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The development of low-carbon vehicles in China

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ABSTRACT

Reducing CO_2 emissions from vehicles in China is crucial and will significantly alleviate the environmental burden of the Earth. Some promising technologies that make possible low-carbon vehicles are reviewed in this work, including electric vehicles, fuel cell vehicles, hybrid vehicles, biofuels vehicles, other alternative fuel vehicles, and conventional internal combustion engine vehicles with improvement. In the short term, expanding the use of mature technologies in conventional gasoline or diesel vehicles is the most realistic, effective, and timely solution for China to meeting the urgent challenges of energy saving and greenhouse gas reduction; while in the long run biofuel is a promising candidate due to their renewability and carbon neutrality. The blueprint of low-carbon vehicles for China depends on three aspects: breakthroughs in technology, awareness of public, and government guidance.

1. Introduction

Thirty years ago, bicycles were the main transportation tool for commuters in China. But in the recent 10 years, China has advanced from the bicycle age to the car age. Roads once flowed bicycles are now compact with cars and motorcycles. These changes enable more convenient life for the public, but they are also largely responsible for the greenhouse gas (GHG) emission. The total CO_2 emissions in China account for more than 20% of global CO_2 emissions in 2008 (International Energy Agency, 2010), while the transportation sector represents 7% of China's CO_2 emissions in 2008 (International Energy Agency, 2010), below the 22% of transportation contribution in global CO_2 emissions. But this ratio will be increased with the development of vehicle market in China, and might rise to 12–17% in 2030 (International Energy Agency, 2009). Furthermore, switching to low-carbon or carbon neutral energy sources is much more difficult in transportation than in other sectors due to its scattered utilization. Vehicles are the major CO_2 contributor in the transportation sector. The total number of vehicles in China exceeded 70 million by September 2010, which is approximately 1/4 of the total vehicle population of the United States. Meanwhile, it is expected to go up to 550–730 million by 2050 (Wang et al., 2006), exceeding the United States by 38–83% (Singh et al., 2003). Therefore, reducing CO_2 emissions from vehicles in China is crucial and will significantly alleviate the environmental burden of the Earth.

Ou and Zhang (2010c) reported the status quo and development trend of low-carbon vehicle technologies in China. The low-carbon vehicle technologies are sorted into three categories in their study—integrated energy-saving technologies for conventional vehicles, vehicle powertrain systems electrification technologies, and low-carbon vehicle alternative fuels. However, some characteristics of low-carbon vehicle technologies were not reviewed in detail but demonstrated the status quo and macro development trend in that paper. In this study, 6 promising technologies in low-carbon vehicles were detailedly reviewed. Based on the technologies and market status quo, the development direction of low-carbon vehicles in China was proposed in the case of short term and long term.

2. Promising technologies in low-carbon vehicles

There are some promising technologies that make possible low-carbon or carbon neutral vehicles. The progress, advantages, and disadvantages for these promising technologies are reviewed in this section. They are listed as but not limited to the following.

2.1. Electric vehicles (EVs)

Today, EVs are being proposed in China as one of the potential options to satisfy the skyrocketing energy demand from on-road

Abbreviations: CCS, carbon capture and sequestration; CNG, compressed natural gas; DME, dimethyl ether; E-bikes, electric bikes; ETC, electronic throttle control; EVs, electric vehicles; FCVs, fuel cell vehicles; GHG, greenhouse gas; HEVs, hybrid electric vehicles; ICE, internal combustion engine; ICEVs, internal combustion engine vehicles; LPG, liquefied petroleum gas; NG, natural gas; PHEVs, plug-in HEVs; Pt, platinum; VVT, variable valve timing

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transportation. EVs might cut the dependence on petroleum using other energy sources such as coal, hydro, nuclear, wind, etc. to provide the required electricity. Furthermore, there are no tail-pipe GHG emissions or other harmful gas emissions for EVs and less noise pollution than an internal combustion engine vehicle.

Although EVs have few direct emissions, energy created through electricity generation will emit pollution and generate waste. EVs could increase CO_2 emissions by 7.3% compared to conventional gasoline internal combustion engine vehicles (ICEVs) in the north region of China where the majority of electricity (98%) is generated from coal, while in regions that feature about 35% non-fossil electricity (the south regions), EVs have the same CO_2 emission level as gasoline hybrid electric vehicles (HEVs) and 30% lower than gasoline ICEVs (Huo et al., 2010). Meanwhile, Huo et al. (2010) also forecasted the CO_2 emissions in 2030 and found that the theoretical CO_2 breakeven point between EVs and ICEVs is 87% coal power, which means that EVs would have a CO_2 reduction advantage over ICEVs if the coal fraction is below 87%, as shown in Fig. 1. This prediction was based on that the energy efficiency of coal-based power plants is raised to 40% in 2030 from the current 32–34% (Institute of Nuclear and New Energy Technology at Tsinghua University, 2009), while the prediction for ICEVs was based on the fuel consumption rates reduction from 8 L/100 km to 5.5 L/100 km. The fuel consumptions of widely used cars are shown as following: i.e. Toyota Corolla with 1.6 L displacement and manual transmission is 6.8 L/100 km (Tianjin Faw Toyota Motor Co., Ltd.); Volkswagen Golf VI with 1.4 L displacement, turbocharger, and 7-gear DSG transmission is 6 L/100 km (Faw-Volkswagen Co., Ltd.); and Chery QQ3 with 1.0 L displacement and manual transmission is 3.8 L/100 km (Chery Automobile Co., Ltd). Fig. 1 also illustrates the range of share of coal-based capacity projected by various institutes. The 78–81% coal fractions projected by Energy Information Administration (2007) and International Energy Agency (2007) translated to a CO_2 reduction of 10% compared to ICEVs. Under the more aggressive projections for coal fractions made by Chinese institutes (65–72%) (Institute of Nuclear and New Energy Technology at Tsinghua University, 2009; Ye, 2004), the CO_2 emissions of EVs were 18–25% lower than ICEVs, but 7–18% higher than HEVs. Similar results have also been reported by Ou et al. (2010a), indicating that electric bus has a lower GHG emissions than diesel bus, while has a higher GHG emissions than diesel hybrid bus—DB@HEV20, which means the

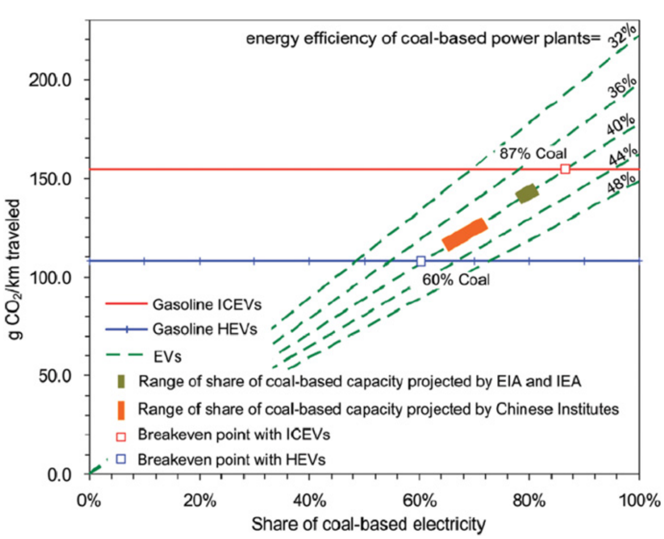

Fig. 1. Future fuel-cycle CO_2 emissions of EVs as a function of the fraction of coal-based electricity (Huo et al., 2010).

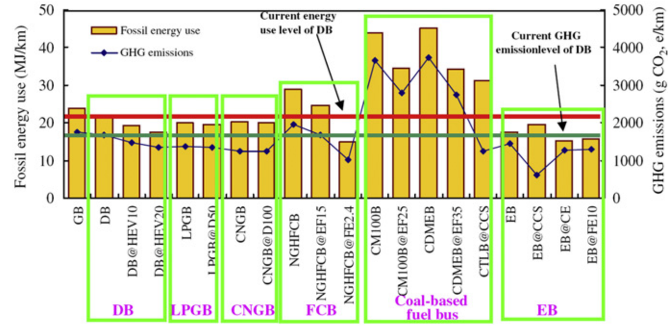

Fig. 2. Well to wheel fossil energy use and GHG emissions under different future scenarios (Ou et al., 2010a). DB: diesel bus; DB@HEV20: DB fuel economy gets an improvement of 20%. FCB: fuel cell bus; NGHFCB@EF15: hydrogen production efficiency from natural gas is improved substantially by 15%. NGHFCB@FE2.4: extensive efforts have been made to raise the efficiency of FCBs to be 2.4 times that of diesel buses from the value of 1.24 for the current study. A more detailed introduction for this figure can be found in Ou et al. (2010a).

diesel bus fuel economy gets an improvement of 20% due to the hybrid technology, as illustrated in Fig. 2. Therefore, the lower CO_2 emissions for EVs strongly depend on the fractions and the energy efficiency of coal-based power plants.

Generally, it is easier to build pollution control systems into centralized power stations than retrofit enormous numbers of scattered cars. Carbon capture and sequestration (CCS) technologies can help earn more carbon credits for EVs. Ou et al. (2010a) reported that in comparison to diesel buses, CCS is a potential method to reduce about 65% of GHG emissions for electric bus. However, CCS is subjected to many technical uncertainties, such as the likelihood of CO_2 leakage, higher fossil energy consumption, and a high cost of commercialization (Ou et al., 2010a, 2010b; Huo et al., 2010). In addition, emissions associated with the construction of EVs recharging infrastructure were not taken into consideration by Huo et al. (2010), which could make EVs even more unfavorable as compared to ICEVs and HEVs. Technical uncertainties for CCS and the building recharge station will increase the potential GHG emissions for EVs.

In addition, studies have demonstrated that the EVs could increase other pollutant emissions compared to ICEVs or HEVs. Power plants are believed to be the largest contributor to China's SO_2 and NO_x emissions (Zhang et al., 2009), therefore EVs might emit higher or lower pollutants like SO_2 and NO_x, which counts on the technologies improvement for coal-fired power plants. Study has indicated EVs could cause a significant increase in SO_2 emissions by 3–6 times relative to ICEVs and 5–10 times relative to HEVs in the current. Even with an additional 100% flue-gas desulfurization and coal washing, which is infeasible in practice, it is not possible to bring the SO_2 emissions of EVs down to the level of ICEVs and HEVs for most regions in China. For NO_x emissions, the widespread application of selective catalytic reduction will be the key for EVs to compete with ICEVs (Huo et al., 2010). Other environmental impacts associated with coal-fired power plants, such as mercury emissions (by a rough estimation, EVs could give off 0.01 mg of mercury emissions for every kilometer driven) (Streets et al., 2005), may become environmental concerns for EVs too.

Electric vehicles do represent a very promising solution to energy issues due to their solid merits in substituting petroleum fuels. But for now the high pollution levels of coal-fired power plants will trade off EVs' potential energy benefits in China. Furthermore, it should be noted that the technology breakthrough in batteries is another critical problem to the wide utilization of EVs because many electric designs are limiting the driving range due to the low energy density of batteries compared to ICEVs.