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What is the Role of Electric Vehicles in a Low Carbon Transport in China?

Jing Yang, Wei Shen and Aling Zhang
*Institute of Nuclear and New Energy Technology, Tsinghua University
 China*

1. Introduction

In December 2009, China government has officially announced, for the first time, a voluntary quantitative target of controlling its carbon dioxide emissions, which is to cut the carbon dioxide intensity (kg CO₂ per GDP) by 40%~45% by the year 2020 (relative to the level of 2005). Transportation is one of the major sources of carbon dioxide emissions resulting from fossil fuel utilizations all over the world. In 2008 carbon dioxide emissions caused by transportation fuel combustion accounted for about 8% of the national total in China (Yang, 2011). This percentage is far behind some advanced economies, such as 33% in United States in 2004, 26% in Europe in 2004 (Wallington, 2008), and so forth. In either developing countries or developed countries road sector is responsible for approximate 80% of total carbon dioxide emissions resulting from transportation (Yang, 2011; Wallington, 2008), which indicates that road transportation has been playing a significant role in reducing transportation carbon dioxide emissions now and in the future. Compared with 824 vehicles per 1,000 people in United States in 2008 and 608 vehicles per 1,000 people in Japan in 2009, there were only about 68 vehicles per 1,000 people in China in 2010. It is clear that China's vehicle population will be twice as many as present level when the vehicle ownership is doubled and meanwhile the national population is sustained. As an emerging economy, this situation will probably happen in next 5~10 years. Without revolutionary change of transportation system, the consequent carbon dioxide emissions from road transportation will possibly be doubled as well. It can be predicted that transportation sector would become one of the fastest growing sources of carbon dioxide emissions in China in next several decades. Thus, a low carbon transport system is expected to be proposed soon as a potential solution to addressing the conflict between the development of transportation and economy and the mitigation of climate change.

In response to concerns over establishing the low carbon transport system and meeting the increasing domestic petroleum demand, interest in developing advanced vehicle technologies and alternative vehicle fuels has risen considerably in past ten years. Many research and demonstration programs of various technologies were supported by Chinese government, including light-duty vehicles (LDVs) using methanol (M85) and ethanol (E10), buses and taxis using liquefied petroleum gas (LPG), compressed natural gas (CNG), and liquefied natural gas (LNG), passenger cars and buses using dimethylether (DME), passenger cars using diesel, and so forth. Ethanol gasoline (E10) has been put into mandatory use since 2003 in five Chinese provinces (Jilin, Hei Longjiang, Henan, Anhui,

and Liaoning) and a number of large cities (in provinces of Hubei, Shandong, Hebei, and Jiangsu).

In recent years, China's strategy of new technology development of vehicle and alternative fuel has been gradually shifted from multiply pathways to a few significant pathways – especially electric vehicles, i.e. battery electric vehicles (BEVs), regular hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs). Research and development (R&D) of electric vehicles were incorporated in the National High Technology Research and Development Program (863 Program) by the Ministry of Science and Technology. According to the latest application guideline of this program issued in October 2010, a total of 738 million RMB (about 113 million U.S. dollars) funding will be used to support the laboratory study on key technology and system integration of electric vehicles (National High Technology Research and Development Program, 2010).

Meanwhile the demonstration of all sorts of electric vehicles has been started. In 2008, 370 battery electric vehicles (50 buses and 320 shuttles), 100 hybrid electric vehicles (25 buses and 75 passenger cars), and 23 fuel cell vehicles (3 buses and 20 passenger cars) provided service at the Beijing Olympics Games. Two years later 1,017 electric vehicles showed up in the 2010 World Expo in Shanghai, including 321 battery electric vehicles (181 buses and 140 shuttles), 500 hybrid electric vehicles (150 buses and 350 passenger cars), and 196 fuel cell vehicles (6 buses, 90 passenger cars, and 100 shuttles).

Central government have also launched policies to promote the popularization of electric vehicles. In response to the severe global economic recession triggered by the financial crisis in the United States in late 2008, Chinese Automotive Industry Revitalization Plan, as an important part of the national industry revitalization program, was published in March 2009. According to this three-year plan, China aim to create a capacity to produce 500,000 “New Energy Vehicles” by 2011, including battery electric vehicles, plug-in hybrid electric vehicles, and regular hybrid electric vehicles. The plan also set a goal for the year 2011 that is to increase the sales fraction of such new energy cars to 5% of total passenger cars. To achieve the above target, at the beginning of 2009 a pilot project of energy conservation and new energy vehicles was officially launched in 13 cities including Beijing and Shanghai, according to a circular issued by the Ministry of Finance and the Ministry of Science and Technology. New energy vehicles were encouraged to be used in area of public transportation, taxi, postal, sanitation, and other public services. The central government announced to provide a subsidy to vehicle purchase, and the local government was required to be responsible for the infrastructure construction, such as building charge station for electric vehicles. It was reported that there were 12,000 new energy vehicles had been sold since the project started (Ministry of Science and Technology, 2010).

June 2010 the Ministry of Science and Technology and the Ministry of Finance launched a subsidy policy for the private purchase of battery electric vehicles and plug-in hybrid electric vehicles in 5 cities (Shanghai, Changchun, Shenzhen, Hangzhou, and Hefei) through 2012. The subsidy is calculated as 3,000 RMB (about 460 U.S. dollars) per kWh, with the caps of 60,000 RMB (about 9,190 U.S. dollars) per vehicle and 50,000 RMB (about 7,659 U.S. dollars) per vehicle for battery electric vehicles and plug-in hybrid electric vehicles, respectively. Now several vehicle models in domestic auto market are expected to benefit from the policy. One example is BYD E6 model (battery electric vehicle) with a rated price of 270,000 RMB (about 41,000 U.S. dollars), in which 60,000 RMB will be paid by the central government. Another example is BYD F3DM model (dual modes, i.e. battery electric mode

and regular hybrid electric mode) with a rated price of 150,000 RMB (about 23,000 U.S. dollars), in which 50,000 RMB will be paid by the central government. Moreover, some large cities subsequently launched their own policies which offered an even better deal to customers with an additional subsidy of 50,000 RMB (about 7,659 U.S. dollars) or more. Private customers, however, have hardly been attracted by the subsidies due to plenty of uncertainties of the new technology utilization, and therefore the sales of new energy vehicles were not very well. For instance, BYD Auto Company, as a pioneer and the largest domestic producers of electric vehicles, has merely sold 480 vehicles (417 BYD F3DM and 63 BYD E6) until the end of 2010.

China's Twelfth Five-Year Plan for National Economic and Social Development (2011~2015) was newly approved by the legislature, the National People's Congress (NPC), in March 2011. The new energy vehicle industry, as one of the seven strategic industries, was enclosed in the state scheme. The large-scale demonstration and subsequent commercialization of plug-in hybrid electric vehicles and battery electric vehicles were underlined in the national plan, indicating that electric vehicles would experience a prime period of development in recent years.

In this chapter, the title question was addressed by quantitatively analyzing the climate change impacts of electric vehicles in China. The circular life cycle energy consumption and greenhouse gas emissions (GHGs) of battery electric vehicles, fuel cell vehicles and conventional internal combustion engine vehicles (ICEVs) were calculated via well-to-wheel (WTW) method. An improved GREET (Greenhouse, Regulated Emissions and Energy use of Transportation) model was used in this study, inside which over 640 of total 730 parameters were updated with localized Chinese data by Shen (Shen, 2007; Shen & Zhang, 2008). Modelling results showed that battery electric vehicles had the great advantages over both traditional gasoline vehicles and fuel cell vehicles in either well-to-wheel fossil fuel consumption and petroleum consumption or greenhouse gas emissions. And fuel cell vehicles were anticipated to play a more important role after the breakthrough of hydrogen production technology. We further concluded that electric vehicles would greatly contribute to the future low carbon transport system. Besides, market penetration of electric vehicles was able to largely reduce the dependency of traditional gasoline.

Electric vehicles provide a promising solution to the transportation energy problem and climate change concern. However, in China electric vehicles presently have to face several urgent problems, such as the high cost of purchase, the absence of infrastructure network, the disposal and recovery issues of batteries, and so forth. Hence, special follow-up policies should be addressed to promote commercialization progress of electric vehicles in China.

2. Methodology

Well-to-wheel method is a specific life cycle assessment (LCA) used for transportation fuels and vehicles. Energy consumption and greenhouse gas emissions of the fuel cycle accounts for over 70% of the whole life cycle (composed of fuel production, vehicle production, and vehicle operation). Therefore, in this study we focus on energy consumption and climate change impact of the fuel cycle rather than the vehicle cycle. In general the fuel cycle well-to-wheel study is divided into two stages - well-to-tank (WTT) and tank-to-wheel (TTW). The former indicates upstream stage, including mining, processing, and transportation of feedstock, and production, delivery, and storage of vehicle fuels. The latter is also called downstream stage, which means vehicle operation in particular.

An improved GREET 1.7 model was used in this study, inside which the America-based database was ultimately replaced by China-based one. It can be also called ChinaGREET because 367 of 394 parameters of feedstock and fuel production stage and 282 of 336 parameters of transportation and distribution stage have been updated according to Chinese real conditions.

2.1 Assumption

This study incorporated 12 pathways for production and application of vehicle fuels, including a conventional gasoline vehicle pathway, a battery electric vehicle pathway, and ten fuel cell vehicle pathways (Table 1). Coal, natural gas, and water were considered as sources of hydrogen used for fuel cell vehicles. Electricity for vehicle use was assumed to come from national electrical grid. Passenger cars were studied due to their larger potential of growth in the future compared with other vehicle types.

Pathway name	Feedstock	In-process product (site)	Fuel	Vehicle
SI: 93# Gasoline	Petroleum	-	Gasoline 93#	Gasoline vehicle (spark injection)
FCV: MeOH-NG	Natural gas	Natural gas -> methonal -> hydrogen (on-board)	Gaseous hydrogen	Fuel cell vehicle
FCV: MeOH-Coal	Coal	Coal -> methonal -> hydrogen (on-board)	Gaseous hydrogen	Fuel cell vehicle
FCV: GH ₂ ,RS,MeOH-NG	Natural gas	Natural gas -> methonal -> hydrogen (refill station)	Gaseous hydrogen	Fuel cell vehicle
FCV: GH ₂ ,RS,MeOH-Coal	Coal	Natural gas -> methonal -> hydrogen (refill station)	Gaseous hydrogen	Fuel cell vehicle
FCV: GH ₂ ,RS,Electrolysis	Water	Water -> hydrogen (refill station)	Gaseous hydrogen	Fuel cell vehicle
FCV: GH ₂ ,CP,NG	Natural gas	Natrual gas -> hydrogen (central plant)	Gaseous hydrogen	Fuel cell vehicle
FCV: LH ₂ ,RS,MeOH-NG	Natural gas	Natural gas-> methonal-> hydrogen (refill station)	Liquid hydrogen	Fuel cell vehicle
FCV: LH ₂ ,RS,MeOH-Coal	Coal	Coal -> methonal -> hydrogen (refill station)	Liquid hydrogen	Fuel cell vehicle
FCV: LH ₂ ,RS,Electrolysis	Water	Water -> hydrogen (refill station)	Liquid hydrogen	Fuel cell vehicle
FCV: LH ₂ ,CP,NG	Natrual gas	Natrual gas -> hydrogen (central plant)	Liquid hydrogen	Fuel cell vehicle
EV	Various primary energy	Grid electricity	Electricity	Battery electric vehicle

Table 1. Feedstock, in-process product, fuel, and vehicle type of each pathway

2.2 Data

Data of coal-based, natural gas-based, and grid electricity pathways and data of vehicle stage were described below.

2.2.1 Coal-based pathways

Energy consumption of coal mining was mostly caused by mining equipments and boilers. The former mainly consumed electricity, and the latter basically used coal. Chinese raw coal was mostly provided by domestic coal mines since the country was rich in coal resources and the price was much lower than import coal. Therefore in this study we assumed that the coal used to generate hydrogen and electricity was produced in the country. According to the investigation of large national and local mines and the data of China Energy Statistical Yearbook, there were 34.4 kWh power and 26.7 kg raw coal would be used when 1 tonne coal was excavated in domestic coal mines. Coal chemical industry in China usually took washed coals as feedstock although they were only about 30% of raw coal output would be further washed. According to our investigation, 0.92 tonne coal equivalent (tce) raw coal, 3.0 kWh power, and 0.1 tonne water was consumed when 1 tonne coal was washed. Another issue that should draw our attention to was the release of absorbed gases from coal bed, such as methane and carbon dioxide. On considering current mining technology, we estimated that there were approximately 7~8 cubic meters methane, 6 cubic meters carbon dioxide, and a small quantity of sulphur dioxide and nitrous oxide that would be emitted when 1 tonne coal was excavated (Alternative Energy Program by National Development and Reform Commission, 2006).

It was known that coal resources were mainly located in the east and the north of China. Over 60%~70% of state coal reserves were found in Shanxi, Shaanxi, Inner Mongolia, and Xinjiang provinces. But end users of the energy were concentrated in north-eastern regions. So coal transportation from producing areas to consuming regions became a necessary and complicated work. Coal was usually delivered by rail, road, and water. The volume of coal transported and the average transferring distance by each means come from Year Book of China Transportation & Communications and China Energy Statistical Yearbook (Table 2). It can be found that sum of the share was over 100% because some coal was transported by more than one means which resulted in repeated calculation in statistics. Coal losses during transportation were assumed to be 0.5%~1.0% (Xiao, 2005).

	Data source	Rail	Road	Water
Share of coal volume (%)	China Coal Research Institute (CCRI)	60%	30%	20%
	Ministry of Transport of China (MOT)	60%	10%	40%
	Assumption in this study	50%	30%	20%
Average transport distance (km)	Investigation	550~595	-	650
	Assumption in this study	600	80	650

Table 2. Share of coal volume and average transferring distance by each means

Coal was first gasified to produce syngas (mixture of carbon monoxide and hydrogen gas). Next, syngas was converted into high purity hydrogen gas via decarbonisation and

desulfurization processes, i.e. carbon monoxide conversion, low-temperature methanol washing, and solvent adsorption. Overall efficiency of producing hydrogen gas from coal by Chinese chemical industry was around 50%, lower than that of international companies using advanced technology. Large central plant of coal-based hydrogen production had great advantage over small-scale on-site plant. And the resulting hydrogen product was needed to be further transported to refill station. Hydrogen gas could be directly transported by vehicle or after liquefaction. But in this study gaseous hydrogen and liquid hydrogen were assumed to be delivered by pipeline and tanker, respectively, due to economical concerns. Average transport distance of gaseous hydrogen by pipeline was assumed to be 50 km on considering cost and energy efficiency. Average transferring distance of liquid hydrogen by tanker was calculated as 110 km.

2.2.2 Natural gas-based pathways

During natural gas exploitation, 10% natural gas output was used as fuel by purification and separation processes, and about 0.4% output was missing. Natural gas product was transported by pipeline to nearby chemical industry plant to produce methanol which were located 50 km~100 km away. Then methanol was delivered by rail, road, and water to downstream plant or refill station to generate hydrogen gas or liquid. Average distance from hydrogen plant to local storage was assumed to be 1000 km, and that from local storage to refill station was about 50 km. Natural gas-based hydrogen was transported by the same means as coal-based hydrogen (Chapter 2.2.1).

2.2.3 Grid electricity pathways

Grid electricity was consumed at refill station by electrolysis reaction to generate gaseous or liquid hydrogen. Electricity used for powering electric vehicles was also provided by grid. Various sources of primary energy were combusted in power plant to produce grid electricity. On average, about 80.4% grid electricity was from coal, 1.0% from natural gas, 1.1% from oil, 1.9% from nuclear, 0.5% from biomass, 14.2% from hydro, 0.8% from wind, and 0.1% from solar. Energy efficiency of thermal power plant was estimated to be 360 gram coal equivalent (gce) per kWh electricity generation. Approximately 7% of power became losses during grid transmission.

2.2.4 Vehicle stage

The FOX 1.8MT passenger car made by Ford Motor Company was used to calculate the downstream energy consumption and greenhouse gas emissions. This model employed port injected spark ignition (PISI) technology and combusted gasoline that was labelled 93 (Research Octane Number, RON). Fuel efficiency of the car under urban condition was estimated to be 8.5L/100km (equal to 27.7mpg). For fuel cell vehicle, the fuel efficiency was assumed 80% higher than the above conventional gasoline vehicle. Electricity consumption of electric vehicles was assumed to be 22 kWh/100km.

3. Results

Well-to-wheel fossil energy consumption, petroleum consumption, and greenhouse gas emissions of coal-based pathways, natural gas-based pathways, and grid electricity pathways were presented and compared with those of the conventional gasoline pathway in this section.

3.1 Well-to-tank results

WTT fossil fuel consumption of each pathway was shown expect the 2 on-board hydrogen generation pathways (Figure 1). No pathway consumed less WTT fossil fuel than the conventional gasoline pathway when 1 MJ vehicle fuel was generated. The reason was that present overall energy efficiencies of hydrogen production or electricity generation from either coal or natural gas were between 40%~60%, which was much lower than the energy efficiency of petroleum refining process (over 90%). Large central plant of hydrogen production using natural gas as feedstock had the advantage of energy consumption by 350%~540% over other methods, indicating that this kind of central plant was likely a better choice to make hydrogen than refill station production or on-board generation ways. Fossil fuel required to produce grid electricity was about 6.3 times more than that required by the conventional gasoline due to numerous coal utilization in power plant.

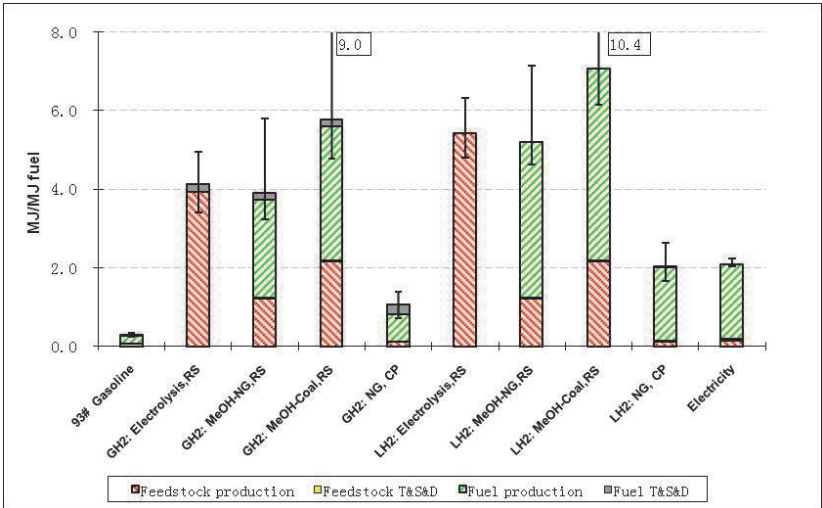


Fig. 1. Comparison of WTT fossil fuel consumptions

WTT greenhouse gas emissions resulting from fossil fuel consumption of each pathway was presented expect 2 on-board hydrogen generation pathways (Figure 2). Greenhouse gas emitted during hydrogen and electricity generation was 5~35 times higher than gasoline production.

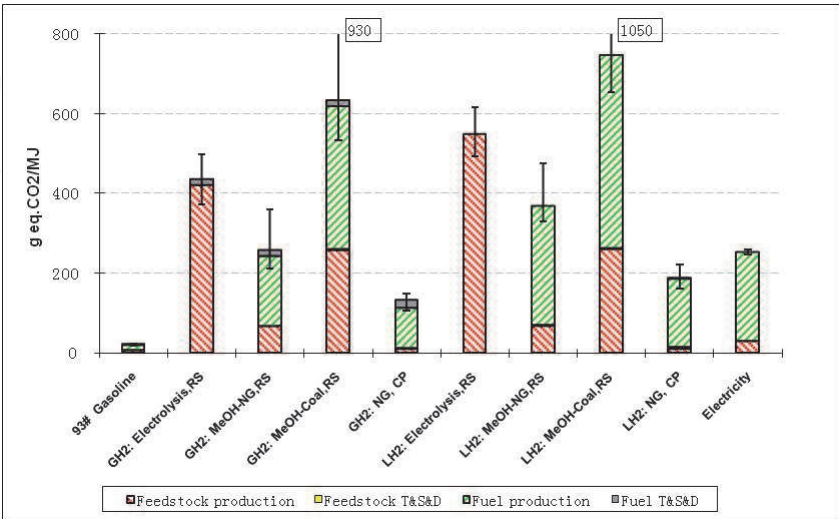


Fig. 2. Comparison of WTT greenhouse gas emissions

3.2 Well-to-wheel results

WTW fossil fuel consumption (Figure 3) and petroleum consumption (Figure 4) of total 12 pathways were described as how much MJ energy was required for the car to travel 1 km. WTW energy consumptions of fuel cell vehicle pathways were very different due to feedstock and process variety. The pathway of fuel cell vehicle using gaseous hydrogen generated either from natural gas in large central plant or by on-board generator had a comparable WTW fossil fuel consumption to the gasoline pathway, because the fuel efficiency of fuel cell vehicles was higher the conventional gasoline vehicles. Electric vehicle pathway using grid power consumed 10% less WTW fossil fuel than gasoline pathway, because electric vehicles was more efficient than the conventional gasoline vehicles which made great contributions to decrease WTW energy consumption.

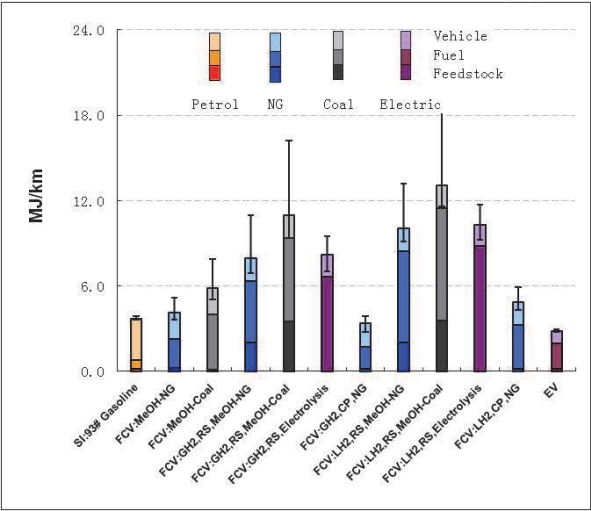


Fig. 3. Comparison of WTW fossil fuel consumptions

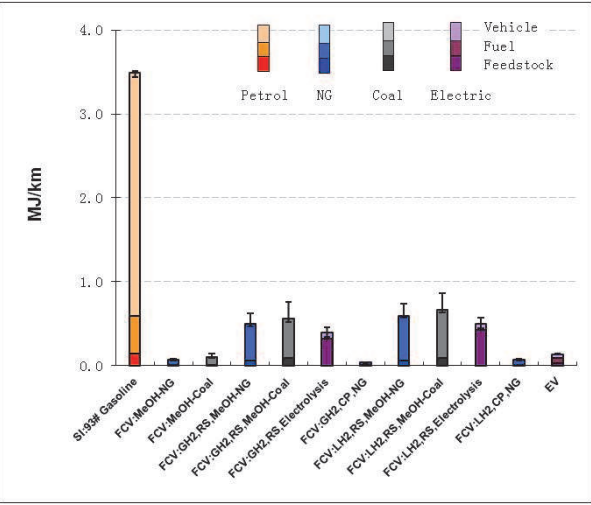


Fig. 4. Comparison of WTW petroleum consumptions

Alternative fuels were able to largely substitute petroleum, and therefore import volume of petroleum would be reduced and energy security of the country would be strengthened. WTW petroleum consumption of fuel cell vehicle and electric vehicle pathways proved the above theory (Figure 4). All 11 alternative fuel pathways used less than 1/3 petroleum of the conventional gasoline pathway.

WTW greenhouse gas emissions of different pathways were described as how much grams of equivalent carbon dioxide (g eq. CO₂) emission was emitted when the car travelled 1 km (Figure 5). There were 2 fuel cell vehicle pathways that had lower WTW greenhouse gas emissions than the conventional gasoline pathway. One was fuel cell vehicle with hydrogen generated from natural gas by on-board generator (9% lower); the other one was fuel cell vehicle with gaseous hydrogen produced from natural gas in large central plant (23% lower). Besides, greenhouse gas emitted from electric vehicles using grid power was 12% less than that from the conventional gasoline vehicle.

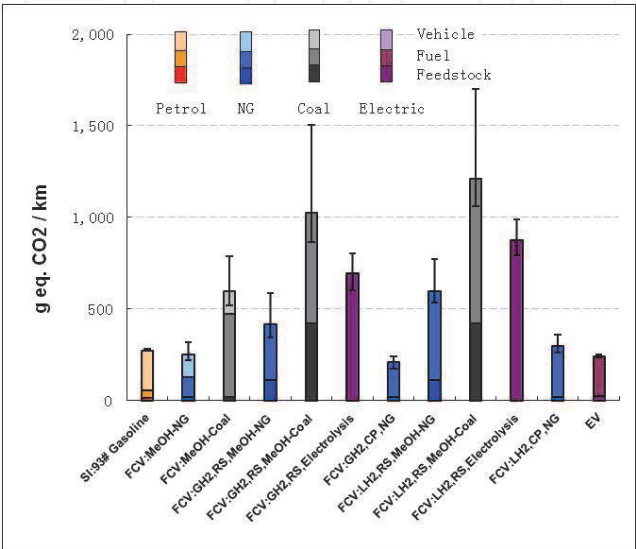


Fig. 5. Comparison of WTW greenhouse gas emissions

4. Conclusion

From the well-to-wheel study, we found that 1) the pathway of battery electric vehicle using grid electricity had some advantage of both fossil fuel and petroleum consumptions and greenhouse gas emissions. It could be concluded that plug-in hybrid electric vehicle that was the combination of conventional gasoline vehicle and battery electric vehicle probably held the same advantage; 2) for fuel cell vehicle, there were few pathways whose WTW energy consumption and greenhouse gas emissions were comparable to the conventional gasoline. So fuel cell vehicle pathways now had little advantage over both the conventional gasoline vehicle and the battery electric vehicle. Battery electric vehicle and plug-in electric vehicle should be given high priority when China builds the low carbon transport system. Fuel cell vehicle would probably become a promising way in the future. However, electric vehicles in China presently have to face several key problems, such as the high cost of purchase, the absence of infrastructure network, the disposal and recovery issues of batteries, and so forth. Hence, special follow-up policies should be addressed to push the commercialization of electric vehicles in China.

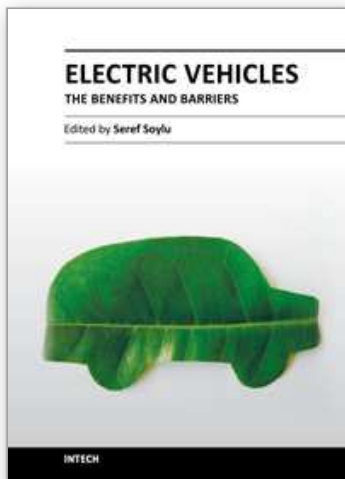
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In this book, theoretical basis and design guidelines for electric vehicles have been emphasized chapter by chapter with valuable contribution of many researchers who work on both technical and regulatory sides of the field. Multidisciplinary research results from electrical engineering, chemical engineering and mechanical engineering were examined and merged together to make this book a guide for industry, academia and policy maker.

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University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

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