Electrification of Transportation:
A Study of the Electric Vehicle Industry in China

by

Shuai Shao

Dr. Lori S. Bennear, Advisor

April 29, 2011

Masters project proposal submitted in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment of
Duke University

2011
Acknowledgements

I would like to express my sincere gratitude to my advisor Dr. Lori S. Bennear, Nicholas School of the Environment and Earth Sciences, Duke University for supervising this master project and providing regular feedback and helpful advice; Claire Yang from Accenture, China for sharing her experience on environmental consulting and her perceptions of the EV industry; all my friends in Nicholas School for accompanying me through this endeavor; and most importantly my parents for supporting me unconditionally all these years.
Abstract

The world transportation industry is experiencing a significant transaction with the emergence of new technologies in alternative energy. Among different technologies, the electric vehicle (EV) is considered to be the future trend of transportation that could replace the use of hydrocarbons fuels completely as well as reduce emission to zero. The development and commercialization of EV will have a great influence on the landscape of transportation energy in the next decade.

This project assesses the current situation and future development of the EV industry in China, focusing on economic analysis and population projection. Based on market research, the study identifies the opportunities as well as challenges for China’s EV industry. Strong government support and large power battery industry are the comparative advantages for the EV industry in China. Currently, charging technology and accessibility to charging stations are the major bottleneck that hinders the commercialization of EV.

Lifecycle costs analysis of different EV types was conducted to study the economic competitiveness of EV, and the results show that with government subsidies hybrid electric vehicles and plug-in hybrid electric vehicles are economically competitive in China’s vehicle market. The next 10 years will be an important phase for EV’s market penetration. According to projection, EV will account for more than 8.8% of total vehicle population in China, by the end of 2020.
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Introduction

Transportation industry is predominately an oil market, which not only is responsible for more than half of China’s oil consumption, but also contributes to a major part of carbon emission. Therefore in order to ensure energy security as well as achieve emission reduction commitment, it is extremely important for the transportation sector to go “green” in China.

Currently, the world transportation industry is experiencing a significant transition with the emergence of new technologies in alternative energy. Twelve technologies are identified as “disruptive technologies” in the transportation sector and possess the potential to completely change future energy supply and demand levels (Accenture, 2009). Technologies identified by Accenture as “disruptive technologies in transport fuels” include: next-generation internal combustion engine, next-generation agriculture (cellulosic ethanol), waste-to-fuel, marine scrubbers, sugar cane-to-diesel, butanol, biocrude, algae, airline drop-ins, electric vehicle (including hybrid electric vehicle HEV, plug-in hybrid electric vehicle PHEV and pure electric vehicle BEV), charging and vehicle-to-grid. These new technologies either have higher yields per unit of energy input or allow new sources of energy to be cost-competitive.

Among all these developing technologies, the electric vehicle (EV) is considered by many countries, namely China and the US, to be the future trend of transportation that could replace the use of hydrocarbons fuels completely as well as reduce emission to zero. The adaptation and commercialization of EV will fundamentally change the landscape of energy structure of transportation sector and even the whole economy.
Recognizing the tremendous opportunities in China has proactively joined the race to obtain global leadership. Both governments and enterprises have expressed their interests in this new industry.

The paper starts with an overview of transportation sector in China with its energy consumption and carbon emissions. The second part of this paper is about the current situation of the EV industry in China identifying major challenges as well as possible opportunities, and the third part will try to forecast the future development of the EV market by analyzing the economic competitiveness and market share of EVs in the next decade.

1 Energy consumption and emissions from transportation sector

1.1 World transportation overview

Globally, the transportation sector is responsible for about 61% of world oil consumption and about 28% of total final energy consumption in 2008 (IEA, 2009). Growth in transportation energy use has been highest in the fastest growing economies: China, East Asia and parts of Latin America (Yan and Crookes, 2007). Currently, 20% of fossil fuel carbon emissions are from the transportation sector worldwide (IEA, 2008), 33.6% in the US (Davis and Diegel, 2009) and 26% in the EU (European Commission, 2007).

1.2 China’s road transportation sector

China was the third largest automobile producer and the second largest consumer in the world in 2008 (NBS, 2009), but China is expected to reach to number one in vehicle
production as well as sales mainly due to two reasons: Chinese domestic financial subsidies for buyers and reduction market of US and Japan in the financial crisis time.

China’s road transportation sector is predominantly an oil market, consuming 16.5 million tons (six billion gallons) of gasoline, 47.5 million tons (14.6 billion gallons) of diesel and 0.8 million tons (0.26 billion gallons) of ethanol in 2009 (NBS, 2010). In China, traditional energy such as diesel and gasoline are still the main sources of road transport energy, accounting for more than 96% of total energy consumption. In contrast, compressed natural gas (CNG) and other alternative energy (e.g. biofuel) only contribute to less than four percent of the transportation energy. The breakdown of the current road transportation energy composition is illustrated in Figure 1.

![Energy Composition of Road Transportation](image)

**Figure 1.** China’s energy structure in transportation sector

Transportation energy consumption will keep increasing along with the rapidly growing vehicle population. According to previous studies (Hao et al, 2010; Ou et al, 2010), the annual sale of automobiles will be over 25 million and the total amount of
automobiles will reach 200 million by 2020. Consequently, by 2020 the energy consumption of transportation sector will equivalent to 80 million tons (29 billion gallons) of gasoline and 180 million tons (55 billion gallons) of diesel, almost two times as many as current transportation energy consumption. By that time, the transportation sector will account for more than 45% (250 million tons) of China’s total oil consumption, an increase of 12% from the current figure of 33% (130 million tons).

![Figure 2. Projections on vehicle sale and transportation energy consumption in China](image)

2 The EV industry Today in China

The EV industry differs from traditional vehicle industry by introducing a new energy source into the industry. Thus the industry structure is also changed as reviewed by Figure 3.
2.1 Technologies available

The concept of EV is in contrast with conventional ICE vehicles, which uses gasoline (or diesel) as its major energy source. EV contains an electric operating system together with power battery. Currently there are three types of EVs: hybrid electric vehicle (HEV), plug-in electric vehicle (PHEV) and pure electric vehicle (or battery electric vehicle, BEV).

HEV adds a battery and electric motor to a car that uses an ICE. By marrying advanced power electronics and computer controls with conventional and electric drive trains, HEV operates more efficiently than those that run on ICE alone and reduces emissions. They lessen fuel usage because they employ the electric motor frequently (especially in slow traffic), because they shut down the ICE when the vehicle has stopped for a predetermined amount of time, and because they recapture otherwise discarded kinetic energy during braking. However, HEV still mainly relies on gasoline as energy source. (Denholm, Short, 2006)
PHEV uses HEV technology, but it features a larger battery and a plug-in charger. The PHEV differs from HEV in that PHEV typically relies entirely on battery power over a fixed distance and can be recharged from the electric grid (Kromer, Heywood, 2007). Most PHEV prototypes contain a battery capable of powering the vehicle between 20 and 60 miles (about 30-100 km) on electricity alone, which is defined as “all-electric range”. In comparison, BEV as its name implies, contains battery system only with no ICE. The vehicle relies on electricity solely.

2.2 Opportunities

1. Strong government support

The Chinese government has shown great interests in the EV industry and implemented supportive policies to facilitate its development. Currently, the government provides appealing financial incentives to EV consumers. PHEV consumers could receive RMB 50,000 (USD 7,400) subsidies, while for BEV consumers; the subsidies could be as high as RMB 70,000 (USD 10,000).

Moreover, in order to boost the commercialization of the EV industry, the Chinese government will devote huge amount of investment into this new industry. According to the latest official plan, the government will invest more than RMB 100 billion (USD 14.8 billion) in the next 10 years to facilitate the development of the entire EV industrial chain (Table 1).

Table 1. Investment plans of the Chinese government in the EV industry (2011-2020)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Advantages in battery industry

The power battery is the key component of EV, which accounts for more than 60% of total production cost. Battery costs as well as qualities such as battery endurance, battery life and charging time play an important role in the commercialization of EV. Among the 5 major types of power battery in the market, lithium battery is the most promising one because of its excellent performance (Table 2). Lithium battery will lead the revolution of transportation electrification in the future.

Table 2. Criteria assessment of power battery (CIC, 2008; CIC, 2009)

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Cost (RMB)</th>
<th>Energy density</th>
<th>Battery endurance (50kWh)</th>
<th>Energy efficiency km/kWh</th>
<th>Battery life (charging)</th>
<th>Charging time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead battery</td>
<td>2.4/Wh</td>
<td>70 Wh/L</td>
<td>80-160 km</td>
<td>3.2 km</td>
<td>0.17</td>
<td>500 times</td>
</tr>
<tr>
<td>NI-MH battery</td>
<td>3/WH</td>
<td>90 Wh/L</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>500-700 times</td>
</tr>
<tr>
<td>Zinc air battery</td>
<td>--</td>
<td>270Wh/L</td>
<td>400 km</td>
<td>8 km</td>
<td>0.09</td>
<td>--</td>
</tr>
<tr>
<td>Aluminum air battery</td>
<td>--</td>
<td>79 Wh/L</td>
<td>1600 km</td>
<td>32 km</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
### Lithium ion battery

<table>
<thead>
<tr>
<th><strong>Cost:</strong> average unit cost of battery production (RMB/kWh)</th>
<th><strong>Energy density:</strong> how much energy a unit volume/mass of battery contains</th>
<th><strong>Battery endurance:</strong> how long a 50 kWh capacity battery can power a vehicle before recharge</th>
<th><strong>Energy efficiency:</strong> how long can a unit (kWh) of battery support a vehicle and how much it costs to power the vehicle to run a kilometer</th>
<th><strong>Battery life:</strong> how many times can the battery be charged before recycle</th>
<th><strong>Charging time:</strong> how long it takes to fully charge the power battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.8/Wh</td>
<td>220 Wh/L</td>
<td>380 km</td>
<td>7.6 km</td>
<td>0.06</td>
<td>1000-2000 times</td>
</tr>
<tr>
<td>150 Wh/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Five types of commonly used power batteries are compared in this table from six different criteria. Cost: the average unit cost of battery production (RMB/kWh). Energy density: how much energy a unit volume/mass of battery contains. Battery endurance: how long a 50 kWh capacity battery can power a vehicle before recharge. Energy efficiency: how long can a unit (kWh) of battery support a vehicle and how much it costs to power the vehicle to run a kilometer. Battery life: how many times can the battery be charged before recycle. Charging time, how long it takes to fully charge the power battery.

* All the data in this table are based on the power battery industry in China.

In the power battery production industry, China possesses a comparative advantage in industry scale over the other main players in this field. At present, China supplies 20% of batteries to the global market (CIC, 2009). With one of the world’s top lithium battery companies (BYD), China can currently provide lithium batteries for more than 200 thousand electric vehicles. Based on current estimates, China’s lithium battery production capability is expected to continue increasing over the course of the next five years. As a result of large industry scale, the average production cost of power battery in China is $700/kWh, lower than world average $1000/kWh (CIC, 2009).

Lithium ion is the key material for lithium power battery production. China is one of the few countries with both substantial lithium reserves and battery production technology. The country’s approximately 710,000 tons in recoverable lithium reserves (CIC, 2009) could support China’s power battery needs for about 300 million electric vehicles or 1 billion PHEV (assuming EV battery capacity of 30 kWh, and PHEV battery capacity of 8 to 15 kWh). The abundant lithium resources give China a comparative advantage in the EV industry.
3. Potential for technology leadership

In rare occasion does China possess technology leadership in automobile innovation, with Germany, Japan and the US leading the world’s vehicle industry. However, the EV industry could be a turning point for China to succeed in the competition of world technology leadership. After recognizing the great potential of the EV industry, the Chinese government implemented its EV developing plan in 2001. With almost one billion RMB direct investments on technology R&D, the technology innovation of the EV industry started to boom in China ever since (Figure 4). Currently, China owns the second most intellectual patents (IPs) in the world’s EV industry. With continuous direct government investments and policy support, China possesses the potential to become the world’s leader in the EV industry.

Figure 4. The Developing Trend of Global EV IPs (CATARC, 1999-2010)
2.3 Challenges

High cost, battery performance and charging have been widely considered as the three major barriers to the development of the EV industry. This part of the paper focuses on battery performance and charging, while costs and economic competitiveness of EV will be discussed in detail in section 3.

Charging technologies and the accessibility of charging stations are two important factors that affect market penetration of EV. Table 3 provides an overview of charging technologies in the world.

Table 3. Types of charging for EV – development and performance (BP, 2009)

<table>
<thead>
<tr>
<th>Type</th>
<th>Availability</th>
<th>Cost (SUS)</th>
<th>~Charging time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>PHEV60</td>
</tr>
<tr>
<td>- Standard outlet (residential use)</td>
<td></td>
<td>≥ 0</td>
<td>8</td>
</tr>
<tr>
<td>- Power outlet (residential and commercial use)</td>
<td></td>
<td>500</td>
<td>2</td>
</tr>
<tr>
<td>- High ampere outlet with rapid charger (commercial use)</td>
<td></td>
<td>&gt;1,500</td>
<td>1</td>
</tr>
<tr>
<td>- Rapid charger and 2-way communication for control</td>
<td></td>
<td>3,000</td>
<td>1</td>
</tr>
<tr>
<td>- Battery swap stations</td>
<td></td>
<td>0.5 - 1.0M</td>
<td>5 min</td>
</tr>
<tr>
<td>Industrial super chargers</td>
<td></td>
<td>&gt; 0.1M</td>
<td>10 min</td>
</tr>
</tbody>
</table>

Currently available; ● will be available in 5 to 10 years; ● longer than 10 years to be feasible.

*Cost is the cost of building charging stations (or outlet).
Currently only the basic charging technologies such as standard outlet and power outlet are available (both for residential and commercial use). It will still be a couple of years for the fast centralized charging stations to be widely accessible. With current charging technologies, a full charging cycle would take hours. The long waiting time of battery charging prevents customers from choosing EVs when make their purchase decisions.

Moreover, the lack of supporting facilities is also a bottleneck that hinders the adaptation of EV in China. Currently the number of charging stations is extremely small and only distributed in a few major cities. By the end of 2009, there were only 9 public charging stations for located in a few cities such as Shenzhen (Table 4).

**Table 4.** China’s EV charging stations by the end of 2009

<table>
<thead>
<tr>
<th>City</th>
<th>Number of charging stations</th>
<th>City</th>
<th>Number of charging stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenzhen</td>
<td>2 stations, 134 piles</td>
<td>Chengdu</td>
<td>1 station</td>
</tr>
<tr>
<td>Beijing</td>
<td>1 station</td>
<td>Nanjing</td>
<td>1 station</td>
</tr>
<tr>
<td>Shanghai</td>
<td>1 station, 9 piles</td>
<td>Tangshan</td>
<td>1 station</td>
</tr>
<tr>
<td>Hangzhou</td>
<td>1 station</td>
<td>Xinxiang</td>
<td>1 station, 20 piles</td>
</tr>
</tbody>
</table>

In order to solve this problem and speed up the commercialization of EV, the Chinese government has implemented a construction plan that will build 110 charging stations in the next two to three years (Figure 5). By the end of 2020 the number of charging stations in China will reach 250, and will be distributed in 18 provinces and more than 30 cities. Nevertheless, most of the charging stations located in major cities and the distribution is not continuous, meaning that even if a city has plenty charging
stations there might not be any in the contiguous cities. Consequently, EV will be restricted to local travel inside cities.

Figure 5. Distribution of EV charging stations in China by 2015

3 Future of Transportation Electrification

With an understanding of the current status of EV, this section will try to project the future of this new technology in China. First, decide under what combination of cost and
technology will EV be economically competitive in vehicle market, given current cost, technology, oil price, and government policies. Second, forecast the market penetration of EV and project population of EVs in the next 10 years.

3.1 The economics of EV

One major factor that determines the commercialization of EV is economic competitiveness. The price differences between retail electricity and gasoline open the possibility for EVs to become cost effective than ICE vehicles. Total costs of EV also depend on vehicle initial costs and battery characteristics. This section will analyze the life-cycle cost of EV in order to identify the combinations of costs and technologies conditions that make EV economically viable.

In examining the net costs over the vehicle lifetime, the paper took into account the initial costs of vehicle purchasing, net present value of operation costs, and maintenance costs such as battery replacement. The equation for the net present value of lifecycle cost is given by:

\[
C_{LC} = C_V + \sum_{n=1}^{N} \frac{D_{VDT} \cdot (1-UF) \cdot BE \cdot P_E}{(1+r)^n} + \sum_{n=1}^{N} \frac{D_{VDT} \cdot (1-UF) \cdot GE \cdot P_E}{(1+r)^n} + \frac{C_B}{(1+r)^{N/2}}
\]  

(1)

where \( C_{LC} \) = the present value of total lifecycle cost of different vehicle types;

\( C_V \) = the initial cost of purchasing the vehicle;

\( D_{VDT} \) = the annual vehicle distance traveled; UF is the utility factor;

\( BE \) = the battery efficiency;
\[ P_E = \text{the price of electricity}; \ r \text{ is the discount rate}; \]

\[ GE = \text{the gasoline efficiency}; \ C_B \text{ is the cost of battery}; \]

\[ \varepsilon = \text{the battery replacement factor}, \ \varepsilon=0 \text{ for no battery replacement and } \varepsilon=1 \text{ for battery replacement at half vehicle life}. \]

### 3.1.1 Initial cost and energy efficiency

1. Initial cost

Currently, only HEV is in trade in China’s private vehicle market, and thus the price data of PHEV and EV is not available. In order to analyze the economics of EV, this paper used market price for HEV and estimation values for PHEV and EV.

Past studies have identified and summed estimated components to determine the total cost of EV (Simpson, 2006; Anderman et al, 2000; Graham, 2001; Duvall, 2004). While battery is the main driver of PHEV cost, translating battery costs into vehicle costs involves adding the costs of the battery management system and other battery-related components. Moreover, battery costs are affected by technology breakthrough, manufacturing scale and raw materials prices, all of which add up to the uncertainty of the estimation of EV costs. In estimating the costs of different vehicles, the paper set up a baseline for ICE vehicles according to average market price in China as $23,000 (CATARC, 2009). Retail costs for HEV are calculated using the same approach by averaging the market prices of commercialized HEVs such as the Toyota Prius and Honda Civic.
The costs of PHEV are calculated in three parts: the base vehicle cost, battery cost and additional cost. The base vehicle cost is the same as the ICE vehicle cost; battery cost is based on battery capacity together with a unit cost of $700/kWh (CIC, 2009); the additional cost is estimated to be $5000 for PHEV (Simpson, 2006). BEV does not contain ICE in the power system, and according to industry studies battery cost will account for approximately 60% of total cost. Thus in this paper, the cost of BEV is assumed to be $52,500.

2. Energy efficiency

ICE vehicles and HEVs consume gasoline (or diesel) only, while HEVs have much higher energy efficiency. The energy efficiency data for ICE and HEV are calculated as the average level of vehicle energy efficiencies in China (CATARC, 2009).

The calculation of energy efficiency of PHEV is slightly more complicated. Because PHEV can be powered by both ICE and electric system, one important factor that determines the energy efficiency of PHEV is the proportion of vehicle-miles driven in all-electric mode. In this paper this fraction is denoted as the utility factor, UF, which can take on values $0 < UF < 1$ (Simpson, 2006). The value $1 - UF$ is then the fraction of miles powered by the ICE power system. The main factors determining the UF are the vehicle’s all-electric range and users’ driving and recharging habits, which make the values of UF fluctuate and hard to determine. The paper adopted theoretical values of UF from Simpson’s paper.
BEV uses electricity as the only driven power, and thus the UF factor is 100%.

Battery efficiency is adopted from past study (Karplus et al., 2010) and the same battery efficiency is used for both PHEVs and BEVs.

Table 5 is a summary of battery capacities, initial costs, energy efficiencies and UFs of different vehicles.

Table 5. Costs and Energy Efficiency Factors for Different Types of Vehicles

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Battery capacity (kWh)</th>
<th>Retail costs (USD)</th>
<th>Gasoline efficiency (gal/100mile)</th>
<th>Battery Efficiency (kWh/100mile)</th>
<th>Utility factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE vehicle</td>
<td>0</td>
<td>$23,000</td>
<td>3.53</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HEV</td>
<td>3</td>
<td>$30,000</td>
<td>1.93</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PHEV20</td>
<td>8</td>
<td>$36,000</td>
<td>2.00</td>
<td>18</td>
<td>40%</td>
</tr>
<tr>
<td>PHEV40</td>
<td>17</td>
<td>$45,000</td>
<td>2.04</td>
<td>18</td>
<td>60%</td>
</tr>
<tr>
<td>PHEV60</td>
<td>26</td>
<td>$54,000</td>
<td>2.09</td>
<td>18</td>
<td>80%</td>
</tr>
<tr>
<td>BEV</td>
<td>45</td>
<td>$60,000</td>
<td>-</td>
<td>18</td>
<td>100%</td>
</tr>
</tbody>
</table>

3. Vehicle usage

Historical data for average annual vehicle distance traveled (VDT) is not available in China. Therefore data must be determined directly by taking earlier studies into consideration (Chen and Lu, 2003; Chen et al., 2005; Guo et al., 2007; He et al., 2005; Meng et al., 2006; Wang et al., 2007; Yan et al., 2009). The VDTs for different vehicle types are listed in Table 6. Furthermore, future projection on VDT might not be reliable because of the interaction of this parameter with car ownership, traffic infrastructure, administrative interventions and personal driving habits (Zachariadis et al., 1995). Thus
the paper assumed the annual VDT in China to be 12,500 miles (20,000 km) and will stay constant over the forecast horizon.

**Table 6.** Average annual vehicle distance traveled (miles) in China

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Truck</strong></td>
<td>15400</td>
<td>15276</td>
<td>15152</td>
<td>15028</td>
<td>14904</td>
<td>14904</td>
<td>14904</td>
<td>14904</td>
<td>14904</td>
<td>14904</td>
</tr>
<tr>
<td><strong>Bus</strong></td>
<td>19375</td>
<td>19189</td>
<td>19003</td>
<td>18816</td>
<td>18630</td>
<td>18630</td>
<td>18630</td>
<td>18630</td>
<td>18630</td>
<td>18630</td>
</tr>
<tr>
<td><strong>Passenger car</strong></td>
<td>11551</td>
<td>11489</td>
<td>11364</td>
<td>11302</td>
<td>11178</td>
<td>11178</td>
<td>11178</td>
<td>11178</td>
<td>11178</td>
<td>11178</td>
</tr>
</tbody>
</table>

4. Lifecycle data and interest rate

Lifecycle data are estimated based on the current vehicle-scrapping standard in China. Survival data are generated according to the historical vehicle data. The survival rate $R_n$ is the percentage of vehicles that still running on the road $n$ years after they were sold. Survival rates of different vehicle types are estimated in Table 7. Consider the estimation data and the fact that the market penetration of EV will most likely start with passenger cars and buses, this paper used 12-year as the average vehicle scrappage in China.

**Table 7.** Vehicle survival rate estimation (%)

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Truck</th>
<th>Bus</th>
<th>Passenger car</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>99</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>97</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>95</td>
<td>99</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
<td>96</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>85</td>
<td>93</td>
<td>100</td>
</tr>
</tbody>
</table>
3.1.2 Electricity and gasoline price

The prices of gasoline and electricity are extremely important to the economic analysis of EV. These prices are with great uncertainties, and thus different scenarios are designed in this paper to discuss the possible results in the future.

1. Electricity price

In order to define the electricity price, this paper started with the current electricity prices in China. In China the electricity prices are greatly different between city and rural area. Considering that EV penetration will hardly take place in the rural area, this paper will only discuss the electricity prices in cities. Electricity prices are also different according to different uses. Table 8 shows the electricity prices in major cities (these
cities are identified to have high potential in the EV market, according to the charging station construction plan) in China. This gives us three average electricity prices: low price 8.26 cent/kWh, medium price 10.3 cent/kWh, and 12.3 cent/kWh.

Table 8. Electricity prices in major cities of China, 2010 (cent/kWh)

<table>
<thead>
<tr>
<th></th>
<th>Beijing</th>
<th>Shanghai</th>
<th>Tianjin</th>
<th>Chongqing</th>
<th>Shenzhen</th>
<th>Hangzhou</th>
<th>Changchun</th>
<th>Changsha</th>
<th>Chengdu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (residential)</td>
<td>7.18</td>
<td>8.94</td>
<td>7.18</td>
<td>7.62</td>
<td>12.61</td>
<td>7.77</td>
<td>7.62</td>
<td>7.77</td>
<td>7.62</td>
</tr>
<tr>
<td>High (business)</td>
<td>11.44</td>
<td>12.90</td>
<td>12.32</td>
<td>12.02</td>
<td>14.66</td>
<td>9.97</td>
<td>13.34</td>
<td>11.44</td>
<td>12.61</td>
</tr>
</tbody>
</table>

Another thing need to be considered about electricity price is a new pricing scheme that contains peak price (during the peak period of electricity use) and valley price (during the low electricity use period). The government is working on this new pricing scheme together with the implementation of smart grid. Currently this new pricing system is already in use in Shenzhen.

2. Gasoline price

Currently, the average market price of #93 gasoline is $3.52/gallon in China.

Table 9. Current gasoline prices in different provinces in China, 2011 ($/gal)

<table>
<thead>
<tr>
<th>Province</th>
<th>Gasoline price ($/gal)</th>
<th>Province</th>
<th>Gasoline price ($/gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>3.70</td>
<td>Jiangsu</td>
<td>3.48</td>
</tr>
<tr>
<td>Shanghai</td>
<td>3.67</td>
<td>Jiangxi</td>
<td>3.40</td>
</tr>
<tr>
<td>Tianjin</td>
<td>3.51</td>
<td>Liaoning</td>
<td>3.45</td>
</tr>
<tr>
<td>Region</td>
<td>Price</td>
<td>Region</td>
<td>Price</td>
</tr>
<tr>
<td>--------------</td>
<td>-------</td>
<td>--------------</td>
<td>-------</td>
</tr>
<tr>
<td>Chongqing</td>
<td>3.56</td>
<td>Inner Mongolian</td>
<td>3.47</td>
</tr>
<tr>
<td>Fujian</td>
<td>3.46</td>
<td>Anhui</td>
<td>3.50</td>
</tr>
<tr>
<td>Guangdong</td>
<td>3.60</td>
<td>Shandong</td>
<td>3.49</td>
</tr>
<tr>
<td>Guangxi</td>
<td>3.42</td>
<td>Shanxi</td>
<td>3.50</td>
</tr>
<tr>
<td>Hebei</td>
<td>3.50</td>
<td>Sichuan</td>
<td>3.55</td>
</tr>
<tr>
<td>Henan</td>
<td>3.50</td>
<td>Heilongjiang</td>
<td>3.56</td>
</tr>
<tr>
<td>Hubei</td>
<td>3.47</td>
<td>Yunnan</td>
<td>3.56</td>
</tr>
<tr>
<td>Hunan</td>
<td>3.51</td>
<td>Zhejiang</td>
<td>3.48</td>
</tr>
<tr>
<td>Jilin</td>
<td>3.42</td>
<td>Shenzhen</td>
<td>3.63</td>
</tr>
</tbody>
</table>

There are three scenarios concerning the changing pattern of gasoline prices:

- **Increase**: as a result of increasing energy demand as well as the depletion of oil resource, the market price (scarcity rent) of gasoline will keep increasing in the future.
- **Stable**: the gasoline price will stay stable in the near future in China. Although the energy demand will increase rapidly in the next decade, the development of renewable energy could balance this need. Additionally, due to the strong government control in China, even the global market could fluctuate significantly the oil price will be comparatively stabilized in China.
- **Decrease**: renewable technologies such as EV will improve significantly and gradually commercialized, which provides a “backstop technology” for conventional energy. Consequently, there is a chance that gasoline price may even drop in the future.
Considered the increase energy demand and the developing trend of renewable energy in China in the next 10 years, it is possible that alternative energy will take up a considerable portion of transportation energy but conventional energy such as gasoline and diesel will still account for the majority part of energy consumption. It seems that it is more likely for the gasoline price to increase or stay comparatively stable in China in the next decade.

3.1.3 Results and scenario analysis

According to the assumptions and the data from previous sections, a baseline situation of EV economics was first setup with current gasoline price, average electricity price, current battery costs and no government subsidies. Two different situations either with or without battery change are discussed under baseline scenario.

Based on baseline scenario sensitivity analysis was conducted with four major factors that have great influences on the EV economics: electricity price, gasoline price, battery cost and government subsidy.

Finally, an optimistic scenario was discussed, which is considered by this paper to be the “most likely” situation for China.

1. Baseline scenario

In the baseline scenario for economic analysis, the gasoline price is the average level of the current prices in China ($3.52/gallon); the battery cost is the unit cost of lithium ion battery on current power battery market ($700/kWh); the electricity price is set to be
the average of medium electricity prices in cities that have the potential to have EVs within the next 10 years (i.e. cities with charging station construction plan); additionally no government subsidies will be provided in the baseline scenario. Two different total costs are calculated for each type of vehicle with or without one battery change during the vehicle lifecycle. (Figure 6, 7)

Figure 6. Total costs of different vehicles under baseline situation without battery change
Figure 7. Total costs of different vehicles under baseline situation with battery change

2. Sensitivity analysis

A. Electricity price sensitivity analysis

The paper set up six different prices for electricity, as the scatter points in Figure 8 from left (the lowest price) to right (the highest price) are: valley electricity price in the “peak-valley” pricing scheme (six cent/kWh), low electricity price in current pricing scheme (eight cent/kWh), medium/baseline electricity price in current pricing scheme (10 cent/kWh), high electricity price in current pricing scheme (12 cent/kWh), and peak electricity price in the “peak-valley” pricing scheme (18 cent/kWh).
As reviewed by Figure 8, lifecycle costs of EV are not significantly sensitive to electricity prices. An explanation for this might be that, the current electricity price is comparatively low and the cost of electricity power bill is too small a portion of the total cost to make a substantial change of lifecycle cost. Therefore, it does not make great difference what electricity price to be used in economic analysis for EV.

B. Gasoline price sensitivity analysis

In comparison with electricity price, the gasoline price plays a more important role in the total costs of EV. In order to examine the influence of gasoline price on EV’s economic competitiveness, the paper calculated the lifecycle costs of EVs with different electricity prices (Figure 9). As discussed before, there would be more potential in the increasing of gasoline price. It is clearly showed that the comparative advantage of EV
becomes more apparent as gasoline price increases. With in the current price range, HEV is already economically competitive, even without taking government subsidies and the future lower battery unit cost into consideration. With the growing of gasoline price, PHEV will become more and more appealing in the vehicle market due to its huge energy saving potential. However, the costs of BEV seem to high to be compensated by the saving on energy bills even with higher gasoline price.

![Figure 9. Lifecycle costs of different vehicles given different gasoline prices](image)

Besides electricity and gasoline prices, battery cost is another important factor that influences the vehicle economy, which contributes to a significant portion of EVs’ initial
costs. Actually, the high unit cost together with low performance of vehicle battery is the major barrier that hinders the commercialization of EV.

In the baseline analysis, the unit cost of power battery is assumed to be $700/kWh. It is reasonable to believe that, with the large investment on battery R&D, technology breakthrough can be expected in the near future, especially considering China’s comparative advantages in the battery industry. According to the projection by China Investment Corporation, battery unit cost will experience a substantial decrease since 2010 and drop to about $500/kWh by 2012 (CIC, 2009). Moreover, with the government development plan in the EV industry, China sets the goal to decrease battery unit cost to $300/kWh by 2015. Thus two lower unit cost levels are discussed in this paper: $500/kWh and $300/kWh. Figure 10 shows the present values of lifecycle costs of different vehicles with three different battery unit costs.

![Figure 10. Lifecycle costs of different vehicles given different gasoline prices](image)

Figure 10. Lifecycle costs of different vehicles given different gasoline prices
According to the analysis result, the initial costs of EVs drop significantly with the decreases of battery costs, making EVs more desirable in the market. But the unit cost of power battery must drop to $300/kWh for the lifecycle cost of PHEV20 to be lower than ICE vehicle. However, the total costs of PHEV40, PHEV60 and BEV are still much higher than that of ICE vehicles. As reviewed by this analysis the high cost will still be a barrier for the commercialization of EV in the future. Therefore, other government must take actions to help the EV industry to conquer this challenge.

D. Government subsidies sensitivity analysis

Since the high cost of EV is a major barrier that hinders the wide adaptation of EV, government support such as subsidy is in need. In China, government plays a crucial and active role in the market penetration of EV. In order to facilitate the development of EV the Chinese government provides a very appealing policy for EV (including HEV) consumers as in Table 10.

**Table 10. Government subsidies (or tax reduction) for EV consumers**

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Government subsidies</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEV</td>
<td>50% purchase tax reduction</td>
</tr>
<tr>
<td>PHEV</td>
<td>$7,300 direct subsidies</td>
</tr>
<tr>
<td>BEV</td>
<td>$10,000 direct subsidies</td>
</tr>
</tbody>
</table>

The paper took current government subsidies into consideration and calculated the total cost of EV (Figure 11).
Figure 11. Total costs of different vehicle types with government subsidies

The appealing incentives from the Chinese government make EV more competitive in today’s vehicle market. After four years operation, the saving on energy bills of PHEV20 will compensate the extra purchasing cost. The payback cycle of HEV is approximately 10 years. The lifecycle cost of PHEV40 is approaching to that of ICE vehicle.

3. Optimistic scenario

Given the previous analysis, an optimistic scenario is designed in this paper, which would closely represent the future situation in China.

The sensitivity analysis reviews that EV costs are sensitive to gasoline price, battery costs and government subsidies. On the contrary, electricity price has little influences on
EV’s economic competitiveness. Thus the paper assumed electricity in optimistic scenario to be the same as the baseline scenario.

It is reasonable to believe that the government support will continue for at least 10 years. With the strong and centralized government control, gasoline price will be comparatively stable with slight increase in China within the next 10 years. Therefore the optimistic scenario would be with current electricity and gasoline price, with government subsidies and a battery cost of $500/kWh. The lifecycle costs of different vehicles are calculated according to these criteria (Figure 12).

![Figure 12. Total costs of different vehicle types under optimistic scenario](image)

Under the optimistic scenario, PHEV20 is the most appealing type of EVs, with a payback cycle of three years. HEV and PHEV40 can also be considered as economically competitive in the vehicle market and both types have a payback of 10 years. If
considered on a lifecycle basis, most types of EVs (HEV, PHEV20, PHEV40) are already economically competitive in China’s vehicle market.

If the Chinese government continues its support and investments on the EV industry, the problem of high cost will no longer be a major barrier for the HEV and PHEV. However, the commercialization of BEV would still be challenged with the high cost even with savings on energy bills and government subsidies. Moreover, PHEVs could switch to ICE system if the electricity power run off, but BEVs can only rely on power batteries. That indicates that the commercialization of BEV is highly subject to the accessibility of charging stations and other supportive facilities. Therefore, the commercialization of BEV will be slow in the next 10 years and the market share of BEV will mainly be government and public purchase.

3.2 Market penetration projection on EV

3.2.1 Methodology

The development and internal dynamics of automobile market have always been of great interests to numerous institutions dealing with transportation planning, energy demand, emission control, and auto industry (Zachariadis et al., 1995). One of the critical issues in this respect is the growth potential of the car market. Consequently, multiple approaches have been developed to describe the market penetration pattern and to forecast vehicle populations. The projection models can be classified into three categories:
• Economic approaches, in which financial parameters are used as explanatory variables for the car ownership forecasts and the technology substitution process (Jorgensen et al., 1990; Dargay et al., 1997; Dargay et al., 2007);
• Engineering approaches, which are primarily based on empirical analysis, account only implicitly for the influence of financial parameters, projecting future trend based on historical data (Zachariadis et al., 1995);
• System dynamics approaches, which can become very analytical about the growth of the car market and the penetration of different technologies (and may therefore suffer from lack of appropriate statistical data) (Romanowicz et al., 1988).

One common thing about these models is that they are all developed based on historical data and mathematic simulation. However, in the projection of EV population, there is little historical data available. The truth is, except for HEV, all the other types of EVs are currently not on the market. In this case, it is trying to determine the size of a market that does not yet exist. Other approaches have been adopted to overcome this difficulty. For example, survey method was used in previous researches to assess the potential demands for EVs (Beggs et al., 1981; Kurani et al., 1994). The paper used a combination of the aggregate time series model and EV’s business model to project EV population in China.

1. Dynamic model

The aggregate time series model contains a sigmoid-shape function for the development of car ownership over time that increases slowly in the beginning, then rises
steeply, and ends up approaching a saturation level. The model also well describes the vehicle market penetration pattern. As showed in Figure 13, Part A of the S-curve is the beginning phase of market penetration, Part B as the booming car markets, and Part C as the nearly saturated markets.

\[ VP_i(t) = \frac{1}{e^{e^{-M_i+b_i^t+K_i}}} \]  
\[ K_i = -\ln(S_i) \]

where \( VP_i(t) \) = the population of vehicle type \( i \) at time \( t \);
\[ t = \text{the time in years} \ (t=0 \text{ is the year where vehicle comes to market}); \]

\[ S_i = \text{the saturation value for vehicle type } i: \ S_i = \lim_{t \to \infty} VP_i(t); \]

\[ M_i, b_i = \text{the parameters of the function.} \]

In solving parameters \( M \) and \( b \), an equation is derived from equation (2):

\[
\ln[-\ln[VP_i(t)] - K_i] = M_i + b_i \ast t \quad (4)
\]

With given saturation value \( S_i \) and historical data of vehicle population, this linear regression leads to the estimates of \( M_i \) and \( b_i \).

The saturation point \( S \) cannot be given precisely for every vehicle type. In fact, the saturation value for vehicles was considerably underestimated in previous studies in China, as the market has been expanding so dramatically. Several explanations were given for the underestimation in this methodology (Samaras et al., 1992):

- As growth proceeds, the saturation level may increase (a behavior similar to that of biological populations).
- The curve may oscillate when approaching the saturation point.

Sensitivity analysis reveals that the forecast is not particularly sensitive to some variation of the saturation point (Zachariadis et al., 1995). Therefore the paper assumed that \( S \) lies within a certain margin and will use the \( S_{\text{min}} \) in the modeling forecasting. The \( S_{\text{min}} \) of total vehicle population is derived from previous study (Hao et al., 2010; Qu et al., 2010) and the saturation values of different EVs are assumed to be the same as \( S_{\text{min}} \).
2. Business model for EV

The development of EV in China will experience a transition from HEV to PHEV and then BEV. The commercialization of EV can be divided into three phases.

- Beginning phase 2010-2012: the market size relies on government and public purchase. As any other new products, the commercialization of EV will be constrained by the limited initial market demand, due to technology uncertainty and high unit cost at the beginning phase. Therefore, government support will play a crucial role in this phase, as government purchase will be the major source of market demand. Moreover, government’s efforts in supportive facility constructions will also determine the future development of the EV industry.

- Metaphase 2013-2015: this is a transition phase for the EV market to move from government purchase to private purchase. With the considerable market demand built up by public purchase (including government and other organizations), the technology uncertainty and high cost decrease gradually. Additionally, as the supportive facilities approaching to adequation, private purchase begins to take over the market, when government mainly engaged in facilitative actions (incentives such as tax reduction and direct subsidies).

- Mature phase 2016-2020: this is the real commercialization phase for the EV industry. Government intervention will be minimized and private customers will pull the market demand of EV.
Based on this business model and government plan for the EV industry, the paper assumed that in China the market entry year for PHEV and BEV are 2010 and 2012 respectively. The market penetration of PHEV and BEV will follow the same pattern.

### 3.2.2 Projection results

Three sub-models are built separately for HEV, PHEV and BEV, so as to estimate the total EV population in China. The dynamic model for HEV is developed based on historical data of HEV population in China since its market entry in 2005. The paper assumed that the development of PHEV and BEV would follow the same pattern. The initial population (vehicle population of year 0) is defined according to government goals.

HEV is by nature an ICE vehicle, which does not rely on battery performance or charging. Thus once HEV become economically competitive in the market, the market penetration should follow the same pattern as conventional ICE vehicles. Therefore a projection model was developed based on the historical data of HEV population in China since 2005 (Figure 14). The first few years since HEV entered China’s vehicle market, the sales were considerably low. At the end of 2008, the total amount of HEVs on the road in China was less than 10,000. This low penetration rate was due to the specific situation back then: high purchasing cost, low gasoline price, and no government incentives. As the government intervention started in 2009, the market share of HEV began to grow rapidly. According to the projection result, by the end of 2020 the number of HEVs will be over 10,000,000 in China.
Figure 14. Projection on HEV population in China

Due to the lack of population data for PHEV and BEV, it is impossible to build independent models on vehicle population. PHEV and BEV are fundamentally different from conventional ICE vehicles in that electricity is the major energy source. Consequently, cost is not the only concern for PHEV and BEV. Market penetration also relies heavily on battery performance and charging technologies as well as the accessibility of charging facilities.

Based on the business model of EV in China, the beginning market size of PHEV and BEV is determined by government and organization purchasing. Thus it is rational to assume that the vehicle populations on the road to be consistent with the numbers in
government plan for EV development in China. Once all the barriers are concurred, PHEV and BEV will follow the same developing pattern as HEV.

The paper used the government goals for PHEV population in 2010 to 2012, BEV in 2012 to 2015. Then justified the model of HEV for PHEV and BEV. The simulation result is showed in Figure 15. By the end of 2020, the combined population of HEV, PHEV and BEV will be approximately 25 million in China.

![Figure 15. Population projections on three different types of EVs in China](image)

Besides the population, it is also important to examine the portion of EV in total vehicle population. An estimation of China’s total vehicle population is calculated follow the same dynamic model of EV projection, and the result is reviewed by Figure 16.
According to the projection results, the portion of EV will experience a significant increase in the next 10 years. By 2020 EV will account for more than 8.8% of China’s total vehicle population (Figure 17). In the next 10 to 20 years, EV will play an important role in the transportation sector by gradually replacing ICE vehicles.

**Figure 16.** China’s Vehicle population in the 21st century

**Figure 17.** EV percentage of total vehicle population in China
Conclusion

The EV industry has just started in China, but is growing at a rapid speed. With the strong government support, large power battery industry and fast-growing vehicle market, China has the potential to become a world leader in the EV industry.

Government plays a crucial role in the development of the EV industry in China. The government shapes the future of EV market through investment, incentive policies, facility construction and direct purchase. Currently, public purchase is still the major driver of EV’s market demand.

According to the economic analysis of EVHEV and PHEV are already economically competitive in the vehicle market on a life-cycle basis on the condition of government subsidies. If the Chinese government continues its support and investments on the EV industry, the problem of high cost will no longer be a major barrier for the HEV and PHEV. However, the commercialization of BEV would still be challenged with the high cost even with savings on energy bills and government subsidies.

The economic analysis and market research also review that the major challenge for the development of EV is not high cost but charging. The commercialization of EV, especially BEV is highly subject to charging time and the accessibility of charging stations. Given the current available charging technologies and the distribution of charging stations in China, the use of EV will be highly restricted to large cities and only domestic travel.
In the next decade, EV will experience a rapid growth in China. The market expansion will rely on the growth of HEV and PHEV. According to projection, EV will account for more than 8.8% of total vehicle population in China, by the end of 2020.

The adaptation of EV will replace the use of conventional vehicles, and in turn save energy as well as reduce emission. The environmental impacts of EV is obvious, however, it is very complicated to quantify these impacts on a life-cycle analysis. Different components must be taken into consideration such as battery production process, electricity generation and energy efficiency of EV. Although, this master’s project does not touch this perspective of EV, it is definitely worth studying in the future. Additionally, it would also be beneficial to analyze how much influence would the adaptation of EV has on the grid.
Reference

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