2014, China has been the country with the greatest total capacity and generation capability of renewable power. China has global leadership in the production of hydroelectricity, wind, and solar energies (REN21, 2014; Clover, 2014). By 2040 it is estimated that China alone will account for more than one-quarter of the global expansion in renewables-based power generation (IEA, 2014f).

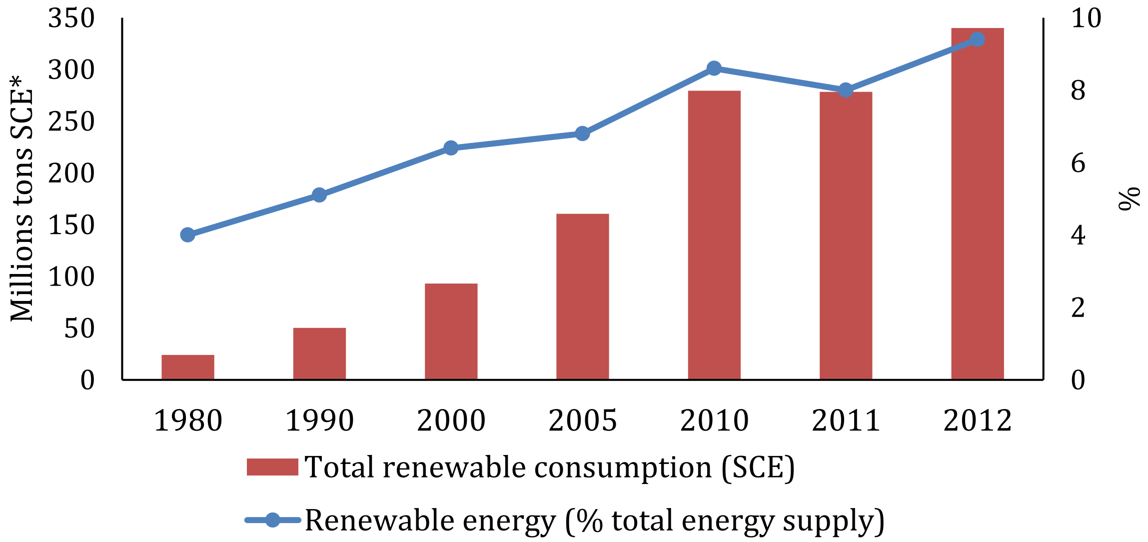

*Figure 3. China's renewable energy consumption, absolute and relative to total energy (selected years); source: based on data from China (2013); *SCE=Standard Coal Equivalent*

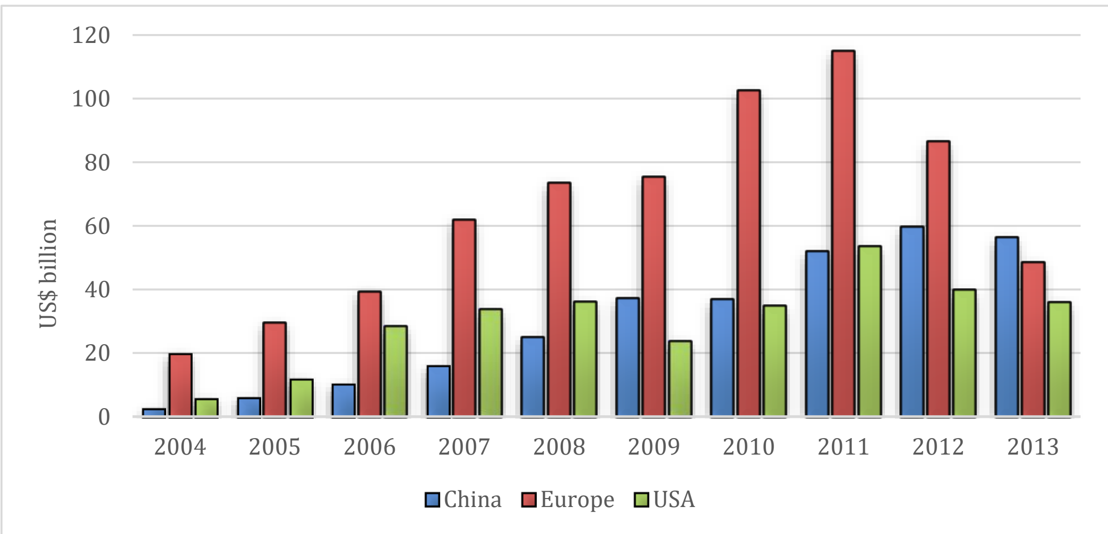

Figure 4. New Investment in Renewable Power and Fuels: China, Europe, and US (2004-2013); source: based on data from REN21 (2014)

Domestic production of renewable energies for 2005 and 2010, as well as targets to 2020 are detailed in Table 1.

Table 1. China's renewable energies production, by source (selected years)

Source	2005 levels	2010 planned[b]	reached	target 2015	2020
Hydro (GW)	117[d]	190	216[d]	290[e]	420[d]
Nuclear (GW)	8.7[g]	12	10.8[b]	40[e]	40-45[b]-58[c]
Solar (GW)	0.07[a]	0.3	0.9[d]	21[e]	50[d]
Wind (GW)	1.26[a]	5[h]	31[d]-42[a]	100[e]	200[d]
Biomass (GW)	2[d]	5.5	5.5[d]	13[d]	30
Biogas (billion m^3)	7[d]	19	14[b]	22[e]	44
Biofuels (million tons)	0.9[f]	2.2	2.2[f]	5[e]	12
(billion liters)	1.1	2.8	2.7	6.2	15.0
Ethanol (million tons)	0.9[f]	2	1.7[f]	4[e]	10
(billion liters)	1.1	2.5	2.2	5.1	12.7
Biodiesel (million tons)	-	0.2	0.5[f]	1[e]	2
(billion liters)	-	0.2	0.6	1.1	2.3

Sources: based on data from (a) Campbell, 2014; (b) Yuan et al., 2014; (c) EIA, 2014a; (d) CNREC, 2014; (e) China, 2012a; (f) USDA, 2013; (g) IEA, 2013; (h) Chang et al., 2012.

1.2 TRANSPORTATION FUEL USE, VEHICLE SALES AND THE RISE OF "NEW ENERGY/ELECTRIC VEHICLES"

It has been estimated that roughly two-thirds of China's growth in total oil demand between 2013 and 2019 will be due to growth in transportation fuels (IEA, 2014c) and that oil demand for transportation will rise from 221 Mtoe in 2012, to 417 Mtoe in 2030, and 507 Mtoe in 2040 (IEA, 2014f).

The USDA's estimates for total gasoline and diesel demand in China (Table 2) note that diesel volumes include industrial applications, not just on-road use, and that when this is taken into consideration, transport related diesel use is similar to the gasoline volumes that are used (USDA, 2015).

Table 2. Fuel use projections in billion litres (rounded) (USDA, 2015)

Fuel (billion litres)	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Gasoline	145	153	162	170	180	190	194	198	202	206	211
Diesel	208	211	214	217	221	225	227	230	233	235	238

Following a growth spike in 2010 oil demand in China has decelerated (EIA, 2015), primarily as a result of a decline in diesel demand. This was due to several factors such as; slower economic growth, decrease demand from the coal and mining sectors that transport products via rail and trucks, greater efficiency in heavy-duty vehicles, and increased use of natural gas-fired vehicles.

According to the EIA, gasoline demand was still increasing as a result of growth in light-duty vehicle sales, partly due to China's expanding middle class. The US EIA report further states that, "Future gasoline consumption will depend on the pace of economic development and income growth, fuel efficiency rates, and government regulations on passenger vehicle use in certain congested urban areas" (EIA, 2015).

Over the last few years the world's largest automobile market has shifted from the US to China. In 2009, the Chinese government provided its automotive sector a one-year subsidy of US$960 million dollars as well as a tax reduction ranging between 5% and 10% to stimulate the production and consumption of "small engine capacity" cars. One result of this strategy was that China surpassed the US and became the world's largest automobile market resulting in anthe average annual growth rate (AAGR) of car sales of 24% from 2005 to 2011. Although growth has slowed down, it is still in double digits according to a recent report published by Scotiabank (Scotiabank, 2016).

More recently the Chinese government has emphasised the production and expanded use of so-called "new energy", electric and hybrid vehicles (Yuan et al. 2015). The need to develop "new energy vehicles" is profiled in many of China's policies, including the recent INDC submitted to the UNFCCC COP21. The enhanced role of electric vehicles was part of China's 'Development Plan for an Energy-Saving and Alternative-Energy Automotive Industry (2012-2020)' which set goals to achieve: 1) an accumulated production and sales of pure-electric and plug-in hybrid vehicles at 500,000 units by 2015, and 2) a cumulative production and sales of more than 5 million cars by 2020 (IEA, 2014e). However, despite electric vehicle production starting in China in 2005, according to the China Association of Automobile Manufacturers, only 74,763 electric vehicles were sold in 2014 (*CAAM,* 2015). While this represents a 320% increase from the previous year, it still only represents 12% of the 2015 production target for alternative vehicles. Thus, the target of producing 5 million electric vehicles by 2020 seems quite ambitious. In the same way that the Chinese government stimulated overall automobile production, the state is also trying to enhance the production of electric vehicles through various policy drivers that would make it easier for electric vehicle manufacturers to enter the market (Bloomberg, 2014a). Related policies are also aimed at stimulating sales of electric vehicles through consumer incentives including subsidies for purchase of electric vehicles (exemption from 10% purchase tax) and waiver for license fees (which can amount to as much as $12,000 in Shanghai). However, greatest success has occurred in those specific areas which have encountered heavy air pollution (Beijing, Tianjin, Hebei, Yangtze River Delta (Shanghai region) and Pearl River Delta (Guangzhou region) where new energy vehicles have accounted for 15% of government vehicle purchases in 2014 (USDA, 2015). Although new energy vehicles were supposed to account for 10% of new vehicle purchased by government over the last few years, with this supposedly increasing to 20% by 2015 and 30% by 2016 (USDA, 2015), Chinese consumers have complained about the inadequacy of the infrastructure required to charge vehicles and this continues to be a major challenge which will restrict the expansion of electric vehicle use (Bloomberg, 2014b; Levin, 2015).

Although new energy vehicles could potentially reduce localised air pollution in cities, the vast majority of Chinese electricity is still generated via coal-fired power plants. Thus, this limits the capacity of electric vehicles to reduce overall pollutant emissions, even if this strategy does help reduce direct emissions from transportation (Ji et al., 2012; OECD, 2014).

Compressed natural gas is another alternative to gasoline and China's government has a goal of having 3.8 million cars, trucks, and buses operating on compressed or liquefied natural gas by 2020 as part of an overall targeted of having natural gas contribute 10% of the country's total energy consumption by 2020. China has a network of 4,900 refueling stations and recently completed a $400 billion agreement with Russia to supply natural gas (Bloomberg, 2014c). However, natural gas is still a fossil fuel and it will have a limited effect on mitigating overall GHG emissions. Huo et al. (2013) reported a 6% reduction in overall GHG emissions based on a life cycle analysis when gasoline was replaced by natural gas. Although several government policies are in place to help enhance the expansion of natural gas vehicles, the requirement for completely different infrastructure will likely prove to be a significant challenge (Wang et al. 2015). It is not clear whether biogas production (Table 1) is intended for use in road transportation or electricity generation.

1.3 DRIVERS OF BIOFUEL PRODUCTION AND CONSUMPTION

The initial development of biofuels at a global level was mainly driven by energy security concerns resulting from the oil crisis of the 1970s. Although the development of unconventional oil and gas supplies has created a more distributed supply, this remains a concern for many countries including China. As mentioned earlier, China is the world's 4th largest oil producer and the biggest producer of coal. However, the country's strong economic growth is partially a result of China becoming a net importer of crude oil and petroleum since 2009 (US EIA, 2015). China's oil consumption has and will keep increasing and the country accounted for about 43% of the growth in world's oil consumption in 2014. In 2014 China consumed about 10.7 bbpd of oil with imports accounting for 6.1 bbpd. Domestic production at 4.6 bbpd has been unable to keep up with oil demand (US EIA, 2015). Thus, energy security (oil security) is an ongoing concern and the initial development of biofuels was likely linked to this concern. However, China has addressed energy security concerns through several avenues and, to date, biofuels have played a relatively insignificant role. As well as expanding its domestic oil exploration efforts, Chinese national oil companies have invested heavily in overseas oil and gas assets. The US EIA reports an estimated $73 billion investment between 2011 and 2013 in the Middle East (Iraq), North America (Canada), Latin America (Brazil), Africa (Sudan, South Sudan), Asia and Australia (EIA, 2015). The largest overseas acquisition was in 2013 when CNOOC purchased NEXEN in Canada. China has also secured long-term supply contracts for oil and natural gas. China's energy needs are enormous and it will keep growing, completely dwarfing the insignificant contribution made by biofuels which currently contribute less than 0.1% of the country's energy demand.

In the last few decades another important driver of global biofuels development has been climate change mitigation. The use of biofuels based on renewable feedstocks can reduce the GHG emissions associated with transportation fuel use as compared with fossil-based transportation fuels. However, the extent of the reduction has to be determined through a full life cycle analysis of the biofuel production process. Many factors have an impact on the outcome, including feedstock, fertilizer use, conversion process, the source of electricity, co-products produced, etc. Although general values for GHG reduction potential are often used, every pathway (feedstock/conversion combination) has to be assessed separately. It has been shown that, in most cases, ethanol produced from crops such as corn or wheat has a lower carbon reduction potential than cellulosic ethanol based on agricultural residues. It has been reported that corn ethanol can reduce emissions between 18-28%, while cellulosic ethanol can result in reductions of up to 87%. However, many factors have to be taken into consideration such as, if coal is used as the source of electricity, corn ethanol may not produce any carbon reduction benefits (EERE, 2007).

China has become increasingly committed to climate change mitigation with the country participating in the UNFCCC COP21 and signing the agreement reached at this forum. Prior to COP21 China submitted an INDC and subsequently announced its new 13th Five-year plan (March 2016) which describes a large number of new initiatives the country will pursue to achieve carbon reduction targets (Gutterman, 2016). The plan primarily focuses on environmental issues and 10 of its 13 binding targets relate to the environment and natural resources. However, included in the plan is a commitment to an 18% reduction in 2015 carbon emissions per unit of GDP by 2020 and a 15% reduction in energy consumed per unit of GDP in 2015 by 2020. It also re-commits to generate 15% of the country's primary energy from non-fossil sources and introduces an important new target of keeping energy consumption below 5 billion tonnes of standard coal equivalent by 2020. With a focus on air quality the plan also sets a target to reduce harmful PM2.5 particulates by 25% (Geall, 2016). Further initiatives include a roll-out of a nationwide carbon market by 2017, although some reports suggest that this target date is ambitious (Hongliang, 2016). However, it should be noted that China has been piloting an emission trading scheme in seven areas for the past number of years.

China's INDC to the COP21 conference included objectives relating to transportation and alternative fuels as follows: "*To develop a green and low-carbon transportation system, optimizing means of transportation, properly allocating public transport resources in cities, giving priority to the development of public transportation and encouraging the development and use of low-carbon and environment-friendly means of transport, such as new energy vehicle and vessel; To improve the quality of gasoline and to promote new types of alternative fuels".* However, it should be stressed that alternative fuels refer to shale, coal-to-methanol, natural gas, etc. not necessarily biofuels (Lux Research, 2015). According to Argus media, coal-to-methanol production is growing in China as China already produces half the world`s methanol with this likely to double by 2020 (Agarwal, 2015). Coal-based methanol will form 80% of China`s methanol production by 2018. Methanol is currently used in blends of 5-100%, accounts for 7-8% of transportation fuel in China and is used to make MTBE (IEA AMF). As mentioned earlier, China has encouraged the development of natural gas vehicles (NGVs) and 1.57 million NGVs were on the road in 2012. Although expansion has been slow, market penetration in some provinces was up to 21% (Wang et al. 2015). The considerable expansion of natural gas use is an integral part of China's future plans, as described in the country's 13th Five-Year Plan, and its increased use is seen as at least a partial solution to reducing emissions in cities (Clemente, 2016).

Given its commitment to reducing emissions, biofuels could potentially play an important role in helping China meet its climate goals within the transportation sector. Although the government has supported the development and expansion of new energy vehicles, the disadvantage of this strategy is that an entirely new infrastructure has to be built, including charging stations, fuelling stations (for natural gas vehicles) and gradual replacement of current internal combustion powered vehicles. Biofuels have the advantage that they can be inserted into the existing infrastructure and, if drop-in biofuels are used, no blending limits would be applied. In addition, current electricity production still relies mainly on coal-generated power which means the use of electric vehicles can actually result in even higher emissions. Zhang & Chen (2015) sees biofuels as "indispensable to China's transport decarbonisation" and that "policy will be needed to propel the sustainable development of biofuels".

However, not much is known about the actual environmental benefits of biofuels use in China as there is a lack of information on life cycle assessments of biofuel pathways. Two reviews that assessed the life cycle emission reduction potential of different biofuel pathways (Yan & Crookes, 2009; Xunmin et al. 2009) reported that corn and wheat derived ethanol resulted in no significant GHG emission reductions with only cassava derived ethanol showing only minor reductions in GHG emissions. In fact, Yan & Crookes (2009) reported that corn and wheat ethanol use increased emissions. In the USA, corn ethanol can achieve GHG emission reductions of between 18-28% (eere.gov). The factors that likely impacted the Chinese assessment were the source of electricity, the yields of feedstock as well as the impact of co-products. It is likely that increased efficiencies in growth and harvesting of the feedstock and enhanced production efficiencies such as, generating electricity from straw or biogas; increasing co-products, etc., would improve the environmental benefits of producing and using ethanol in China. This paucity of GHG emissions data highlights the need for further life cycle analysis of biofuel production in China. Current policy does not take potential emission reductions into account for promotion of biofuels. However, improved information could help direct future policy support towards the environmentally beneficial effects of using biofuels, resulting in greater emission reductions.

It should be noted that MTBE is still used extensively in China as a gasoline additive, partly because it is much cheaper than ethanol. However, ethanol development in the USA was directly linked to the banning of MTBE (methyl-tert-butyl-ether) as a gasoline additive, due to its leaching from underground tanks into groundwater which rendered the groundwater undrinkable. Ethanol is considered to be an effective and safe octane booster in the USA.

2. Biofuels development and current status

In 2014 the United States and Brazil combined to produce 86% of the world's biofuels (Figure 5), with China contributing 2% of global production (IEA, 2014g).

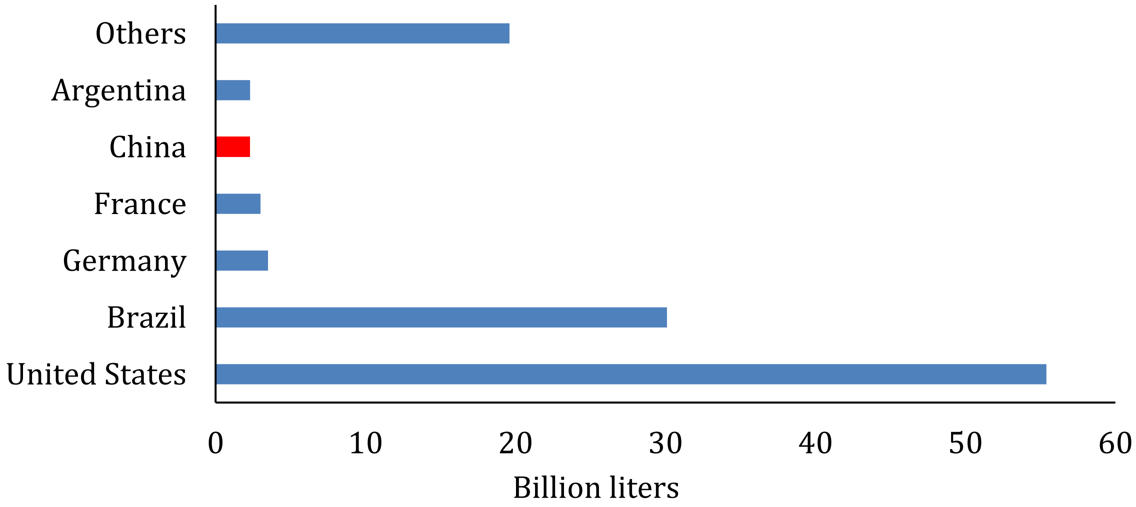

Figure 5. Global biofuels production, top countries, 2014 estimate; source: based on data from IEA (2014g).

In terms of ethanol production, China is currently the world's 3rd largest producer, after the US (#1) and Brazil (#2), although volumetric production in China is quite small by comparison (Figure 6).

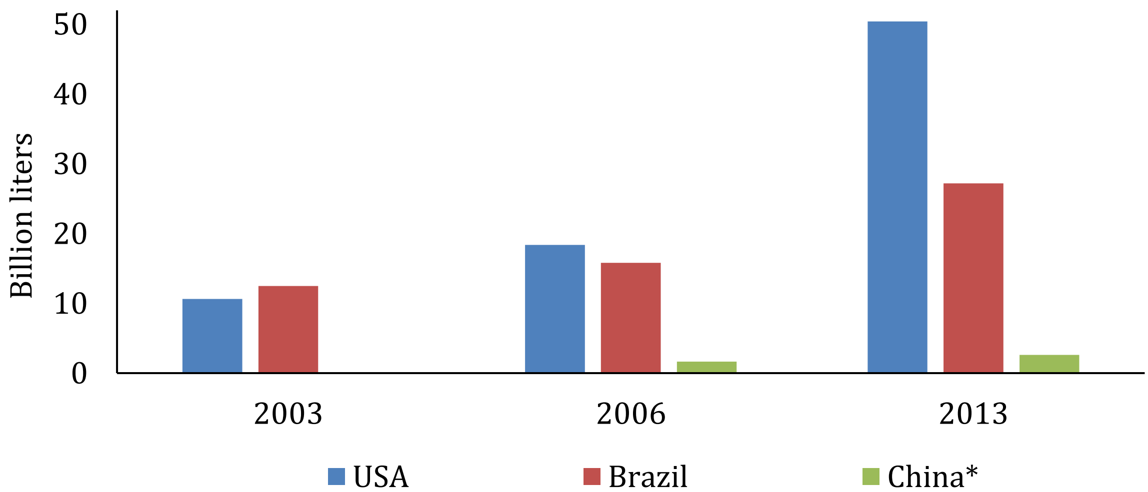

*Figure 6. Top 3 world ethanol producers (selected years); sources: for USA, based on data from RFA (2014); for Brazil, based on data from MME-EPE (2014); for China, 2003 and 2006 based on data from USDA (2014), 2013 based on IEA (2014g); * China estimate for 2013.*

Unlike the ethanol market, global biodiesel production is quite dispersed. In 2014, the US was the world's major biodiesel producer, at an estimated 17% of global output and the top three (US, Germany, and Brazil) accounted for 40% of the global output. China was ranked at number 15, only supplying 1.1% of the world’s total biodiesel output (IEA, 2014g).

2.1 DEVELOPMENT OF BIOFUELS IN CHINA

In 1986 the Chinese government initiated its first research and development program related to biofuels, within the so-called “863 Plan” for National High-Tech R&D Program. However, the move to domestic ethanol production only occurred 15 years later, in 2001, where the 10th Five Year Plan detailed government directives for the 2001-2005 period (China, 2001).

The initial scope of China’s 2001pro-biofuels policies had a major goal of “experimenting with bioethanol production, marketing, and support measures” (ADB, 2009). Under this directive pilot tests for ethanol fuel use in transport were carried out in five cities in the country’s Central/Northeastern provinces of Henan (Zhengzhou, Luoyang and Nanyang) and Heilongjiang (Harbin and Zhaodong).

In 2003, the first of four government-approved ethanol production facilities became operational. The following year, the government expanded the pilot projects for mandatory E10 blending to six provinces (Heilongjiang, Jilin, Liaoning, Henan, Anhui, and Guangxi), plus 27 cities in four other provinces (Hebei, Shandong, Jiangsu and Hubei) (Figure 7). These are still the only areas in China where E10 is available and fuel distributors cannot blend or sell E10 outside of these areas.

Figure 7. Locations in China with Ethanol mandates.

Initially, ethanol production was based on using stale grains from government reserves which were no longer suitable for human consumption (Qinghai, 2004; Qui et. al., 2011). However, China's 11th Five Year Plan for 2006-2011 (China, 2006), described a new policy which prohibited the construction of any new ethanol production facilities based on grains (i.e., maize/corn, wheat) due to concerns over food security. An exception was made for the country's four existing ethanol facilities, which had already been using "new" grains as the original, excess-stale-grain stocks had been depleted. According to the policy, any new ethanol facilities in China could only use so-called 1.5 generation feedstocks (non-grain sugar or starch crops), such as cassava, sweet sorghum, sweet potato and sugarcane, or lignocellulosic feedstocks such as forestry or agricultural wastes. Although so-called 1.5 generation feedstocks are used as food in many cases, the main emphasis in this category was the move away from using grains for biofuel production.

In the same year the first policy to support domestic biodiesel production was introduced. A major focus was the government plan to develop "energy forests" (oilseed producing trees such as jatropha). One 2010 target was to plant about 850,000 ha of oilseed-bearing "energy forests" increasing this to 13 million ha by 2020. In 2010 the government announced several initiatives such as National Technical standards for Biodiesel Fuel Blend (B5), a trial biodiesel program in the Hainan Province and the elimination of the 5% consumption tax on biodiesel (China, 2009a).

In 2007 the Chinese government established biofuels production targets for the first time under the Medium and Long Term Development Plan for Renewable Energy (China, 2007a). One goal was to produce 2 million tons of ethanol (≈ 2.53 billion liters) and 0.2 million tons (≈ 0.23 billion liters) of biodiesel by 2010. Targets were also set for 2020 to produce 10 million tons (≈ 12.67 billion liters) of ethanol and 2 million tons (≈ 2.28 billion liters) of biodiesel. The 12th Five Year Plan covering the period of 2011-2015 (China, 2011) targeted production of 4 million tons (≈ 5.1 billion liters) of ethanol by 2015. However, this target was not achieved.

The 2007 Medium and Long Term Development Plan for Renewable Energy also established the important policy, applicable to both ethanol and biodiesel, that domestic production of feedstocks for biofuels should not compete with land needed for food or feed production and must not inflict harm to the environment (China, 2007a). A chronological summary of biofuels policies used in China up until 2014 are summarised in the box below. China's 13th five-year plan was released in March 2016.

Chronology of China's biofuels milestones (2001-2014)

2001	"10th Five Year Plan (2001-2005)": initial steps towards mass scale use and production of ethanol
	Introduction of "Pilot Testing Program of Bioethanol Gasoline for Automobiles" and "Detail Regulations for Implementing the Pilot Testing Program of Bioethanol Gasoline for Automobiles"
	National technical standards for fuel ethanol (E10)
	Pilot projects for mandatory E10 in five cities
2003	First ethanol plant becomes operational
2004	"State Scheme of Extensive Pilot Projects on Bioethanol Gasoline for Automobiles" (SSEPP)
	Pilot projects for mandatory E10 in five provinces (currently six provinces) and 27 cities (in other four different provinces)
2005	"Renewable Energy Promotion Law": China's first legislative piece dealing exclusively with renewable energy
2006	New ethanol policy: production should not compete with grains; from now on, all from ethanol non-grain feedstock (e.g. cassava, sweet sorghum, cellulose)
	State Forest Administration's National Energy Forestry plan sets target for energy forests (e.g. jatropha): 13 million ha by 2010
2007	"Medium and Long term Development Plan for Renewable Energy" sets targets for 2010 and 2020

	First cassava-based ethanol plant becomes operational
2010	National technical standards for Biodiesel Fuel Blend (B5)
	Trial biodiesel program in Hainan Province; since then, program has been limited to only two counties
	Government eliminated 5% consumption tax on biodiesel
2011	"12th Five Year Plan (2011-2015)" sets new target for ethanol: 4 million tons by 2015
2012	Government approved construction of two cassava-based ethanol plants in two provinces
2013	Cut in ethanol subsidies from US$ 0.19/L (in place since 2009) to US$ 0.06/L
2014	First sweet sorghum-based ethanol plant becomes operational

China's R&D capacity in biofuels has developed in parallel with the different regional and central governments' medium and long term development plans. Initially, most of the China's biofuel R&D efforts were carried out by: 1) the country's Chemical/Forestry Engineering Advanced Universities (e.g. Tsinghua University, Beijing University of Chemical Technology, Nanjing University of Technology, East China University of Science and Technology, South China University of Technology, Beijing Forestry University, Nanjing Forestry University, etc.); 2) the leading Energy/Process Engineering Research Institutes of the Chinese Academy of Sciences (CAS) (e.g. Guangzhou Institute of Energy Conversion, Beijing Institute of Process Engineering, Qingdao Institute Of Bioenergy & Bioprocess Technology, and Tianjin Institute of Industrial Biotechnology); and 3) the major Chinese Energy Enterprises (e.g. COFCO, China National Petroleum Corporation, siHenan Tianguan Group, and Sinopec Corporation).

However, primarily due to limited coordination, communication and collaboration between the major Chinese biofuel R&D players, progress has not been as positive as might have been expected. To address these issues, the Chinese Centre Government is currently trying to integrate the country's biofuel R&D efforts at a national level. In a similar fashion to the three US Department of Energy (DoE) funded research centres of Great Lakes, Oak Ridge and JBEI, four Chinese National biofuel research centres have recently been established (Table 3) with each of these national biofuel research centres having a different focus. For example, the National Energy R&D Center for Non-food Biomass, which is led by the China Agricultural University, has the major responsibility for biomass breeding, cultivation and logistics research, while the National Energy Research Center of Liquid Biofuels, which is led by COFCO, is mainly focussed on technology implementation. The other two national research centres put their major efforts into technology development and integration.

Table 3 China National biofuel research centres

China National biofuel research centres	Leading institute
National Energy R&D Center for Biorefinery	Beijing University of Chemical Technology
National Energy Research Center of Liquid Biofuels	COFCO
National Energy R&D Center for Non-food	China Agricultural University

Biomass	
National Energy R&D Center for Biofuels	Guangzhou Institute of Energy Conversion, (CAS).

2.2 GROWING 1.5 GENERATION CROPS – LAND AND WATER AVAILABILITY

After the ban in 2007 on the use of grains as the feedstock for new biofuels facilities, the Chinese government tried to encourage the development of new facilities based on 1.5 generation feedstocks such as cassava, sweet sorghum and sweet potato for ethanol production. Jatropha and other oilseed-bearing trees were highlighted as potential biodiesel feedstocks. All of these potential crops had to be cultivated on marginal land so as not to compete with food production. The Chinese definition of marginal land 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 et al., 2008), including shrub land, sparse forest land, moderate dense grassland and sparse grassland (Jiang et al, 2014).

China is one of the world’s largest countries, an area of approximately 9.4 million km^2. It is also the most populous nation, home to some 1.37 billion people. Thus, China has almost 20% of the world total population on about 7% of global landmass. China also has a considerable area of mountainous regions with topographical features that limit the expansion of agriculture. Mountains, plateaus, and hills respectively account for 33%, 26% and 10% – a combined 69% – of the country’s total land (China, 2009b). In addition, current uses of land for agricultural, industrial, and urban purposes restrict the areas available in China for expansion of agricultural crops. Increasing urbanisation and past pollution of land has also imposed further limitations.

Various Chinese studies have estimated the availability of marginal land for the potential production of 1.5 generation and energy crops. According to Jiang et al. (2014), the amount of marginal land that was available in 2010 was 1.14 million km^2 (down from 1.36 million km^2 in 1990), with this land mainly distributed across the four provinces of Yunnan, Xinjiang, Sichuan, and Inner Mongolia. Other reported estimates include Naylor et al. (2007), who estimated 1.16 million km^2 of marginal land, of which the only about 20% (0.23 million km^2) was suitable for feedstock production while Li & Chan-Halbrendt (2009) estimated China’s marginal land at 0.35 – 0.75 million km^2. It is apparent that not all marginal land will be suitable for biofuels feedstock production and that further research will be required. This future work should also factor in conditions under which land will be suitable for agriculture, taking into consideration potential environmental impacts and economic viability. Related work has shown that crops grown on marginal lands generally display low productivity and yields (Cai et al., 2010), require high fertilizer inputs (Qui et al., 2011), are often located in remote areas far from where most demand is located (higher shipping costs) and have low economic viability (Liu et al, 2011). Growing sufficient quantities of 1.5 generation feedstocks has proved challenging both in China and other jurisdictions and many projects have had poor results or have failed to materialize.

In addition to problems of land availability, limited water supply is also a challenge. According to

Yang et al. (2009), the associated water requirement necessary to meet China's biofuels goals for 2020 would amount to 32–72 km^3 per year, approximately equivalent to the annual discharge of the Yellow River. At the same time freshwater availability in China has shown a significant decline over the past decades. From over 4,000 m^3 per capita in 1967, to 2,516 m^3 per capita two decades later, to an estimated 2,005 m^3 per capita in 2014.

Water is also unevenly distributed throughout the country with the two provinces with highest water availability (Qinghai and Xizang/Tibet) located in the Qinghai-Tibetan Plateau. Their high altitude and mountainous terrain makes these regions unsuitable for large scale commercial biofuels projects.

It is likely that existing and future water demands for human, agricultural and industrial uses will limit the extent of feedstock expansion projects in many provinces. Thus future expansion of biofuel production and use based on the growth 1.5 generation crops is likely to be challenging.

2.3 ETHANOL

It has proven difficult to accurately determine China's bioethanol production volumes as different sources such as the International Energy Agency (IEA) and the US Department of Agriculture (USDA), report different values. These figures also differ from the values published in the official documents of the Chinese government (CNREC) (Figure 8). Part of the problem seems to be that the official ethanol statistics don't distinguish between ethanol used for fuel, beverage or industrial use.

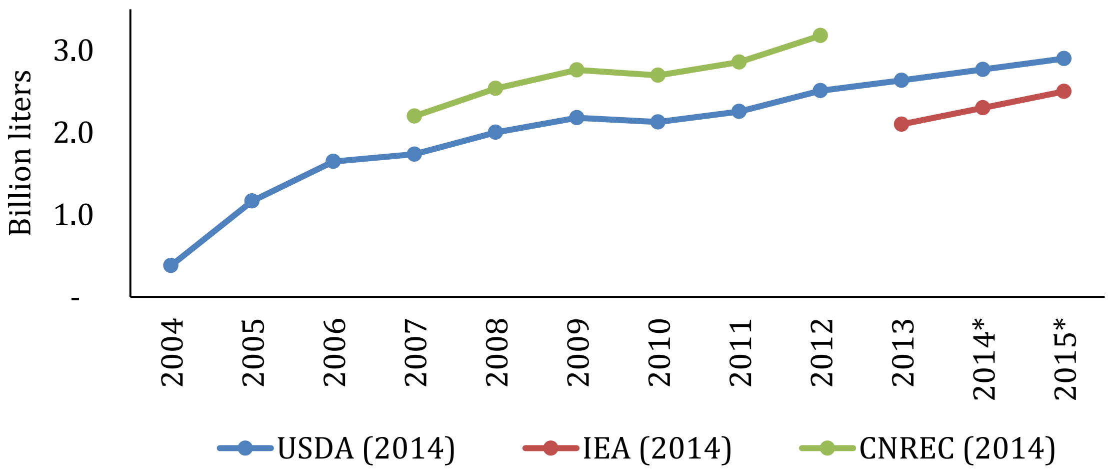

*Figure 8. China's ethanol production (2003-2015) by sources; * 2014 and 2015 are projections. USDA (2013, 2014) (CNREC, 2014) IEA (2014g)*

The most recent USDA Gain Report (USDA, 2015) estimated that, in 2015, about 3 billion litres of ethanol was produced, with a forecast production of 3.15 billion litres in 2016 (an increase of

2.6%). According to the USDA, in 2014, corn accounted for 76% of fuel ethanol production, wheat 14%, cassava 8% and less than 1% from sweet sorghum. However, in their 2015 report, the USDA reported that 70% of production was from corn, 25% from cassava with molasses from cane or beets accounting for the remaining 5% (USDA, 2015). This reflected a shift away from wheat as a feedstock. As in other jurisdictions, cellulosic ethanol production only occurs at a small scale in China with the USDA estimating volumes of 42 million liters (33,000 tons) in 2014, or about ~1% of the country's ethanol production (USDA, 2014).

As mentioned earlier, the commercial ethanol facilities that are currently operating in China (Table 4) have all had to be government approved, potentially restricting access of new entrants into the market.

Table 4 China's commercial scale ethanol plants (operational)

Name	Province	Initial oper.	Capacity		Feedstock
			tonne/y	M L/y	
COFCO Bio-energy Co. Ltd.	Heilongjiang	2001	280,000	354.9	Corn
Jilin Fuel Alcohol Co. Ltd.	Jilin	2003	600,000	760.5	Corn
Anhui BBCA Biochemical Co. Ltd.	Anhui	2005	440,000	557.7	Corn
Henan Tianguan Group	Henan	2005	500,000	633.7	Wheat, Cassava
Guangxi COFCO Bio-energy Co. Ltd	Guangxi	2008	200,000	253.5	Cassava
ZTE Energy Ltd.	Inner Mongolia	2012	50,000	63.4	Sorghum
Longlive Biotechnology Co. Ltd	Shandong	2012	50,000		Corncob

Source: data obtained from QIBBT (2010) and company websites.

In addition to the commercial biofuel facilities summarised in Table 4, a number of advanced biofuel facilities at the pilot, demonstration and small commercial scale are either operating or are planned (Table 5).

Table 5 China's advanced ethanol plants (items in bold refer to announced facilities that have not been constructed yet and includes the proposed date of construction)

Name	Province	Initial oper.	Capacity M L/y	Feedstock
COFCO Biochemical Energy (Zhaodong) Co., Ltd.	Heilongjiang	2007	0.6 (2007); 63 (2013)	Corn stover
Tian Guan Fuel Ethanol Co., CNPC	Henan	2007	6 (2007); 12 (2012)	Straw
Beijing Shougang Lanzatech New Energy Technology Co.	Beijing, China	2013	0.38 (2012); *95 (2015)*	Steel flue gas
LanzaTech Baosteel New Energy Co. Ltd.	Shanghai, China	2012	0.38 (2012); *40 (2015)*	Steel flue gas
White Biotech (WBT)	Kaohsiung	2014	100 kg/day	Steel flue gas

Source: data obtained from F.O. Lichts' database and Lanzatech website.

In April 2015 China Steel Corporation announced a US$46 million investment into Lanzatech for a 17 million gallon (64 million litres) facility with construction to begin in 2015. The intention was to scale up to 34 million gallons (128 million litres) sometime in the future (Lanzatech, 2015; Lane, 2015). In July 2015, DuPont announced a licensing agreement with Jilin Province New Tianlong Industry Co., Ltd., (NTL) to begin the development of China's largest cellulosic ethanol manufacturing plant that would be located in Siping City, Jilin Province, China. The agreement will allow NTL to license DuPont's cellulosic ethanol technology and use DuPont™ Accellerase® enzymes, to produce renewable biofuel from the leftover biomass from Jilin Province's corn farms (DuPont, 2015). Beta Renewables also reported that the M&G Group had entered into a JV with the Chinese Guozhen group, to produce bioethanol from wheat straw and corn stover. The facility will be located in Fuyang (Anhui Province) and construction is supposed to begin in 2016. The fuel grade bioethanol produced will be sold locally to a Chinese oil company (Beta Renewables). Back in 2010, Novozymes had announced that they had signed a Memorandum of Understanding (MOU) with COFCO and Sinopec for the construction of an advanced cellulosic ethanol demonstration facility. However, the current status of these projects is unclear, probably influenced by the current low price of oil.

It should be noted that the low price of oil has probably contributed to the slowdown in global development of cellulosic ethanol. Although several commercial facilities are currently operating in Europe and North/South America all of the companies operating these "Pioneer Plants" have experienced some sort of technical difficulties related to feedstock supply challenges, with agriculture residues proving to be the major feedstock.

However, cellulosic ethanol offers a potential route for expansion of bioethanol production in China as, when using residues, no additional land or water will be required to produce these feedstocks. A number of studies have been carried out to determine the availability of agriculture residues (Chen et al., 2009; Xie et al., 2010; Zhang et al., 2009; Wang et al., 2013) and an estimate of field and process residues in China, based on Wang et al. (2013) is summarized in Table 6. As process residues are generated at the processing facility they should not incur additional transportation costs from the field. In contrast field residues will require collection and transportation to a processing facility and will therefore be more costly.

Table 6. *Estimated field and process residues in China, 2008/2009 (Mt)*

Residue Type	Amount (Mt)
Field Residues	660.8
Rice	220.6
Corn	153.9
Wheat	145.9
Canola	37.4
Beans	26.8
Cotton	19.8
Other cereals	18.1
Tubers	15.7
Peanut	14.4

Sugarcane	12.2
Others[a]	16.0
Process Residues	89.6
Rice hull	35.7
Corn cob	25.0
Sugarcane bagasse	19.2
Others[b]	9.7
Total residue	750.4

Notes: (a) Other oil crops, Other fibers, Tobacco, Sesame, Sugarbeet, and Jute & Ambary; (b) Cotton seed hull, Peanut husk, and Sugarbeet bagasse. Source: Wang et al. (2013).

It should be noted that this is theoretical potential and the actual availability of residues has to be determined by taking into account existing uses, such as burning of residues for fuel, use as feed, left in the field and industrial uses. A summary of various studies that have tried to quantify the current uses of agricultural residues and therefore determine their actual availability for potential biofuels production is shown in Figure 9.

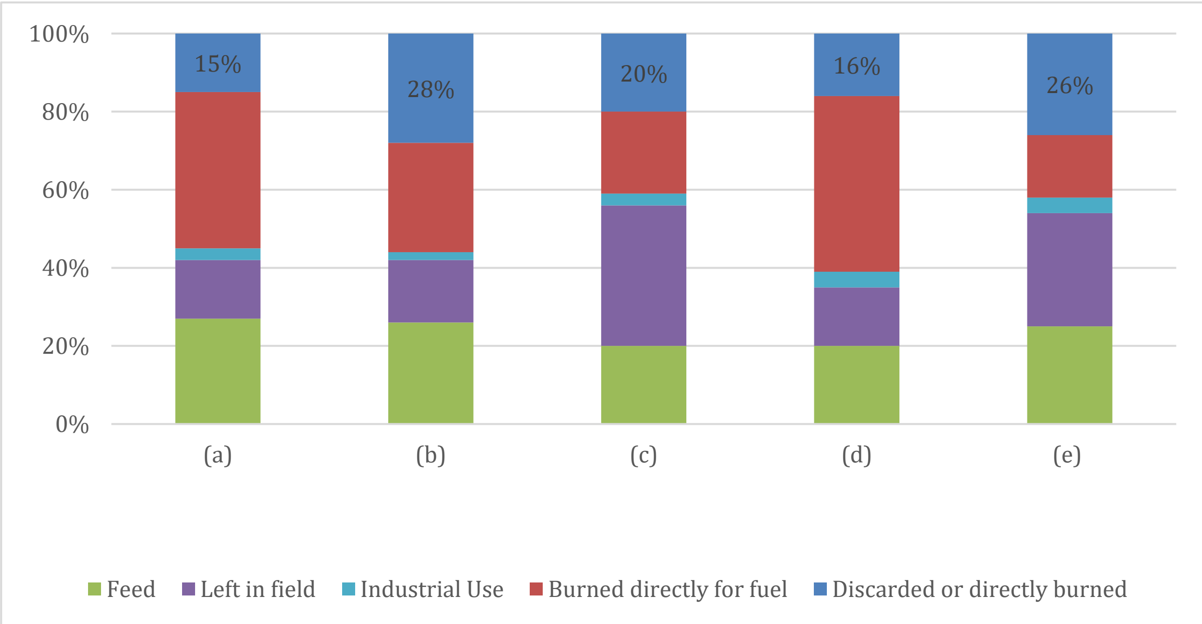

Figure 9. *Relative estimates of current uses of agricultural residues (%), based on different sources (a) Zhang et al., 2009; (b) ERI, 2010; (c) Tian, 2010; (d). Shi, 2011; (e) Wang et al., 2013*

These estimates show significant variations of potentially available residues (discarded or directly burnt) from a low of15% (Zhang et al., 2009) to a high of 28% (ERI, 2010). Based on the estimated residue available that are summarised in Table 6 the potential feedstocks that could be used for cellulosic ethanol production could be between 112.3 Mt (15%) and 209.7 Mt (28%). Using a conversion rate of 70 gallons ethanol per dry tonne of residues, or 265 L/dry tonne, the lower 15% value for agriculture residues (112.3 million tonnes) could potentially produce 29.8 billion liters of ethanol, while the higher 28% value would yield 55.6 billion liters. Although these values are all theoretical, it is apparent that China could potentially produce significant volumes of cellulosic ethanol from agricultural residues. Although a recent study by Chen et al. (2016) estimated that 50% of China's straw crop could provide 350 million metric tonnes of feedstock, a more conservative estimate is described in this report.

The commercial cellulosic ethanol plants that have been operating over the last year or so have found that establishing and operating new feedstock supply chains have been challenging. This recent experience has also indicated that, to be economically attractive, the feedstock needs to be transported within a relatively small supply area radius (30-50 miles). It is possible that the collection and use of feedstocks are even more likely to be problematic in China due to the relatively small scale of farming in China. Although this is a topic that requires more detailed studies and more accurate data, China seems well positioned to produce significant volumes of cellulosic ethanol from its agricultural residues. However, major challenges will be the establishment of an effective feedstock supply chain and ongoing improvements in the commercial viability of the cellulose-to-ethanol technology.

2.3 BIODIESEL

China’s production of biodiesel developed later than ethanol production with the USDA reporting 1.13 billion liters of biodiesel produced in 2014 and 1.14 billion litres in 2015 (although the country’s production capacity is significantly higher, at about 4.25 billion litres) (USDA, 2014). Although the USDA estimates China has 54 biodiesel plants it was also reported that more than half of these plants are not in production, including the biodiesel pilot project in Hainan operated by the state-owned oil company CNOOC (USDA, 2015). Only about 30% of this biodiesel is used for automobile/truck transportation, with the majority used in industry and agriculture. Almost all of China’s biodiesel is produced from used cooking oil, also known as gutter oil. Apart from the logistical challenges of the large-scale collection of this feedstock, an additional problem is the illegal reuse of these oils for food. This creates competition for the feedstock, making it difficult to obtain and more costly (USDA, 2015).

Biodiesel market penetration in transportation fuel is estimated at 0.2% and this is not expected to increase (USDA, 2015). Unlike ethanol, there is no official national (or even provincial) mandate for biodiesel use in the transportation sector, although a small trial program using 2% and 5% biodiesel blends was carried out in Hainan province. The state-owned oil companies, CNPC and Sinopec, control over 90% of the gas stations in China and the sale of biodiesel has not been encouraged. Thus, producers either have to sell to brokers who mix the fuel or sell it directly to end-users at small, private gas stations (Hornby, 2014).

The biggest challenges limiting the expansion of biodiesel are the availability of feedstock and a lack of policy support. China is a net importer of vegetable oils (e.g. soy oil, palm oil) which are the main constituent feedstocks used to make biodiesel. According to the FAO, 58% of the world’s soy imports in 2011 were destined for the Chinese market (FAO, country report), with some further estimates indicating this number had risen to 63% of the globally traded volume (Reuters, 2014). The OECD expects China’s oilseed imports to reach 83 Mt by 2023, 41% higher than the volumes imported each year over the 2010-2012 period. By their estimates, China will account for 59% of global trade, up from around 54% in 2010-2012 (OECD/FAO, 2014). Although other potential feedstocks such as used cooking oil, 1.5 generation oilseed crops and even algal lipids have been discussed for making biodiesel, these are small volumes compared the large amounts of vegetable oils that are currently used for food applications.

As a result, China’s small-scale, private owned biodiesel producers have primarily relied on used cooking oil (UCO) (“gutter oil”) or oil rendered from animal fats as main their main feedstock. Even though China produces approximately 500 million tons of waste cooking oil per year (Bai, 2010), there is a significant demand for used waste oil from other sectors such as the feed industries, chilling oil for leather production and even the illegally refined cooking oil market (Chang et al., 2012). As there is a poorly developed supply chain and no recognised subsidies to encourage biodiesel production and use, the result is lack of feedstock available to make any significant volumes of biodiesel (Zhang et al., 2014).

The biodiesel that is produced is typically used for power generation or for off-road transportation in rural areas (i.e. tractors). One major reason for this type of preferred usage is the low quality of the biodiesel that is produced (ERI, 2010). The difficulty in obtaining a “quality” feedstock combined with the poor quality of the resulting biodiesel has contributed to the high level of underutilised capacity at the Chinese biodiesel refineries (Figure 10).

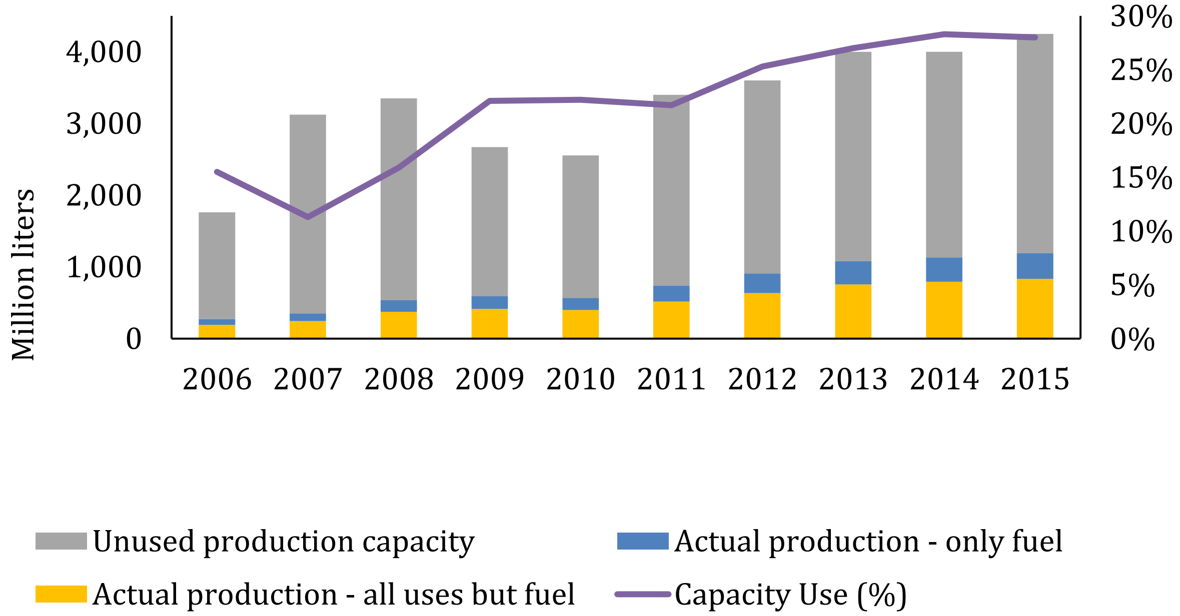

Figure 10. China's biodiesel refineries, by absolute (million liters) and relative (%) used capacity. Source: based on data from USDA (2014).

One of the Chinese government's attempts to make better use of this underutilised biodiesel refinery capacity was to encourage the production of 1.5 generation feedstocks such as oilseed-bearing trees. As mentioned earlier this was incorporated into the Eleventh Five-Year Plan in 2006, where planting targets of 400,000 ha of jatropha, plus another 433,000 ha of other oilseed-bearing trees, such as: yellowhorn (*Xanthoceras sorbifolia*), Chinese pistachio (*Pistacia chinensis*), varnish tree (*Koelreuteria paniculata*), Chinese tallow tree (*Sapium sebiferum*), *Swida wilsoniana*, idesia (*Idesia polycarpa*), sumac (*Rhus chinensis*), aveloz (*Euphorbia tirucalli*), and tung tree (*Vernicia fordii*) was targeted (Chang et al., 2012; Li et al, 2014). It was estimated that the potential production volumes of biodiesel based on oilseed-bearing trees grown on marginal land alone could be between 20.5 and 123.1 billion liters (Chang et al., 2012). However, as of early 2014, the extensive development of these feedstocks has failed to materialise. Jatropha production, which was originally promoted as the most promising of all non-traditional feedstock sources used to make biodiesel, has stagnated. This has been attributed to underdeveloped policies for biodiesel consumption and lack of financial support for farmers (Li et al., 2014).

2.4 OTHER BIOFUELS

Very little information is available on production of biofuels other than bioethanol or biodiesel. For example, there is little information on biobutanol, renewable diesel (HEFA/HVO) or other drop-in biofuels. However, the Chinese government has been encouraging the production and sale of natural gas vehicles, with the 12th Five-Year Plan targeting that 8% of transportation energy demand should to be met from natural gas by 2015 (Clean Energy Compression, 2014).

There has also been some information published in the Chinese media about biojet fuels in recent years. According to the Civil Aviation Administration of China (CAAC), 20 million tons of jet fuel was used by aircraft in China in 2012 and this is expected to increase to 40 million tons by 2020. The report also indicated that China hoped to produce 12 million tons of biojet fuels, although how this would be done or over what type of timeframe was not clear (Asia Biomass Office).

The first, partially fueled, biojet flight in China took place in October 2010. This was a result of a collaboration between the China National Petroleum Corporation, Air China, Boeing, Honeywell, the China National Aviation Fuel Group and Pratt & Whitney. The Sinopec Corporation, another Chinese national oil company, built a biofuel facility in Southeast China's Hangzhou in 2011 with a supposed production capacity of 6,000 tonnes of aviation bio-fuel each year from used cooking oil. Sinopec also built a blending facility within its Zhenhai Refinery to produce aviation bio-fuel products. Biojet developed by Sinopec was used in a demonstration flight in 2013 and in February 2014, the Civil Aviation Administration of China (CAAC) granted China's first biological jet fuel airworthiness certificate to Sinopec Corporation (China Finance Corporation, 2014). Sinopec has a cooperative biojet initiative with China Eastern Airlines, while China's top oil and gas producer, China National Petroleum Corporation, has a joint biojet initiative with Air China. The first, commercial passenger flight using biojet took place on March 25, 2015 (Biofuels International, 2015). This was a collaboration between Hainan Airlines, Boeing and Sinopec. Boeing has been very involved in biojet fuel development in China and the company has collaborated with a range of stakeholders including the Commercial Aviation Corp. of China (COMAC) and several research institutions, such as the Chinese Academy of Science's Qingdao Institute of Bioenergy and Bioprocess Technology (QIBEBT). Boeing and the Commercial Aircraft Corp. of China (COMAC) opened a demonstration facility in 2014 that will produce biojet fuel from used cooking oil at about 160 gallons (650 liters) per day. The project’s goal was to assess the technical feasibility and cost of producing higher volumes of biofuel (Schroeder, 2014). However, the current status of this project is unclear. Ongoing research on the potential of biojet fuel production is currently carried out at several Chinese institutions.

3 Policies, subsidies and incentives

As mentioned earlier, the fuel ethanol market in China is highly regulated and production facilities can only be built with direct government approval. As only official facilities are entitled to subsidies and incentives, all of the current biofuels facilities are owned and operated by state-owned enterprises. In contrast, the biodiesel industry is mostly unregulated and dominated by a large number of small, private producers.

Policy support distinguishes between conventional, 1.5 generation and second generation feedstocks. Although subsidies for conventional grain ethanol were as high as RMB 2000 per tonne in 2009, these subsidies have been gradually phased out and no longer exist. Subsidies for 1.5 generation ethanol (from cassava or sweet sorghum) were introduced in 2013 at RMB750 per tonne (about $114), while cellulosic ethanol started receiving a subsidy in 2014 at RMB 800 per tonne (about $120). No other subsidies or incentives are available for advanced drop-in biofuels such as renewable diesel and biojet.

Although tax incentives for ethanol have been gradually phased out (Table 7), ethanol derived from 1.5 generation feedstocks such as cassava and sweet sorghum, as well as cellulosic ethanol receive maximum exemption from VAT and excise tax (Kang, 2014). It should be noted that these incentives are for domestically produced ethanol and they do not apply to imported ethanol.

Table 7. Tax incentives (Kang, 2014)

Year	**VAT exemption**		**Excise tax rate**	
	Grain-based ethanol	1.5 and 2G ethanol (non-grain)	1G ethanol	1.5 and 2G ethanol
2004-2010	100%	100%	0%	0
2011	80%	100%	1%	0
2012	60%	100%	2%	0
2013	40%	100%	3%	0
2014	20%	100%	4%	0
2015	0%	100%	5%	0

Although biodiesel produced from used cooking oil can obtain 0.8 RMB/L tax exemption, (introduced in 2013 to stimulate biodiesel production), there have been no direct subsidies for biodiesel production similar to ethanol.

Some groups have suggested that policy support for advanced ethanol needs to focus on market deployment policies (Chang et al, 2012). Some of the policy examples that were suggested included a re-evaluation of the current ethanol market structure, (i.e. how to deal with the extensive central government control over the entry of new fuel ethanol companies), better access to financial subsidies, tax exemptions, bank credit support, or distribution channels (Chang et al., 2012). However, it has also been suggested that the overall supply chain will remain fragile, from a market perspective, if the biofuels industries are monopolized by state-owned enterprises and government subsidies which only cover these limited number of companies (Zhao & Liu, 2014).

One recent development that might bring about changes in the China's bioethanol industry is the central government's change in policy of regulating the price and also stockpiling corn, by allowing markets to set the price for grains (Shuping & Stanway, 2016). The new policy will take effect in October 2016. Although the stockpiling system was originally designed to support China's rural workforce it resulted in artificially inflated corn prices of around 30-50% greater that global markets. This had a knock-on effect of encouraging large amounts of cheaper imports. After years of stockpiling, the government reserves are at about 250 million tonnes of corn with the quality of the stored grains deteriorating. It is expected that the government will sell more than 40 million tonnes from the stockpile in 2016 (Shuping & Stanway, 2016). It is also speculated that this change in policy could result in a surplus of corn in coming years. This change in policy could have an impact on the biofuels sector as domestic production of corn ethanol could become more cost-competitive. However, expansion of corn ethanol will still be constrained by the policy limiting expansion of bioethanol based on food and the fact that construction of new facilities can only take place with government approval.

China has also announced plans to introduce a national emissions trading scheme in 2017 to curb pollution and emissions (Worldbank, 2016). The current seven pilot schemes will be incorporated into this national scheme.

It has been suggested that carbon pricing and excise tax exemptions will not have an impact on biofuels development in the near term but could have an impact in the medium-to long-term (Zhao et al, 2015) with these authors also recommending that subsidies will be needed if biofuels development is to expand.

4 Trade in biofuels

The potential of importing biofuels is one way that China might be able to achieve its biofuels targets. Although the amount of imported ethanol increased significantly in 2015, under current legislation this imported ethanol can only be used in the chemical processing sector, not in the fuel sector. Only designated ethanol producers and distributors are allowed to sell ethanol for transportation. Although they are not expressly prohibited from using imported fuel, they are reported to be reluctant to do so (USDA, 2015). Import tariffs are currently in place for denatured and undenatured ethanol with the tariff for denatured ethanol in 2015 dropping to 5% compared to 30% in 2009. However, undenatured ethanol has an import tariff of 40%. Both denatured and undenatured ethanol imports are subject to a 17% value added tax and a 5% consumption tax. In 2012 tariffs on ethanol imported from Pakistan, Chile, Singapore, Vietnam and 10 other ASEAN countries were eliminated (USDA, 2015). Although Pakistan, Vietnam and the USA were the three biggest sources of imported denatured ethanol in the first half of 2015, imports from Brazil also increased in the latter half of 2015. Reuters reported that by July 2015, imports of ethanol were at 126,000 tonnes or nearly five times as much as the whole of 2014. COFCO, who has a majority stake in a Brazilian ethanol producer (Noble Agri) was reported to be one of the importers (Patton, 2015). The Reuters report suggested that the main reason for growth in imports was due to the cheaper price of imported ethanol as well as the high corn price in China (50% higher than corn price on the global market). Another factor impacting the price of domestic ethanol is that the subsidies for conventional ethanol production are supposed to disappear by 2016. The recent USDA report (USDA, 2015), indicated that the price for domestically produced ethanol was RMB 5,541 ($892) per tonne while the price for imported ethanol was about $570 per tonne in June 2015.

At this point in time it is not clear whether this trend of increased imports indicates a potential shift in Chinese policy to allow ever greater imports for fuel blending purposes. If this is the case, this could present a significant, emerging market for ethanol producers in Brazil and the USA. However, the USDA report expresses some pessimism and this is echoed in a quote from the Forbes magazine: "*the decision to increase ethanol imports is more likely a small part of Beijing's broader investment strategy of ensuring security through investments abroad across a range of supply chain stages. A prolonged rise in Chinese ethanol consumption would require both* *continued growth in the automotive sector and government policies mandating the use of ethanol as a transportation fuel. But given Beijing's lack of policy support for expanded ethanol mandates and given competition from alternative technologies in China, the potential for near-term growth in Chinese ethanol demand will remain limited. Nevertheless, so long as Chinese regulations prohibit the use of imported ethanol as a transport fuel, Chinese demand for foreign ethanol is apt to remain small. We may instead see growing interest from Chinese companies in investing abroad in parts of the ethanol supply chain and perhaps smaller opportunities for exporters to China as policy allows"* (Stratfor, 2015).

Regarding the potential growth of the biodiesel market, biodiesel imports have increased from 2013, primarily due to the elimination of a RMB 0.8 per litre consumption tax on biodiesel imports (USDA, 2015; Jaganathan & Hua, 2013). In addition, imports from ASEAN countries, including Singapore and Pakistan were exempt from import duties.

5 Conclusion and Recommendations

China has implemented some policies that have tried to promote biofuel production and use. It is currently the world's third largest ethanol producer, producing and using about 3 billion litres per year. In addition, the country produces about 1.14 billion litres of biodiesel per year. Although the Chinese government has set ambitious targets of producing 2020 12.7 billion litres of ethanol and 2.3 billion litres of biodiesel by 2020, it is highly unlikely that these production targets will be met. As an example, biofuels receive limited attention in the country's recently released 13th Five-year plan.

Biofuels can potentially alleviate energy security concerns and make an important contribution to reducing transportation emissions and air pollution in cities and could help China meet its environmental goals. However, current central government policy is primarily focuses on the development of "new energy vehicles" (electric and hybrid vehicles) with a stated goal of addressing air pollution in cities and transportation emissions. The increased development of natural gas vehicles is also seen as a partial solution to alleviating urban air pollution.

To date, China's biofuels policies have mainly focused on ethanol production and use. About 99% of the country's ethanol production is based on conventional starch-based feedstocks (corn, wheat and cassava). The development of 1.5 generation crops (cassava) on marginal lands has had limited success, with land and water availability proving to be significant challenges. These crop-based feedstocks are perceived to still be in competition with food production.

Cellulosic ethanol has significant potential to expand China's ethanol production using agricultural residues as the predominant feedstock. Several studies have indicated that large quantities of residues could be available for ethanol production. Although several international companies such as DuPont, Beta Renewables and Novozymes have announced plans to construct commercial scale cellulosic ethanol facilities in partnership with existing Chinese ethanol producers, it is unlikely that development of cellulosic ethanol will take place at sufficient speed to meet country's ethanol targets for 2020.

The current biodiesel industry is fragmented and based on used cooking oil as the predominant feedstocks. A government strategy to develop 1.5 generation oilseed-bearing trees and crops such as *Jatropha* has had limited success. Although biodiesel production targets are modest and could be achievable further expansion is likely to be limited without significant investment.

Strong supporting policies will be required to create demand, stimulate production, and facilitate research, development and commercialisation of biofuels. As recent policies such as the 13th Five-year Plan and China's commitments to the COP21 climate change targets make limited mention of biofuels (conventional, advanced or drop-in) it seems unlikely that biofuels will play a major role in the China's future transport markets.

References

Agarwal, A. (2015) Developments in China's methanol market and implications for global supply. https://www.argusmedia.com/mkting/petchems/~/media/371d2fc2c53c4f43afff1e8c53e8b27e.ashx. Accessed 4 August 2016.

Asia Biomass Office. https://www.asiabiomass.jp/english/topics/1210_02.html. Accessed 4 August 2016

Bai, H.R., 2010. An Outlook of Biofuel Produced by Waste Cooking Oil. Science Times, 18th October. *apud* Zhang, H., Li, L., Zhou, P., Hou, J., & Qiu, Y. (2014). Subsidy modes, waste cooking oil and biofuel: Policy effectiveness and sustainable supply chains in China. *Energy Policy, 65*, 270-274.

Beta Renewables http://www.betarenewables.com/projects/6/fuyang-bioproject. Accessed 4 August 2016.

Biofuels International (2015) First commercial bio-jet flight takes off in China. http://biofuels-news.com/display_news/9017/first_commercial_biojet_flight_takes_off_in_china/. Accessed 4 August 2016.

Bloomberg. (2014a, October 29). China Drafts Policy to Allow New Electric-Vehicle Makers. http://www.bloomberg.com/news/2014-10-29/china-drafts-policy-to-allow-new-electric-vehicle-makers.html, last accessed February 2, 2015.

Bloomberg. (2014b, December 10). China Offers Billions to Subsidize Electric Cars on Gas. http://www.bloomberg.com/news/2014-12-10/china-offers-billions-to-subsidize-electric-cars-on-gas.html, last accessed February 2, 2015.

Bloomberg. (2014c, July 4). Choking Smog Puts Chinese Driver in Natural Gas Fast Lane. http://www.bloomberg.com/news/2014-07-04/choking-smog-puts-chinese-driver-in-natural-gas-fast-lane.html, last accessed February 2, 2015.

Cai, X., Zhang, X., & Wang, D. (2010). Land availability for biofuel production. *Environmental science & technology, 45(1),* 334-339.

Campbell, R. J. (2014). China and the United States—A Comparison of Green Energy Programs and Policies. *Congressional Research Service*. http://fpc.state.gov/documents/organization/227631.pdf, last accessed 12 November 2014.

CCAM – China Association of Automobile Manufacturers. (2015, January 15). The sales and production of new energy vehicles boomed. http://www.caam.org.cn/AutomotivesStatistics/20150114/0905144510.html, last accessed February 10, 2015.

CCTV – China Central Television. (2014, December 19). China-Sinopec/Verdict. http://newscontent.cctv.com/NewJsp/news.jsp?fileId=274164, last accessed 23 January, 2015.

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.

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.

Chen, W., Wu, F., Zhang, J. (2016) Potential production of non-food biofuels in China. *Renewable Energy*. 85, 939-944.

China Daily. (2014, December 20). Lawsuit puts biodiesel use under spotlight. http://www.ecns.cn/business/2014/12-20/147462.shtml, last accessed 23 January 2015.

China Finance Corporation (2014) China grants 1st bio jet fuel airworthiness certificate to Sinopec. http://en.xinhua08.com/a/20140213/1299111.shtml. Accessed 4 August 2016

China, People's Republics of. (2001, March 5). *Outline of the Tenth Five-Year Plan for National Economic and Social Development*. Delivered at the Fourth Session of the Ninth National People's Congress. http://www.gov.cn/english/official/2005-07/29/content_18334.htm, last accessed 16 November 2014.

China, People's Republics of. (2005). *Renewable Energy Law of the People's Republic of China*. Adopted at the 14th Meeting of the Standing Committee of the Tenth National People's Congress on February 28, 2005. http://www.npc.gov.cn/englishnpc/Law/2007-12/13/content_1384096.htm, accessed February 2, 2015.

China, People's Republics of. (2006, March 5). *Outline of the Eleventh Five-Year Plan for National Economic and Social Development*. Delivered at the Fourth Session of the Tenth National People's Congress. http://www.shanghai.gov.cn/images/shiyiwu/english.pdf, last accessed 16 November 2014.

China, People's Republics of. (2007a, September). *Medium and Long-Term Development Plan for Renewable Energy in China*. http://www.cresp.org.cn/uploadfiles/2/967/medium%20and%20long-term%20development%20plan%20for%20re%20in%20china%20eng.pdf, last accessed 16 November 2014.

China, People's Republics of. (2007b). *China Statistical Yearbook 2007*. Beijing: National Bureau of Statistics of China.

China, People's Republics of. (2009a). *People's Republics of China – Forestry Outlook Study. Asia-Pacific II Forestry Outlook Study, Prepared by The State Forestry Administration People's Republic of China*. Working Paper Working Paper No. APFSOS II/WP/2009/11. Bangkok: APFSOS.

China, People's Republics of. (2009b). *China Statistical Yearbook 2009*. Beijing: National Bureau of Statistics of China.

China, People's Republics of. (2011, March 16). *Outline of the Twelfth Five-Year Plan for National Economic and Social Development*. http://www.asifma.org/uploadedFiles/Resources/PRC-12th-FYP%281%29.PDF, last accessed 26 January 2015.

China, People's Republics of. (2012a). *China's Energy Policy 2012*. http://www.gov.cn/english/official/2012-10/24/content_2250497_5.htm, last accessed 12 November 2014.

China, People's Republics of. (2012b). *China Statistical Yearbook 2012*. Beijing: National Bureau of Statistics of China.

China, People's Republics of. (2013). *China Statistical Yearbook*. Beijing: National Bureau of Statistics of China.

China, People's Republics of; Ministry of Public Security. (2015, January 27). 2014年全国机动车和驾驶人迅猛增长. http://www.mps.gov.cn/n16/n1252/n1837/n2557/4330449.html, last accessed February 11, 2015.

Clean Energy Compression (2014) Are natural gas vehicles the answer to Beijing's nasty smog problems? https://www.cleanenergyfuels.com/compression/blog/beijing-china-natural-gas-vehicles-strategy/. Accessed 4 August 2016

Clemente, J. (2016) China's rising natural gas demand, pipelines and LNG. http://www.forbes.com/sites/judeclemente/2016/04/24/chinas-rising-natural-gas-demand-pipelines-and-lng/#54ab8ede6a38. Accessed 4 August 2016

Clover, I. (2014, August 11). China surpasses Germany as world's solar bright spot. PV Magazine: Photovoltaic Markets & Technology. http://www.pv-magazine.com/news/details/beitrag/china-surpasses-germany-as-worlds-solar-bright-spot_100016051/#axzz3DVZj3EzG, last accessed 27 October 2014.

CNREC – China National Renewable Energy Center. (2012). *China Renewable Energy Outline 2012*. http://www.cnrec.org.cn/english/publication/2014-01-20-408.html, last accessed 26 January 2015.

DuPont (2015) http://www.dupont.com/corporate-functions/media-center/press-releases/dupont-NTL-sign-historic-deal-cellulosic-ethanol-tech-china.html. Accessed 4 August 2016.

EERE (2007) https://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/ethanol_brochure_color.pdf. Accessed 4 August 2016

EIA – U.S. Energy Information Administration. (2014a, February 04). Country Analysis Briefs -

China. http://www.eia.gov/countries/analysisbriefs/China/china.pdf, last accessed 18 October 2014.

EIA – U.S. Energy Information Administration. (2014b, July). *Issues in International Energy Consumption Analysis: Chinese Transportation Fuel Demand*. Washington DC: US Department of Energy.

EIA – U.S. Energy Information Administration. (n.a.) Countries, opening page. http://www.eia.gov/countries/index.cfm, last accessed 18 October 2014.

ERI – Energy Research Institute of National Development and Reform Commission. (2010). 中国生质能技术路线图研究 [Research on Biomass Energy Technology Roadmap in China]. http://www.efchina.org/csepupfiles/report/2011124448314 14.5005357654043.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, last accessed January 22, 2015.

FAO – Food and Agriculture Organization – AQUASTAT database. (n.a.). http://www.fao.org/nr/water/aquastat/data/query/results.html, last accessed 20 January 2015.

FAO – Food and Agriculture Organization – FAOSTAT database. (n.a.). http://faostat3.fao.org/home/E

FAO – Food and Agriculture Organization. (2013). *Agricultural Outlook 2013.* http://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Oilcrops/Documents/OECD_Reports/OECD_2013_22_biofuels_proj.pdf, last accessed 21 November 2013.

Geall, S. (2016) China's plan for innovation could help it meet climate goals. https://www.chathamhouse.org/expert/comment/china-s-plan-innovation-could-help-it-meet-climate-goals#sthash.iP0wEaO5.dpuf. Accessed 4 August 2016.

Global Carbon Atlas (2014). Fossil Fuel Emissions. http://www.globalcarbonatlas.org/?q=en/emissions, last accessed 23 October 2014.

Gutterman, S. (2016) China and India: Doing the unimaginable to address climate change http://www.energymanagertoday.com/123916-0123916/. Accessed 4 August 2016

Hongliang, C. (2016) Carbon trading in China unlikely to go national by 2017. https://www.chinadialogue.net/blog/8538-Carbon-trading-in-China-unlikely-to-go-national-by-2-17/en. Accessed 4 August 2016.

Hornby, L. (2014, October 9). Lawsuit puts China biodiesel policy in spotlight. *Financial Times*. http://www.ft.com/intl/cms/s/0/613ee6b0-494e-11e4-8d68-00144feab7de.html#axzz3PgGIjfum, last accessed January 23, 2015.

Huo, H., Zhang, Q., Liu, F., & He, K. (2013). Climate and environmental effects of electric vehicles versus compressed natural gas vehicles in China: a life-cycle analysis at provincial level. *Environmental science & technology*, *47*(3), 1711-1718.

IAEA – International Atomic Energy Agency. (2013). Country Nuclear Power Profiles 2013 Edition, China. http://www-pub.iaea.org/MTCD/publications/PDF/CNPP2013_CD/countryprofiles/China/China.htm, last accessed 08 January, 2015.

IEA – International Energy Agency. (2010, July 20). China overtakes the United States to become world's largest energy consumer. http://www.iea.org/newsroomandevents/news/2010/july/2010-07-20-.html, last accessed 22 October 2014.

IEA – International Energy Agency. (2012). *Oil & Gas Security, Emergency Response of IEA Countries - People's Republic of China.* http://www.iea.org/publications/freepublications/publication/china_2012.pdf, last accessed 29 October 2014.

IEA – International Energy Agency. (2014a, March 24). China is now the world's largest net importer of petroleum and other liquid fuels. http://www.eia.gov/todayinenergy/detail.cfm?id=15531, last accessed 10 November, 2014.

IEA – International Energy Agency. (2014b, May 14). China produces and consumes almost as much coal as the rest of the world combined. http://www.eia.gov/todayinenergy/detail.cfm?id=16271, last accessed 10 November, 2014.

IEA – International Energy Agency. (2014c, June 17). *Medium-Term Oil Market Report 2014*. Paris: OECD publishing.

IEA – International Energy Agency. (2014d, July). *Issues in International Energy Consumption Analysis: Chinese Transportation Fuel Demand*. Paris: OECD publishing.

IEA AMF (Advanced Motor Fuels) http://www.iea-amf.org/content/fuel_information/methanol. Accessed 4 August 2016.

IEA– International Energy Agency. (2014e). *Advanced Motor Fuels Report 2013*. Paris: OECD publishing.

IEA– International Energy Agency. (2014f). *World Energy Outlook 2014*. Paris: OECD publishing.

IEA– International Energy Agency. (2014g). *Renewable Energy Medium-Term Market Report 2014 - Market Analysis and Forecasts to 2020*. Paris: OECD publishing.

IMF – International Monetary fund. (2014, October 07). *World Economic Outlook Database October 2014*. http://www.imf.org/external/ns/cs.aspx?id=28

Jaganathan, J. and Hua, J. (2013) Tax incentives boost Chinese biodiesel imports, replace diesel. http://www.reuters.com/article/china-biodiesel-imports-idUSL4N0HY2I820131018. Accessed 4 August 2016.

Ji, S., Cherry, C. R., J. Bechle, M., Wu, Y., & Marshall, J. D. (2012). Electric vehicles in China: emissions and health impacts. *Environmental science & technology*, *46*(4), 2018-2024.

Jiang, D., Hao, M., Fu, J., Zhuang, D., & Huang, Y. (2014). Spatial-temporal variation of marginal land suitable for energy plants from 1990 to 2010 in China*. Scientific Reports, 4:5816*, DOI: 10.1038/srep05816.

Kang, L. (2014) Biofuel Experiences in China. Governance and Market Development updates. Presentation at the 6th Stakeholder Plenary Meeting of EBTP. Brussels http://www.biofuelstp.eu/spm6/docs/liping-kang.pdf

Koizumi, T. (2013). Biofuel and food security in China and Japan. *Renewable and Sustainable*

Energy Reviews, *21,* 102–109.

Lane, J. (2015) China Steel green-lights commercial scale Lanzatech advanced biofuels project. http://www.biofuelsdigest.com/bdigest/2015/04/22/china-steel-green-lights-46m-for-commercial-scale-lanzatech-advanced-biofuels-project/. Accessed 4 August 2016.

Lanzatech (2015) http://www.lanzatech.com/china-steel-corporation-approves-investment-lanzatech-commercial-project/. Accessed 4 August 2016

Levin, D. (2015, February 10). Lurching Start for Tesla in China. *The New York Times*. http://www.nytimes.com/2015/02/11/business/international/tesla-seeks-a-stronger-foothold-in-china.html?emc=edit_th_20150211&nl=todaysheadlines&nlid=54809140, last accessed February 11, 2015.

Lewis, S. M., & Kelly, M. (2014). Mapping the Potential for Biofuel Production on Marginal Lands: Differences in Definitions, Data and Models across Scales. *ISPRS International Journal of Geo-Information, 3(2),* 430-459.

Li, J., Bluemling, B., Mol, A. P., & Herzfeld, T. (2014). Stagnating Jatropha Biofuel Development in Southwest China: An Institutional Approach. *Sustainability*, *6*(6), 3192-3212.

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

Ling, S.Y. (2014, February 13). Gasoline replaces gasoil as China's driver of oil demand growth. *Platts News*. http://www.platts.com/news-feature/2014/oil/china-oil-demand/index, last accessed 16 November 2014.

Liu, T. T., McConkey, B. G., Ma, Z. Y., Liu, Z. G., Li, X., & Cheng, L. L. (2011). Strengths, weaknessness, opportunities and threats analysis of bioenergy production on marginal land. *Energy Procedia, 5*, 2378-2386.

Lux Research (2015) http://www.luxresearchinc.com/news-and-events/press-releases/read/alternative-fuels-china-can-replace-483-billion-gallons-gasoline. Accessed 4 August 2016

Lu W., Wang G.S., Liu J.L., et al. (2008). Forest energy resource and potential analysis. In: Zhang X.L., Lv W. Eds. *China forest energy*. Beijing: China Agriculture Press.

Ma, Z., Zhang, C., & Chen, C. (2014). Analyzing the factors that influence Chinese consumers′ adoption of the biodiesel: The private vehicles owner′ s investigating in Beijing. *Renewable and Sustainable Energy Reviews*, *37*, 199-206.

Martin, R. (2014, May 30). Russia-China Gas Deal Narrows Window for U.S. Exports. *Forbes*. http://www.forbes.com/sites/pikeresearch/2014/05/30/russia-china-gas-deal-narrows-window-for-u-s-exports/, last accessed February 2, 2015.

Murphy, C. (2015, January 12). China's Automobile Sales to Slow Further in 2015 - After 2014 Slowdown, Inventories Are Rising as Economy Cools. *The Wall Street Journal*. http://www.wsj.com/articles/chinas-automobile-sales-slow-in-2014-1421046195, last accessed February 10, 2015.

Naylor, R. L., Liska, A. J., Burke, M. B., Falcon, W. P., Gaskell, J. C., Rozelle, S. D., & Cassman, K.

G. (2007). The ripple effect: biofuels, food security, and the environment. *Environment: Science and Policy for Sustainable Development, 49(9)*, 30-43.

OECD – Organisation for Economic Co-operation and Development. (2014). *The Cost of Air Pollution, Health Impacts of Road Transport*. DOI: 10.1787/9789264210448-en.

OECD/FAO – Organisation for Economic Co-operation and Development / Food and Agriculture Organization. (2013). "Feeding China: Prospects and challenges in the next decade", in *OECD/FAO Agricultural Outlook 2013*. OECD Publishing, http://dx.doi.org/10.1787/agr_outlook-2013-5-en, last accessed February 4, 2015.

OICA – International Organization of Motor Vehicle Manufacturers (Organisation Internationale des Constructeurs d'Automobiles). (2013). Registration or sales of new vehicles – all types. http://www.oica.net/wp-content/uploads//total-sales-2013.pdf, last accessed February 10, 2015.

Paton, J., A. Guo. (2014, November 10). Russia, China Add to $400 Billion Gas deal with accord. *Bloomberg*. http://www.bloomberg.com/news/2014-11-10/russia-china-add-to-400-billion-gas-deal-with-accord.html, last accessed January 06, 2015.

Patton, D. (2015) China ethanol imports seen increasing in months ahead. http://www.reuters.com/article/2015/09/16/china-ethanol-idUSL4N11M2ZV20150916. Accessed 4 August 2016.

QIBBT - Qingdao Institute of Bioenergy and Bioprocess Technology of Chinese Academy of Science. (2010). Development status of bioenergy and technologies prediction in China (pp. 105) [in Chinese]. Qingdao: QIBBT

Qinghai, Guo. (2004). An Analysis on the Maize Market of Jilin Province in China. *Far Eastern Studies, 3*, 11-23.

Qiu, H., Huang, J., Keyzer, M., van Veen,W., Rozelle, S., Fisher, G., & Ermolieva, T. (2011). Biofuel Development, Food Security and the Use of Marginal Land in China. *Journal of Environmental Quality, 40,* 1058–1067

REN21 (2014). *Renewable Global Status Report 2014.* http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf, last accessed 07 November 2014.

Reuters. (2014, January 10). China 2013 soy imports rise 8.6 pct to record –customs. http://uk.reuters.com/article/2014/01/10/china-trade-soy-idUKL3N0KJ2CD20140110, last accessed January 22, 2015.

Schroeder, J. (2014) Boeing, COMAC to open biojet demo facility. http://energy.agwired.com/2014/10/24/boeing-comac-to-open-biojet-demo-facility/. Accessed 4 August 2016.

Scotiabank, (2016) http://www.gbm.scotiabank.com/English/bns_econ/bns_auto.pdf. Accessed 4 August 2016.

Shi, J. (2012). 中国汽车工业发展情况介绍 [Introduction of Chinese Auto Industry Development] [PowerPoint slides]. http://www.autonews.com/Assets/html/12_ancc/pdf/pres_jianhua_zh.pdf, last accessed January 22, 2015.

Shuping, N. and Stanway, D. (2016) China to end state corn stockpiling, free up prices. http://www.reuters.com/article/us-china-corn-stockpiles-idUSKCN0WV06Z. Accessed 4 August 2016

Sivak, M. (2013). *Has motorization in the US peaked?*. Report No. UMTRI-2013-17. University of Michigan, Transportation Research Institute. http://deepblue.lib.umich.edu/bitstream/handle/2027.42/98098/102947.pdf, last accessed February 11, 2015.

Stratfor, (2015) Optimism aside, Chinese ethanol imports will not jump. http://www.forbes.com/sites/stratfor/2015/09/15/optimism-aside-chinese-ethanol-imports-will-not-jump/#32a59d953591. Accessed 4 August 2016.

Tan, Z.; Chen, K; Liu, P. (2015). Possibilities and challenges of China's forestry biomass resource utilization. *Renewable and Sustainable Energy Reviews*, *41*, 368-378.

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.

US EIA (2015) China, International energy data and analysis. https://www.eia.gov/beta/international/analysis.cfm?iso=CHN Accessed 22 June 2016

USDA (2014) People's Republic of China Biofuels Annual 2014. USDA Foreign Agricultural Service. Gain Report number: CH14038

USDA (2015) Peoples Republic of China Biofuels Annual 2015. USDA Foreign Agricultural Service. Gain Report number: CH15030

Wang, H., Fang, H. Yu, X., Wang, K. (2015) Development of natural gas vehicles in China: An assessment of enabling factors and barriers. *Energy Policy*. 85, 80-93

Wang, M., Han, J., Dunn, J. B., Cai, H., & Elgowainy, A. (2012a). Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. *Environmental Research Letters*, *7*(4), 045905.

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.

Wang, Y., Teter, J., Sperling, D. (2012b). Will China's Vehicle Population Grow Even Faster than Forecasted? *ACCESS Magazine, 41 (Fall),* 29-33.

WEC – World Energy Council. (2013). *World Energy Resources, 2013 Survey*. http://www.worldenergy.org/wp-content/uploads/2013/09/Complete_WER_2013_Survey.pdf, last accessed 01 November 2014.

World Bank (n.a.). World Databank. http://databank.worldbank.org/data/home.aspx#, last accessed 01 November 2014.

Worldbank (2016) Continuing momentum for putting a price on carbon pollution. http://www.worldbank.org/en/news/feature/2016/05/25/continuing-momentum-for-putting-a-price-on-carbon-pollution. Accessed 4 August 2016.

Wu, Y., Zhao, P., Zhang, H., Wang, Y., & Mao, G. (2012). Assessment for fuel consumption and exhaust emissions of China’s vehicles: Future trends and policy implications. *The Scientific World Journal, 2012/6,* 591343.

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.

Xingangn, Z., Pingkuo, L. (2014). Focus on bioenergy industry development and energy security in China. *Renewable and Sustainable Energy Reviews, 32*, 302–312.

Xunmin, O., Xiliang, Z., Shiyan, C., Qingfang, G. (2009) Energy consumption and GHG emissions of six biofuel pathways by LCA in the People’s Republic of China. Applied Energy 86, S197-S208

Yan, X., Crookes, R.J. (2009) Life cycle analysis of energy use and greenhouse gas emissions for road transportation fuels in China. Renewable and Sustainable Energy Reviews. 13, 2505-2514

Yan, Z., Zhang, L., Wang, S. Q., & Hu, L. (2008). Potential yields of bio-ethanol from energy crops and their regional distribution in China [in Chinese]. *Transactions of the Chinese Society of Agricultural Engineering, 24*(5), 213-216

Yang, H., Zhou, Y., & Liu, J. (2009). Land and water requirements of biofuel and implications for food supply and the environment in China. *Energy Policy, 37(5),* 1876-1885.

Yuan, J., Xu, Y., Zhang, X., Hu, Z., & Xu, M. (2014). China's 2020 clean energy target: Consistency, pathways and policy implications. *Energy Policy*, *65*, 692-700.

Yuan, X., Liu, X., Zuo, J. (2015) The development of new energy vehicles for a sustainable future: A review. Renewable and Sustainable Energy Reviews 42, 298-305

Zhang, H., Li, L., Zhou, P., Hou, J., & Qiu, Y. (2014). Subsidy modes, waste cooking oil and biofuel: Policy effectiveness and sustainable supply chains in China. *Energy Policy, 65*, 270-274.

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.

Zhang, Q. & Crooks, R. (2012). *Toward an environmentally sustainable future: Country environmental analysis of the People’s Republic of China*. Mandaluyong City (Philippines): Asian Development Bank.

Zhao, L., Chang, S., Wang, H., Zhang, X., Ou, X., Wang, B., Wu, M. (2015) Long-term projections of liquid biofuels in China: Uncertainties and potential benefits. Energy 83, 37-54

Zhao, X., & Liu, P. (2014). Focus on bioenergy industry development and energy security in China. *Renewable and Sustainable Energy Reviews*, *32*, 302-312.

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