Renewable and Sustainable Energy Reviews 82 (2018) 645–653

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# Biofuel for vehicle use in China: Current status, future potential and policy implications

Han Hao[a,e], Zongwei Liu[a], Fuquan Zhao[a,*], Jingzheng Ren[b], Shiyan Chang[c,e], Ke Rong[d], Jiuyu Du[a,e]

[a] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
[b] Centre for Engineering Operations Management, Department of Technology and Innovation, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark
[c] Institute of Energy, Environment and Economy, Tsinghua University, Beijing 100084, China
[d] Institute of Economics, School of Social Sciences, Tsinghua University, Beijing 100084, China
[e] China Automotive Energy Research Center, Tsinghua University, Beijing 100084, China

ARTICLE INFO

*Keywords:*
Biofuel
Fuel ethanol
Biodiesel
Vehicle
China

ABSTRACT

Biofuel is considered to be a promising solution to the energy and environmental challenges in the transport sector. However, there are few studies focusing on the current status, future potential, policy framework, barriers and opportunities of biofuel development in China, these are analyzed in this study. This study finds that China has been promoting biofuel commercialization with multiple measures, including framing national strategy, initiating demonstration programs, providing financial incentives, and establishing national standards. However, due to technology and market barriers, the actual commercialization scale is far lower than previously projected. Accordingly, it is recommended that the development of non-plantation resource-based biofuel should be given high priority, while plantation resource-based biofuel should be developed with caution. Meanwhile, technology innovation for increasing production efficiency and reduce cost is essential for strengthening biofuel market competitiveness. Subsequently, mandatory legal and policy system for regulating the biofuel industry in China should be established, which can effectively engage different stakeholders in promoting biofuel development. Regarding fuel ethanol, the trade price between the fuel ethanol producers and the oil companies should be further adjusted. As for biodiesel, the illegal utilization of waste oil should be strictly prohibited, which can help to increase the feedstock supply, as well as bring down the price. Last but not the least, the financial incentives for biofuel production should also be optimized.

## 1. Introduction

Transport is a major sector concerning energy consumption and $CO_2$ emissions. As estimated by International Energy Agency (IEA), the oil consumption by transport sector accounted for over half of total oil consumption globally [1]. Transport sector was responsible for 23% of global energy-related $CO_2$ emissions in 2013 [2]. China, as the representative of emerging economies, has experienced rapid growth in its vehicle market over recent years [3]. China's domestic vehicle sales increased from 2.1 million in 2000 to 23.5 million in 2014, with an annual growth rate of 19% [4]. By the end of 2014, China's vehicle stock reached 154 million [5]. This has caused great concerns over China's urban air quality, energy security, and $CO_2$ emissions. For example, China's major mega cities have experienced frequent smog weathers over recent years, which can be partially attributed to vehicle tailpipe emissions. GHG emissions from China's passenger vehicles accounted for around 5% of total GHG emissions in 2014 [6], and the freight transport sector for around 8% [7]. To cope with these challenges, intensive mitigation measures have been implemented both in China and globally.

*Abbreviations:* 1 G biofuel, First-generation biofuel; 1.5 G biofuel, 1.5-generation biofuel; 2 G biofuel, Second-generation biofuel; 3 G biofuel, Third-generation biofuel; BP, British Petroleum; CAAM, China Association of Automotive Manufacturers; CARB, California Air Resource Board; CNOOC, China National Offshore Oil Corporation; CNPC, China National Petroleum Corporation; COFCO, China Oil & Foodstuffs Corporation; DEA, Data Envelopment Analysis; EIA, Energy Information Administration; EJ, exajoule; EPA, Environmental Protection Agency; EU, European Union; FAHP, Fuzzy Analytic Hierarchy Process; GHG, Greenhouse Gas; GIS, Geographic Information System; GJ, gigajoule; Gt, gigaton; IEA, International Energy Agency; LCA, Life Cycle Assessment; MOF, Ministry of Finance; Mt, megaton; Mtoe, megaton of oil equivalent; NBS, National Bureau of Statistics; NDRC, National Development and Reform Commission; NEA, National Energy Administration; PJ, petajoule; SAC, Standardization Administration of China; Sinopec, China Petroleum & Chemical Corporation; SWOT, Strength, Weakness, Opportunity and Threats; VAT, Value Added Tax

* Corresponding author.
*E-mail address:* zhaofuquan@tsinghua.edu.cn (F. Zhao).

http://dx.doi.org/10.1016/j.rser.2017.09.045
Received 24 September 2016; Received in revised form 7 July 2017; Accepted 14 September 2017
1364-0321/ 

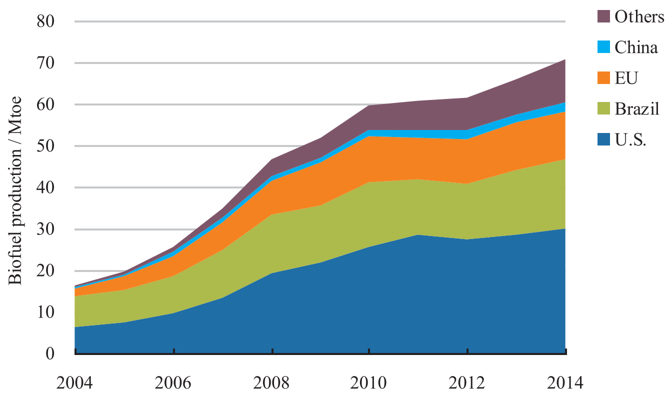


**Fig. 1.** Global biofuel production over the past decade.

Biofuel is considered to be part of the solution to the transport issues. Biofuel is derived from biomass, which helps to decouple transport fuels from petroleum resources. The life cycle $CO_2$ emissions of biofuels are generally lower than petroleum-derived fuels, contributing to reducing $CO_2$ emissions from the transport sector [8]. Moreover, biofuels improve fuel quality when blended with conventional fuels, which helps to reduce vehicle tailpipe emissions and improve air quality [9,10].

Globally, biofuel production and consumption increased steadily over recent years, as Fig. 1 shows [11,12]. Total biofuel production increased from 16.4 Mtoe (megaton of oil equivalent) in 2004 to 70.8 Mtoe in 2014, implying an annual growth rate of 15.7%. As projected by IEA, global biofuel consumption will continue to increase in the coming decades, reaching over 30 EJ (exajoule) (equivalent to about 720 Mtoe) by 2050, implying a ten fold growth compared to the current level [13]. At the same time, the biomass as feedstock for biofuel production will show a major shift from food crops to non-food crops and non-plantation resources. In China, biofuel production and consumption also experienced rapid growth, from 0.5 Mtoe in 2000 to 2.1 Mtoe in 2014 [11]. According to the Mid-long Term Planning on the Development of Renewable Energy released in 2007 [14], China's fuel ethanol and biodiesel consumptions were projected to reach 10 Mt (megaton) and 2 Mt by 2020, respectively.

Intensive studies have been conducted regarding biofuel development in China. Ren et al. compared the life cycle energy efficiency of six biofuels in China by using the Data Envelopment Analysis (DEA) approach, finding that fuel ethanol with sweet potatoes as feedstock has the highest life cycle energy efficiency [15]. Liu et al. established a life cycle assessment (LCA) based biofuel supply chain multi-objective optimization model, with the aim of identifying the optimal conversion pathway, biomass type, biomass locations, facility locations, etc. [16]. Ou et al. evaluated the life cycle energy consumption and GHG emissions of six biofuel pathways in China's context [17]. Lu and Zhou conducted a comprehensive review of the environmental assessments on liquid biofuels in China [8]. Wang discussed the time for commercializing non-food biofuel in China, arguing that more efforts are needed [18]. Koizumi argued that biofuel competes with food and agricultural production in China, and should be promoted with caution [19]. A similar conclusion was reached by Yang et al., who argued that China's biofuel development could pose significant impacts on China's food supply and trade, as well as the environment [20]. Huang et al. examined the impact of biofuel development on China's poverty situation, concluding that China's farmers, especially the poor, might benefit from biofuel development [21]. Besides, biofuel technology evolution in China's context has been examined by several studies, mostly based on patent statistics [22,23].

Macro-level polices are essential in promoting biofuel development. Ren et al. analyzed biofuel development in China by combining Strength, Weakness, Opportunity and Threats (SWOT) and Fuzzy Analytic Hierarchy Process (FAHP) approaches, concluding that policy instruments regarding improving technical performance and consumer awareness are both important in promoting its further development [24]. Qiu et al. comprehensively reviewed China's policies on biofuel development, arguing that the targets of China's biofuel development are cautious and feasible [25]. Chen et al. reviewed China's industrial policies for different kinds of biofuels [26]. Chang et al. assessed the potential policies needed to achieve China's biofuel development target in 2020 [27]. Besides macro-level policies, the micro-level behavior and management factors also affect the market competitiveness of biofuels. Zhang et al. compared the recycling modes of waste cooking oil in China and Japan, finding that the recovery rate of Chinese mode is not necessarily lower than that of Japanese mode [28]. Wang and Shi developed a Geographic Information System (GIS)-based optimization model for the selection of biofuel factory sites, and presented the optimal locations for biofuel factories by using the case of Guangdong province [29]. Zhang et al. compared the incentive effects of four common subsidy modes on waste cooking oil supply by establishing a dynamic game model, finding that raw material price subsidies and finished products sales subsidies have better overall effects [30].

Numerous studies focused on evaluating the potential of biofuel commercialization in China. Chen et al. estimated the potential of non-food biofuel production in China, concluding that there will be 76 Mt to 152 Mt potential capacity from 2015 to 2030 [31]. Jansson et al. discussed the potential of cassava for fuel ethanol production in China [32]. Ji assessed the agricultural residue resources for liquid biofuel production in China, concluding that around 930 Mt crop residuals will be available in 2015, which can be used to produce 44 Mt fuel ethanol or 131 Mt biodiesel [33]. Wang et al. explored the quantity of China's field crop residue and its availability for biofuel production, finding that the total residue quantity for biofuel production could potentially reach 314 Mt [34]. Elmore et al. calculated the spatial distribution of rice straw in China for the period 2000–2004 [35]. Tian et al. estimated the unused land potential for biofuels development in China, suggesting a 22 Mt potential of fuel ethanol production in 2020 [36]. Zhao et al. projected the long-term liquid biofuel potential, finding that the scale of biofuel consumption in China can range from 45 Mtoe to 120 Mtoe by 2050 [37]. Lu and Zhang introduced a species of invasive plant, Spartina alterniflora, and evaluated its potential as biofuel feedstock in China. Their study indicated that its total annual biomass reaches 2.53 Mt, capable of producing 39 PJ (petajoule) bioenergy [38]. Liang et al. evaluated the potential of waste oil as feedstock for biodiesel production, finding that it was equivalent to approximately 7.4% of China's diesel consumption in 2010 [39]. Zhang and Chen evaluated the role of biofuel in China's transport sector by developing the China-TIMES model. The study revealed that the use of biofuel will realize a 0.43 Gt (gigaton) of $CO_2$ emissions reduction in 2050, contributing to 35% of the overall reduction [40].

Besides regular biofuels, the development of emerging biofuel technologies in China has also received attentions from the research community. Li et al. estimated the biological potential of microalgae for biofuel production in China in an integrated bio-refinery approach [41]. Li et al. evaluated the characteristics of Enteromorpha prolifera as feedstock for biofuel production [42]. Zhou et al. conducted a comprehensive review on the development of densified solid biofuel in China [43]. A similar research was conducted by Chen et al. with a focus on the technological aspects [44]. Gu et al. discussed the possibility and potential of utilizing waste nitrogen for biofuel production in China [45]. Zhou et al. analyzed the utilization of the so-called low-input high-diversity grassland biomass to produce biofuel, finding that the potential reaches 15% of China's energy consumption in 2002 [46]. Some alternative biofuels, such as biobutanol, furanic biofuel, etc., are also being considered as potential biofuel options. The production technologies of these alternative biofuels have been intensively developed [47–49]. The impacts of using such biofuels on the performance of the combustion devices have also been investigated [50–52].

Overall, existing studies have covered most of the major issues regarding biofuel development in China. However, with technology improvement and market environment changes, many new opportunities and barriers emerged over recent years. There is an urgent need in updating the understanding of the rationality and feasibility of commercializing biofuel in China. With the aim of filling such a gap, a comprehensive review on biofuel development in China is conducted, covering the aspects of current status, future potential, policy initiatives, barriers and opportunities. This review aims to answer whether, why, to what scale, and how biofuel should be developed in China. This review contributes to establishing a triple-dimension (i.e., biofuel producer-refueling station operator-consumer), cost-benefit perspective-based review framework to reveal the dynamics and interaction among different stakeholders, which can be employed to analyze the development of other alternative fuels; and to comprehensively summarizing China's experiences in promoting the development of biofuel, which is of high relevance to other countries with similar interests. The review is organized as follows. The next two sections describe the current status and future potential of biofuel development in China. Following that, the policy initiatives regarding biofuel production and consumption are summarized. The subsequent section analyzes the market barriers and opportunities. The policy implications are then proposed. The final section concludes the whole review.

## 2. Current status

The biofuel classification, the production and consumption status of biofuel in China are investigated in this section.

### 2.1. Biofuel classification

According to Chang et al., biomass resources can be classified into plantation resources and non-plantation resources [53]. Plantation resources can be further categorized into agricultural crops, oil-bearing crops, and cellulosic crops. Non-plantation resources are mostly cellulosic biomasses, which can be further categorized into agricultural residuals, forestry residuals, among others. The classification and typical resources within each category are presented in Fig. 2.

By biomass feedstock and conversion technologies, biofuels are commonly conceptually categorized into first-generation (1 G) biofuel, 1.5-generation (1.5 G) biofuel, second-generation (2 G) biofuel, third-generation (3 G) biofuel. 1 G biofuel refers to fuel ethanol derived from food crops. 1.5 G biofuel refers to fuel ethanol derived from non-food crops and biodiesel derived from oil-bearing crops. 2 G biofuel refers to fuel ethanol and biodiesel derived from celluloses. 3 G biofuel refers to biodiesel derived from algae.

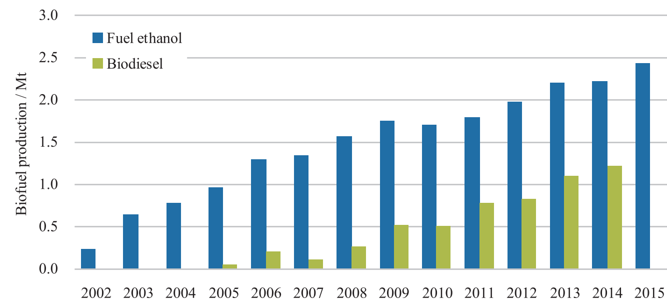


**Fig. 3.** China's biofuel production over the past decade.

### 2.2. Production

Fig. 3 presents China's biofuel production over the past decade [12,54]. Generally, China's biofuel production experienced steady growth, with significant changes in the feedstock composition. Total fuel ethanol production increased from 1.02 Mt in 2005 to 2.21 Mt in 2014 [12,54]. Corn and wheat have been the major biomasses for fuel ethanol production in the early years. However, due to feedstock and policy issues, the production of corn/wheat-based fuel ethanol became saturated over recent years, with total production maintained at around 1.4 Mt per year. Non-food crop-based fuel ethanol, with cassava ethanol as the representative, showed higher growth rate in its production over recent years. The production of cellulosic ethanol is very small in the current stage due to the technology maturity and cost issues. Waste oil is currently the major feedstock for biodiesel production. Total waste oil-based biodiesel production reached around 1.2 Mt in 2014 [55]. Overall, China's biofuel production reached 2.1 Mtoe in 2014, accounting for 2.9% of global total.

Table 1 lists China's major biofuel producing plants. Corn/wheat ethanol is exclusively produced in four major plants, located in Jilin, Heilongjiang, Henan, and Anhui, respectively [56–59]. These four plants were all established in the 2000s. Total production capacity expanded from 1.02 Mt in 2005 to 1.4 Mt in 2014. Regarding fuel ethanol production with non-food crops as feedstock, five projects have been approved for establishment, located in Guangxi, Guangdong, Hainan, Zhejiang and Jiangxi, respectively. All of these plants use cassava as feedstock, with a total production capacity of 0.85 Mt. Two cellulosic ethanol plants have been established, with a total production capacity of 0.21 Mt. Regarding biodiesel production with oil-bearing crops as feedstock, three plants have been planned as pilot demonstrations. All three plants were planned to use jatropha as feedstock, with a total production capacity of 0.17 Mt. The production capacity of waste oil-based biodiesel was estimated to be around 1.8 Mt in 2013, distributed in over fifty plants [60]. It should be noted that not only biochemical companies, but also major petroleum companies, including

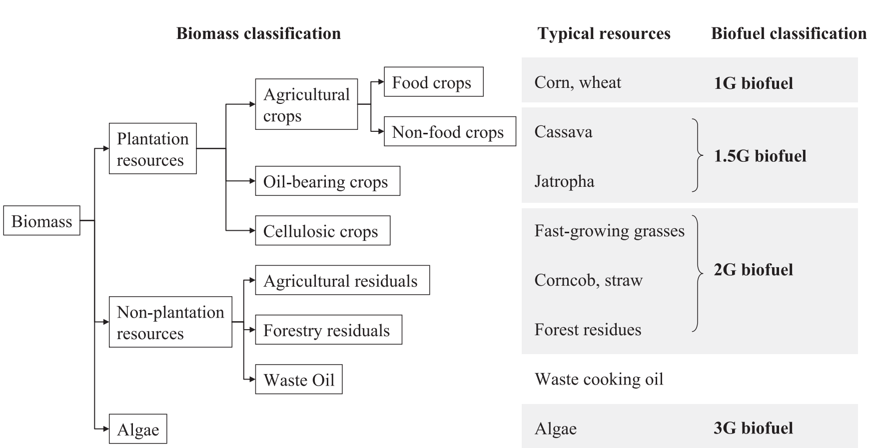


**Fig. 2.** Biomass and biofuel classifications.

**Table 1**
China's major biofuel producing plants.

| Operator | Location | Feedstock biomass | Product | Capacityt/year |
|---|---|---|---|---|
| CNPC, Jilin Grain Group LLC, COFCO | Jilin, Jilin | Corn | Ethanol | 500,000 |
| COFCO | Zhaodong, Heilongjiang | Corn | Ethanol | 280,000 |
| Tianguan Group, Sinopec | Nanyang, Henan | Wheat, corn | Ethanol | 300,000 |
| COFCO, Sinopec | Bengbu, Anhui | Corn | Ethanol | 320,000 |
| COFCO | Beihai, Guangxi | Cassava | Ethanol | 200,000 |
| SDIC | Zhanjiang, Guangdong | Cassava | Ethanol | 150,000 |
| Hainan Yedao Group LLC, Sinopec | Yedao, Hainan | Cassava | Ethanol | 100,000 |
| CNPC, Holley Group | Zhoushan, Zhejiang | Cassava | Ethanol | 300,000 |
| Sinopec, Yufan LLC | Dongxiang, Jiangxi | Cassava | Ethanol | 100,000 |
| CNOOC | Dongfang, Hainan | Jatropha | Biodiesel | 60,000 |
| CNPC | Nanchong, Sichuan | Jatropha | Biodiesel | 60,000 |
| Sinopec | Guizhou | Jatropha | Biodiesel | 50,000 |
| Longlive LLC | Shandong | Corncob | Ethanol | 60,000 |
| Tianguan Group | Nanyang, Henan | Straw | Ethanol | 150,000 |

China National Petroleum Corporation (CNPC), China Petroleum & Chemical Corporation (Sinopec), and China National Offshore Oil Corporation (CNOOC), are all engaged in promoting biofuel commercialization.

### 2.3. Consumption

Fuel ethanol is normally used in the form of E10, a blend consisting of 10% fuel ethanol and 90% gasoline. E10 fuel is currently available in China's six provinces (Heilongjiang, Jilin, Liaoning, Henan, Anhui, and Guangxi) and 27 cities in other four provinces (Jiangsu, Shandong, Hubei, and Hebei). Biodiesel is mainly used in the form of B5, a blend consisting of 5% biodiesel and 95% diesel. The use of B5 fuel has been demonstrated in Hainan province. Besides, the waste oil-based biodiesel is normally consumed locally by blended into conventional diesel with low ratio.

All in all, there is a great market potential for biofuel industry in China. Accordingly, the discussion on the potential of biofuel supply in China is of vital importance for planning China's biofuel industry. Therefore, the future potential of biofuel in China has been investigated in Section 3.

## 3. Future potential

This section mainly focuses on the future potential of biofuel in China, including the plantation resource-based biofuel and non-plantation resource-based biofuel.

### 3.1. Plantation resource-based biofuel

Table 2 summarizes the existing estimations of biofuel potentials in China. The production of plantation resource-based biofuel is mainly constrained by land resource. Fig. 4 presents the breakdown of China's land resources by utilizations. Cultivated land, forestland, and unused

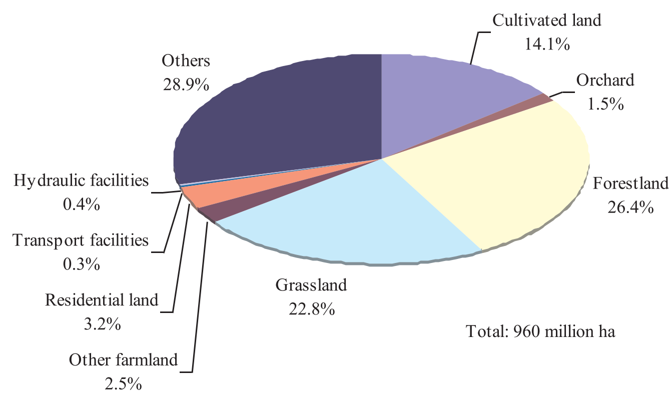


**Fig. 4.** Breakdown of China's land resources by utilizations.

land can be partially utilized as land for planting energy crops. Generally, the land resources available for planting energy crops were estimated to range between 83 million ha and 203 million ha [53], accounting for 8.3–21.1% of China's total land resources. The conversion rate of planting different energy crops, measured in GJ (gigajoule) biofuel output with unit land resource input, can be quite different, as Fig. 5 illustrates. With average conversion rates assumed, the total potential for plantation resource-based biofuel production in China was estimated to be 17.3 EJ per year [53].

### 3.2. Non-plantation resource-based biofuel

The production of non-plantation resource-based biofuel is mainly constrained by the amount of residual resources. Limited by economical feasibility, as well as the competition from other residual resource utilizations, the actual amount of residual resources that can be utilized to produce biofuel is far lower than the theoretical total resource volume. It was estimated that the amount of agricultural and forestry

**Table 2**
Estimations of biofuel potentials in China.

| Evaluation target | Potential | Source |
|---|---|---|
| Non-food biofuel | Fuel ethanol: 64 Mt in 2015, 118 Mt in 2030Biodiesel: 12 Mt in 2015, 34 Mt in 2030 | Chen et al. (2016) |
| Biofuel | Biofuel: 45 Mtoe to 120 Mtoe in 2050 | Zhao et al. (2015) |
| Agricultural residue | Agricultural residue: 931 Mt in 2015Fuel ethanol: 44 Mt in 2015Biodiesel: 131 Mt in 2015 | Ji (2015) |
| Agricultural residue | Crop residue: 750 Mt in 2008 (88% field residue and 12% process residue) | Wang et al. (2013) |
| Spartina alterniflora | Biomass: 2.53 MtBioenergy: 39 PJ | Lu and Zhang (2013) |
| Waste oil-based biodiesel | Biodiesel: 12 Mt in 2010Biokerosene: 6.52 Mt in 2010 (with 3 Mt co-product biodiesel) | Liang et al. (2013) |
| Biofuel | Biofuel: 32.4 Mtoe to 79.7 Mtoe in 2050 | Chang et al. (2012b) |
| Unused land | Fuel ethanol: 22 Mt in 2020 | Tian et al. (2009) |
| Waste nitrogen | Biofuel: 16.4 EJ in 2008 | Gu et al. (2011) |
| Grassland biomass | Biofuel: 6.4 EJ in 2002 | Zhou et al. (2009) |

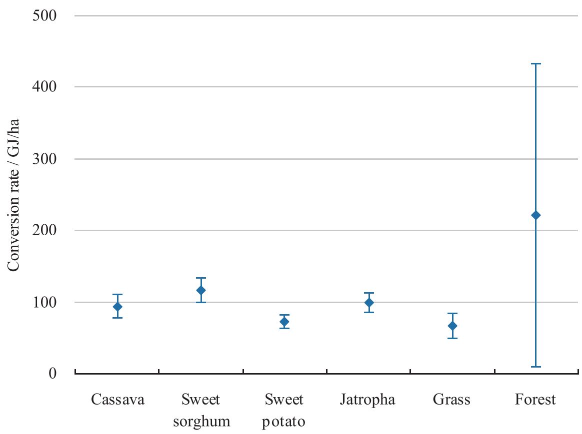


**Fig. 5.** Conversion rates of plating different energy crops.

residual resources available for biofuel production will be 209 Mt to 446 Mt in 2050. Besides, there is an estimated volume of 3.4 Mt waste oil available for biofuel production [53]. With the improvement of residual resource utilization technology and efficiency, the estimation for the amount of residual resources available for biofuel production can be more optimistic in the future.

With both plantation resource-based biofuel and non-plantation resource-based biofuel taken into consideration, the total potential for biofuel production in China is about 32.4 Mtoe to 79.7 Mtoe in 2050 [53]. With regard of China's current 250 Mt gasoline and diesel consumptions per year, the development of biofuel can have substantial impact on China's energy system.

It is apparent that biofuel industry in China for the transport section has a great potential and bright future, and some policy initiatives have also been drafted and implemented for stimulating the consumption of biofuel and enlarging the market share.

## 4. Policy initiatives

The demonstration programs, financial incentives, and national standards for promoting the development of biofuel in transport section have been summarized in this section.

### 4.1. Demonstration

The guidance documents on fuel ethanol development in China are summarized in Table 3 [14,61–66]. China proposed the target of using fuel ethanol for 1.05 Mt per year during China's tenth five-year planning period (2001–2005). To achieve this target, the government initiated a nation-wide fuel ethanol demonstration program. The demonstration program started in 2002, with two fuel ethanol producers (Tianguan Group LLC, Jinyu Group LLC) providing fuel ethanol to five cities in two provinces (Henan, Heilongjiang) [62]. In 2004, the demonstration program was expanded to cover two more fuel ethanol producers (Jilin fuel ethanol LLC, Fengyuan LLC) and three more demonstration provinces (Jilin, Liaoning, Anhui) [63]. As part of the demonstration guidance document, the price for ethanol gasoline was specified to be the same with pure gasoline with the same grade. Besides, the trade price between fuel ethanol producers and petroleum companies was specified to be the price of 90# gasoline multiplied by a coefficient of 0.9111.

With the expansion of the demonstration program, the consumption of feedstock corn increased significantly, from 12.5 Mt in 2001 to 23.0 Mt in 2005, with an annual growth rate of 16.5%. At the same time, driven by the potential profit from fuel ethanol production, many local governments and companies showed high passion on initiating new fuel ethanol projects. The new capacities under consideration were estimated to be over 10 Mt in 2006. To avoid the risk of excessive corn consumption and the resulting threat to domestic food security, the government halted the establishment of new fuel ethanol projects, and restricted the expansion of existing fuel ethanol projects. A series of guidance documents were released to enforce the restrictions [64–66]. Since then, the development of food crop-based fuel ethanol has been almost halted. Instead, the government prioritized the development of non-food crop-based biofuels. In 2008, the Guangxi fuel ethanol project, with cassava as feedstock, was established. Accordingly, the use of E10 started to be demonstrated in Guangxi province. Regarding biodiesel, the demonstration is limited to specific regions, as summarized in Table 4 [67–69]. In 2010, Hainan province started the demonstration of B5 use. The biodiesel is provided by CNOOC, with jatropha as feedstock.

### 4.2. Financial incentives

A series of documents regarding the financial incentives for fuel ethanol production were released, as summarized in Table 5 [70–78]. In terms of the taxation policy, the early documents specified that the excise tax for fuel ethanol production is exempted, and the Value Added Tax (VAT) for fuel ethanol production is reimbursed [71]. However, with the change of the government's attitude towards fuel ethanol development, the tax incentive for food crop-based fuel ethanol production gradually phased out [74]. Specifically, the VAT for food crop-based fuel ethanol production was reimbursed by 80% in 2011; 60% in 2012; 40% in 2013; 20% in 2014; and no reimbursement from 2015 on. The excise tax for food crop-based fuel ethanol production was 1% in 2011; 2% in 2012; 3% in 2013; 4% in 2014; and 5% from 2015 on. Despite this, the tax incentive for non-food crop-based fuel ethanol was retained. Regarding biodiesel, the excise tax for waste oil-based biodiesel production is exempted [68]. Besides, the Biodiesel Industrial Development Policy released in 2014 specified that China should launch dedicated price, taxation, finance and investment incentives to promote biodiesel development [69].

In terms of the subsidy policy, the subsidy scheme for fuel ethanol production experienced frequent changes. From 2001 to 2004, subsidy was determined according to the ‘reasonable profit’ principle [62]. From 2005 to 2008, subsidy became fixed, which was ¥1883/t, ¥1628/t, ¥1373/t and ¥1373/t, respectively [63]. From 2009 to 2011, a so-called ‘elastic loss subsidy mechanism’ was established [72,73]. As a result, the subsidy was ¥2055/t, ¥1659/t, and ¥1276/t from 2009 to 2011, respectively. In 2012, subsidy became fixed again, which was ¥500/t for food crop-based fuel ethanol and ¥750/t for non-food crop-based fuel ethanol [75]. From 2013 to 2016, the subsidy for food crop-based fuel ethanol gradually phased out, from ¥300/t to no subsidy [76]. Despite this, the subsidy for non-food crop-based fuel ethanol production was retained.

### 4.3. National standards

National standards are very important pillars for biofuel development. Since 2001, China has established four essential national standards regarding biofuel production and use, as summarized in Table 6. They are the Denatured Fuel Ethanol (GB 18350) and Ethanol Gasoline for Motor Vehicles (E10) (GB 18351) established in 2001 [79,80], Biodiesel Blend Stock (BD100) for Diesel Engine Fuels (GBT 20828) established in 2007 [81], and Biodiesel Fuel Blend (B5) (GBT 25199) established in 2010 [82]. With technology improvement and market development, these standards have been frequently updated over recent years. Besides, intensive researches have been conducted to test the feasibility of utilizing biofuel in the transport sector [83–86].

Above all, both China's central and local governments have put great efforts in promoting biofuel commercialization. The changes of financial incentives reflect the changes of the government's attitude towards biofuel development. The overall trend is a phasing out of financial incentives, and a shift of emphasis from food crop-based biofuel

**Table 3**
Guidance documents on fuel ethanol development in China.

| Year | Policy document | Major contents |
|---|---|---|
| 2002 | Dedicated plan on the development of fuel ethanol and ethanol gasoline during the tenth five-year planning period | ◆ The scale of fuel ethanol use is planned to reach 1.02 Mt during the tenth five-year planning period |
| 2002 | Planning on the pilot demonstration of ethanol gasoline use | ◆ The pilot cities are Zhengzhou, Luoyang, Nanyang in Henan province, and Harbin, Zhaodong in Heilongjiang province<br>◆ The fuel ethanol for the demonstration in Henan province is provided by Tianguan Group LLC; the fuel ethanol for the demonstration in Heilongjiang province is provided by Jinyu Group LLC<br>◆ The retail price of ethanol gasoline is the same with pure gasoline with the same grade |
| 2004 | Planning on expanding the demonstration of ethanol gasoline use | ◆ The pilot regions were expanded to cover five provinces (Heilongjiang, Jilin, Liaoning, Henan, Anhui) and 27 cities in other four provinces (Jiangsu, Shandong, Hubei, and Hebei)<br>◆ Jilin fuel ethanol LLC, with the 300,000 t fuel ethanol capacity co-established by CNPC, will be responsible for providing fuel ethanol to Jilin and Liaoning; Huarun ethanol LLC, with the 100,000 t fuel ethanol capacity, will be responsible for providing fuel ethanol to Heilongjiang; Tianguan group LLC, with the 300,000 t fuel ethanol capacity co-established by Sinopec, will be responsible for providing fuel ethanol to Henan, Hubei and Hebei; Fengyuan LLC, with the 320,000 t fuel ethanol capacity co-established by Sinopec, will be responsible for providing fuel ethanol to Anhui, Shandong, Hebei and Jiangsu<br>◆ The trade price between fuel ethanol producers and petroleum companies is specified to be the price of 90# gasoline multiplied by a coefficient of 0.9111<br>◆ The retail price of ethanol gasoline is the same with pure gasoline with the same grade (same with previous document) |
| 2006 | Urgent notification on strengthening the management of corn processing projects | ◆ No new corn-based fuel ethanol projects will be approved<br>◆ All existing corn-based fuel ethanol projects should be thoroughly examined regarding their land use, environmental impacts and financial conditions |
| 2006 | Notification on strengthening the management of fuel ethanol projects, and promoting the healthy development of fuel ethanol industry | ◆ Non-food crops are prioritized as the feedstock for fuel ethanol, with tuber crops, sugar sorghum, and cellulosic crops as focuses<br>◆ The establishment and expansion of fuel ethanol capacities are strictly controlled |
| 2007 | Notification on promoting the healthy development of corn deep processing industry | ◆ The amount of corn used for deep processing should be controlled below 26% of total corn consumption |
| 2007 | Mid-long term planning on the development of renewable energy | ◆ By 2010, non-food crop-based fuel ethanol consumption will reach 2 Mt; biodiesel consumption will reach 0.2 Mt<br>◆ By 2020, fuel ethanol consumption will reach 10 Mt; biodiesel consumption will reach 2 Mt |

**Table 4**
Guidance documents on biodiesel development in China.

| Year | Policy document | Major contents |
|---|---|---|
| 2009 | Working plan on promoting the use of biodiesel in Hainan province | ◆ From 2010, B5 fuel is promoted in Hainan province in the closed-operation mode. Namely, all refueling stations are mandated to provide B5 fuel. The sales of pure diesel are prohibited. |
| 2010 | Notification on exempting the excise tax on waste oil-based biodiesel production | ◆ The excise tax for waste oil-based biodiesel production is exempted |
| 2014 | Biodiesel industrial development policy | ◆ China should launch dedicated price, taxation, financial, investment incentives to promote biodiesel development |

to non-food crop-based biofuel. National Development and Reform Commission (NDRC) projected that the consumptions of non-food crop-based fuel ethanol and biodiesel will reach 2 Mt and 0.2 Mt by 2010 [14]. However, the actual biofuel consumption is far lower than projected.

## 5. Barriers and opportunities

Although China's administrations/decision-makers have taken various policies and measures for promoting the development of biofuel industry in a sustainable, harmonious and healthy way, China's biofuel industry faces not only opportunities, but also a quantity of barriers and challenges.

### 5.1. Fuel ethanol

Although China's fuel ethanol production experienced steady growth over the past decade, the actual scale is far lower than previously expected. This can be mostly attributed to the fact that the profit of producing fuel ethanol is not stable. First, the production cost increased significantly over recent years. The production cost of fuel ethanol consists of feedstock cost, facility depreciation cost, operation cost, labor cost, etc. Among all the costs, feedstock cost normally accounts for over 80% of the total cost [87]. At the initial stage of fuel ethanol production, the feedstock was aged corn with a quite low price. However, with the depletion of aged corn, the corn ethanol producers had to use normal corn as feedstock. Fig. 6 presents the warehouse-gate corn prices in China's three major corn-producing provinces, whose corn production accounted for over one third of national production in 2015 [88]. It can be found that corn price has been more than doubled over the past decade. The corn prices in other regions of China generally exhibited similar trends. Regarding cassava, the increasing demand for cassava as fuel ethanol feedstock broke the original supply-demand balance, and boomed its price to significantly higher levels. The cassava price in Guangxi province increased from around ¥400/t before being used as fuel ethanol feedstock, to around ¥800/t at the highest price point. Second, only with subsidy and tax exemption considered, there can be a rational level of profit for the fuel ethanol producers. As the subsidy for corn ethanol producers gradually phased out over recent years, the profit of producing corn ethanol became lower or even negative. Third, the price of fuel ethanol is regulated to be the gasoline price multiplied by a coefficient of 0.9111. With the decrease of gasoline price over the past few years, the price of fuel ethanol also decreased, which further reduced the profit of producing fuel ethanol.

**Table 5**
Financial incentives for fuel ethanol production in China.

| Year | Policy document | Major contents |
|---|---|---|
| 2002 | Planning on the pilot demonstration of ethanol gasoline use | ◆ The excise tax for fuel ethanol production is exempted<br>◆ The VAT for fuel ethanol production is reimbursed<br>◆ The aged crops used for fuel ethanol production are qualified for subsidies<br>◆ Additional subsidies are granted to fuel ethanol producers to guarantee reasonable profit |
| 2004 | Planning on expanding the demonstration of ethanol gasoline use | ◆ The excise tax for fuel ethanol production is exempted (same with previous document)<br>◆ The VAT for fuel ethanol production is reimbursed (same with previous document)<br>◆ The aged crops used for fuel ethanol production are qualified for subsidies (same with previous document)<br>◆ The subsidy for fuel ethanol producers is determined with fixed quotas, rather than with reasonable profit criteria |
| 2005 | Notification on the subsidy policy for fuel ethanol | ◆ The subsidy intensity for fuel ethanol production is specified to be ¥1883/t, ¥1628/t, ¥1373/t and ¥1373/t from 2005 to 2008 |
| 2005 | Notification on the taxation policy for fuel ethanol producers | ◆ The excise tax for fuel ethanol production is exempted (same with previous document)<br>◆ The VAT for fuel ethanol production is reimbursed (same with previous document) |
| 2006 | Notification on the financial incentives for bio-energy and biochemical industries | ◆ The elastic loss subsidy mechanism was established to determine the subsidy for fuel ethanol producers. Namely, when fuel ethanol production is profitable, no subsidy is available; at the same time, the fuel ethanol producers should establish risk funds with the profit; when fuel ethanol production is facing losses, the risk funds will be firstly used to cover the losses; If production losses last for a long time, subsidy from the government will be available<br>◆ Taxation incentive will be established to promote the development of bio-energy and biochemical industries |
| 2007 | Finance management regulations on the elastic subsidy for fuel ethanol | ◆ Detailing of the subsidy mechanism established by the previous guidance document<br>◆ Based on the subsidy mechanism, the subsidy intensity for fuel ethanol production was ¥2055/t, ¥1659/t, and ¥1276/t from 2009 to 2011 |
| 2011 | Notification on adjusting the taxation policy for fuel ethanol producers | ◆ The VAT for food crop-based fuel ethanol production will be reimbursed by 80% in 2011; 60% in 2012; 40% in 2013; 20% in 2014. The VAT reimbursement policy for food crop-based fuel ethanol production will be cancelled from 2015<br>◆ The excise tax for food crop-based fuel ethanol production will be 1% in 2011; 2% in 2012; 3% in 2013; 4% in 2014 and 5% from 2015 on |
| 2012 | Notification on adjusting the subsidy policy for fuel ethanol production | ◆ The subsidy intensity for food crop-based fuel ethanol production is ¥500/t<br>◆ The subsidy intensity for non-food crop-based fuel ethanol production is ¥750/t |
| 2014 | Notification on further adjusting the subsidy policy for fuel ethanol production | ◆ The subsidy intensity for food crop-based fuel ethanol production is specified to be ¥300/t, ¥200/t, and ¥100/t from 2013 to 2015<br>◆ The subsidy for food crop-based fuel ethanol production will be cancelled from 2016 |
| 2014 | Notification on the subsidy quotas for fuel ethanol producers | ◆ The subsidy intensity for cellulosic ethanol production is ¥800/t |
| 2014 | Notification on the taxation policy for non-food crop-based fuel ethanol production | ◆ The excise tax for non-food crop-based fuel ethanol production is exempted<br>◆ The VAT for non-food crop-based fuel ethanol production is reimbursed |

**Table 6**
National standards on biofuel production and use.

| Year | National standards |
|---|---|
| 2001, 2013 | Denatured fuel ethanol (GB 18350) |
| 2001, 2004, 2010, 2013, 2015 | Ethanol gasoline for motor vehicles (E10) (GB 18351) |
| 2007, 2014, 2015 | Biodiesel blend stock (BD100) for diesel engine fuels (GBT 20828) |
| 2010, 2014, 2015 | Biodiesel fuel blend (B5) (GBT 25199) |

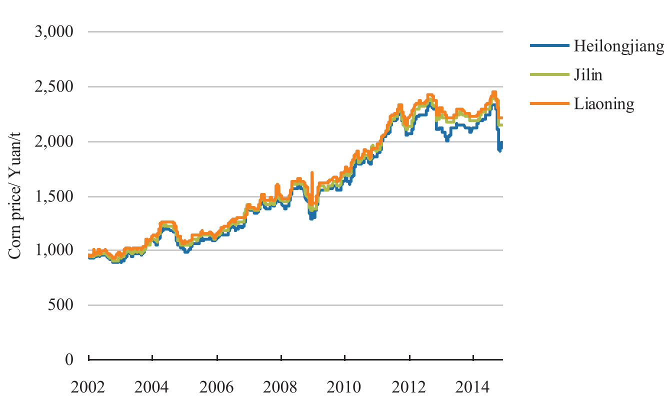


**Fig. 6.** Warehouse-gate corn prices in China's three major corn-producing provinces.

### 5.2. Biodiesel

The production capacity of waste oil-based biodiesel has been increasing rapidly over the past years. However, the capacity utilization rate remained at a very low level, around 30–50%. The major reasons behind this phenomenon are the lacks of market demand and feedstock supply. From the market demand side, as there are no mandatory regulations on biodiesel use, it is not necessary for the oil companies and retailers to blend biodiesel into conventional diesel. Although regional regulations regarding biodiesel blend were released [67], the implementation is not satisfying. Besides, most of the waste oil-based biodiesel producers are small companies, who can not get the back from the major oil companies. Thus the oil companies do not have enough motivation to engage in promoting biodiesel use, which reduces their profit of selling conventional diesel. From the feedstock supply side, waste oil has quite a few alternative utilizations, among which being recycled as cooking oil is the most common one. It was estimated that in the 3–4 Mt waste oil generated per year, around 2 Mt was recycled as cooking oil [89]. Although the government has strictly forbidden the use of waste oil as cooking oil, this illegal use still exists commonly because of the high profit. The purchase price the biodiesel companies can offer for waste oil is much lower than the purchase price the cooking oil producers can offer. Especially, with the collapse of international oil price over recent years, the affordable purchase price of waste oil from the biodiesel producers became even lower, which has intensified the lack of feedstock supply.

Regarding biodiesel production with oil-bearding crops as feedstock, among the three planned pilot demonstration projects, only the Hainan demonstration program was actually established. However, due to feedstock cost and market demand issues, the production was halted. Currently, the production facility has been modified to produce waste oil-based biodiesel.

## 6. Policy implications

Based on the analysis of the current status, future potential, policy initiatives, barriers, and opportunities of biofuel industry in China, the following suggestions are proposed, with the aim of accelerating this process, they are:

(1) Optimizing the development pathway of biofuel: plantation resource-based biofuels depend on the input of land resource, which necessarily affects food production and supply. The energy and environmental impacts of these biofuels are still not fully justified. Thus, the government should be cautious about developing plantation resource-based biofuels. On the other hand, non-plantation resource-based biofuels offer the benefits of low resource input and positive environmental impacts, and thus should be developed with confidence. Although the current market competiveness of non-plantation resource-based biofuels is relatively lower, this can be gradually improved through technology innovation and production optimization.

(2) Establishing complete regulation and policy system: China should implement mandatory regulations on biofuel use. Without mandatory regulations, the relative stakeholders, especially the conventional oil companies, do not have enough motivations to engage in biofuel development. The EU regulation, which requires 10% share of renewable energy in the transport sector [90], and the U.S. regulations, which had similar requirements [91,92], can be the references for China's policy makers. This kind of regulation also helps the policy makers to better control the total scale of biofuel consumption.

(3) Building an open and free market: the trade price of fuel ethanol between the fuel ethanol producers and the oil companies should be market-based, rather than set by the government. The fuel ethanol price, which was set by the government to be 0.9111 times the gasoline price, is the essential factor that leads to the loss of the fuel ethanol producers. With the government releasing the pricing right, the fuel ethanol price is expected to increase accordingly, which benefits the fuel ethanol producers.

(4) Improving the legal utilization efficiency of waste oil for biofuel: the illegal utilization of waste oil should be more strictly prohibited. With more than half of waste oil illegally recycled as cooking oil, the amount of waste oil available for biodiesel production is far from meeting the demand. Restricting the illegal utilization of waste oil can help to increase the feedstock supply, as well as bring down the price, which benefits the biodiesel producers.

(5) Subsidy policies: under current technology status, without financial incentives, biofuel is less market-competitive than conventional petroleum products. Although existing financial incentives have already posed quite positive impacts on biofuel commercialization, they can be further optimized. For example, with the current VAT reimbursement policy, VAT has to be paid in the current year and reimbursed in the next year, which makes the biodiesel producers suffer great cash flow pressures. This can be improved by shifting from the current VAT reimbursement policy to a more favorable VAT exemption policy.

## 7. Conclusions

In this review, the current status and future potential of biofuel development in China are analyzed. It is found that although the current scale of biofuel commercialization is limited by multiple technology and market barriers, the future potential is solid. Based on the discussions of market barriers and opportunities, it is recommended that biofuel development in China should be further promoted by setting mandatory regulations on biofuel use, shifting fuel ethanol pricing from administration-based to market-based, restricting the illegal use of waste oil, optimizing the financial incentive framework, and improving biofuel production technology.

## Acknowledgements

This study is sponsored by the National Natural Science Foundation of China (71403142, 71774100, 71690241), State Key Laboratory of Automotive Safety and Energy (ZZ2016-024), Young Elite Scientists Sponsorship Program by CAST (YESS20160140), China Automotive Energy Research Center of Tsinghua University (CAERC), Beijing Natural Science Foundation (9162008).

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