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The Winding Road for Electric Vehicles in China

Todd J. Edwards

Brussels Institute of Contemporary China Studies, VUB, Belgium, tedwards@vub.ac.be

Abstract

Electric passenger vehicles offer China the opportunity for enhanced energy security, improved urban air quality, reductions in greenhouse gas emissions, and a global leadership position in a transformative automotive industry. Yet China must first relieve consumer anxieties in order overcome a set of intertwined obstacles and ultimately spur organic electric vehicle market growth. The State has supported the electric vehicle market thus far with investments in battery, motor, and vehicle component innovation as well as with consumer subsidies for select pilot cities. China's new energy vehicle program, 1,000 electric vehicles in 10 cities, instituted in 2009 now encapsulates a total of 25 cities with five cities receiving consumer subsidies. Nevertheless, without a stronger consumer base in the near-term, the momentum for electric vehicle deployment may dissolve. The quandary is if China's policies are sufficient. This study highlights the opportunities and evaluates the policies intended to nullify the challenges of China's potentially burgeoning electric vehicle marketplace. Ultimately, the paper identifies persistent consumer concerns and presents several policy scenarios for further analysis.

Keywords: China, Policy, Electric Vehicles

1 Introduction

The birth of a robust electric vehicle marketplace in China is still in an embryonic phase. The path to the evolution and final identity of electric vehicles in Chinese cities is uncertain. Policies have promoted development of electric vehicle technology and have enticed consumers to indulge in electrified transportation, yet electric drive vehicles still must compete. Policies and programs for advancement of other alternative fuel vehicles are pursued in tangent, and overcoming the hardy market for conventional internal combustion engine vehicles is daunting. Three categories of actors in China will determine the fate of electric drive vehicles: government, manufacturers, and consumers. Government, either directly or via state owned enterprises, is responsible for policy, power generation, and infrastructure. Manufacturers produce the automobiles as well as the components for power generation and vehicle operating infrastructure. Consumers will demand. The nuanced interrelationships between these actors will either culminate in electric drive vehicles as the preferred alternative transportation, or not.

Internal combustion engine vehicles (ICEV) are interchangeably also referred to as traditional and conventional vehicles herein, and they will remain alive into the foreseeable future, but it is hypothesized by many that alternative fuel vehicles (AFV) will increasingly gain market share. AFV encapsulate a wide range of technologies that compete for innovation and infrastructure funding from the State. They include hydrogen fuel cell vehicles (HFC), hybrid electric vehicles (HEV), and combustion vehicles using bio-fuels (there are many types of bio-fuels), coal-to-liquid (CTL), compressed natural gas (CNG), liquefied petroleum gas (LPG), and others [1]. Another subset of AFV is electric drive vehicles (EDV), which include battery electric vehicles (BEV), referred to simply as electric vehicles (EV) in this paper, and also plug-in hybrid electric vehicles (PHEV). This paper focuses primarily on policies related to EDV because they contribute to similar technology and infrastructure improvements – notably the battery technology and charging infrastructure. Notwithstanding, since the introduction of all AFV to the mass market is relatively a recent phenomenon, ambiguity has hold of the technology that will compete more vigorously with ICEV. That is not to say that only one winner will arise.

Energy supply and transportation are interdependent, and the ratio of transportation to energy consumption should decline as well as the environmental externalities as technologies advance. Fuel economy standards for conventional vehicles will improve and so will EDV efficiencies. Therefore, it is only prudent to project scenarios that attempt to evaluate the stream of future benefits associated with each type of vehicle technology. A comparison of these scenarios can suggest which technology should receive the most attention, but, as is the case with predictions, nothing is certain. Therefore China's strategic approach to develop a portfolio of transportation alternatives and periphery technologies is correct.

This paper presents a case for progressive EDV enhancements from the State because the potential benefits are poised to outweigh competitive forces. The benefits, presented in the next section, are achievable, but China has a set of complex challenges (section 2) to overcome during the evolution of an EDV marketplace. Evidenced by China active policy involvement (section 3), the State acknowledges the opportunities, but there are still some policy gaps that cloud consumer perceptions of electrified private passenger transportation. The final section of this paper suggests supplemental policy solutions.

2 Rationale to Electrify Passenger Vehicles in China

Over the past decade China has invested in electric vehicle technology in hopes to harvest high returns in economic development, energy security, and improved environmental conditions. China is not alone in this vision. Europe, Japan, Korea, and the US to name a few like-minded competitors are at the heels of China, but China is poised to hold the global leadership position in this transformative field. The benefits that China can garner instill inspiration to devote capital and resources for this presently ambiguous clean energy concept. If the fortunetellers are correct, then China will reap rewards for her stern motivation. Domestic and international demand for all types of vehicles will grow exponentially over the next 20 years, which will gradually consist of higher ratios of alternative fuel vehicles.

China cannot compete as well in the mature market for traditional vehicles, but electric vehicles are a new frontier. Many Chinese consumers will also be first-time auto-owners that in theory may never own an old-fashioned gas-guzzler. Electric vehicles also offer the opportunity to wean a portion of their transportation energy demand away from the oil rich nations of the world. The objective is to direct some of the outflow of capital toward inward development of clean coal. China is coal rich. The positive prospects associated with China's aims for economic development and energy security are environmental improvements. Under the right conditions, electric vehicles emit fewer greenhouse gases and other air and water pollutants that plague China's expansive urban populations as well as the Earth's atmosphere. The section below illuminates viable benefits for electric vehicles in China.

2.1 Economic Development

China's central government desires the global leadership position for electric drive vehicles in part because of the associated economic development benefits. In China, vehicle ownership is projected to increase to density levels similar to the US and EU during the first half of this century [2]. The growth in vehicle sales in China is thought to be a result of improvements in social and economic development as well as urbanization. Globally, vehicle ownership will continue to rise as population and gross domestic product (GDP) per capita also increases. Unless the push for this future marketplace falters, a perpetually increasing proportion of China's and the world's vehicle ownership is projected to contain elements of electric drive technologies.

According to one study, vehicle ownership in China grew exponentially in over the past several decades. Between 1990 and 2007 the portion of the stock of the private passenger vehicles grew nearly 36 times from 0.8 million to 28.8 million [3]. This is a conservative calculation compared to other studies that indicate higher numbers in 2007 and state that 2010 the private vehicle stock was between 70 and 122 million.

The projection of total vehicle stock is important for policy-makers and researchers because it is incorporated as a factor of future energy demand calculations and subsequent environmental externalities [4]. With any type of forecasting there are various models that use different assumptions, data, and time horizons. Some previous predictions suggest that total vehicle population (private passenger, public, and commercial) in China is expected to reach 230 million by 2020 and 425 million by 2030; however these figures are also conservative compared to predictions presented below.

An econometric standard in predicting vehicle stock and sales is a model known as the Gompertz curve, an S-shaped curve that relies predominately on GDP per capita. Some basic projections based on the standard S-curve model suggest that there could be 273 million automobiles, present count plus aggregate sales minus salvage, in China by 2020 [5]. The total stock would then grow to between 550-730 million by 2050 [6].

An adapted S-curve model that takes into account other variables such as vehicle price and policies related to vehicle sales incentives and vehicle retirement may result in better predictions. One such model suggests total vehicle stock of 530-623 million by 2050 of which more than 90 percent will be light-duty passenger vehicles [4]. A key element of the prediction is that 16-28 percent of passenger vehicle sales will be from first-time purchasers. In the United States, nearly 99 percent of vehicle purchases in 2050 will be replacement purchases, which indicates that in China the vehicle marketplace will have not yet reached maturity. Nevertheless, the total vehicle stock in China is projected to exceed the US by the year 2024 [4].

The S-curve prediction model of total vehicle stock has some potential inaccuracies especially when calculating vehicle sales. Therefore, this study reviewed another model that relied on historical vehicle ownership data and GDP per capital in a global context for its trajectory of vehicle stock in China. As a critique, there is arguably not enough historical data to extrapolate vehicle sales and total stock out to 2050 [4]. Although there are other models that dismiss standard S-curve assumptions, such as those using historically country comparisons, most literature reflects similar vehicle projections as stated above or even higher sales and stock figures.

This paper is not intended to provide an in-depth analysis or comparison of the various models; however, it does suggest that China's passenger vehicle sales and total vehicle stock is expected to continue to grow at exponential rates. The leading factor found in all models is the recognition that income is the primary driving force. As China's GDP per capita continues to rise, then vehicle sales and subsequently vehicle stock will grow. Moreover, the various studies also indicate that a significant proportion of vehicle ownership during the next 40 years will be first-time vehicle owners, which gives China the opportunity to encourage electric drive vehicle consumer loyalty [2].

The current competitive barriers for the traditional automobile market create a strong incentive for China to direct attention to the new EV market [7]. China has an opportunity to become a leader with an early-mover advantage in what is now a relatively niche market. China is also increasingly meeting needs of global automobile demand with becoming a net exporter of cars in 2005 and reaching 330,000 auto exports in 2009 [8]. The global EV market is expected to grow to more than $250 billion USD by 2020 and represent 10% of new vehicle sales per year by 2025 [7]. Industry analysts believe that the global EV market could be an economic growth alternative for China compared to the already mature market for conventional vehicles.

This is an opportunity for China to take advantage of the growing demand for passenger vehicles, and in particular for domestic and global electric vehicles, which is especially the case with new-vehicle owner demand. Furthermore, China already possesses some key advantages in the EV value chain. China is a world leader in the production of electric motors because of its endowment of rare earths. Rare earths, by cost, comprise nearly 30% of electric motors [7]. China currently owns about 95% of global production for rare earths and is expected to have approximately 30% of the world's reserves [9]. Furthermore, China is the world's third largest producer of lithium, which is used in lithium-ion battery technologies for EV. China also has experience in lithium-ion battery production, albeit primarily for consumer electronics [10]. These resources and technological know-how endow China with a viable competitive advantage in the global electric vehicle marketplace.

2.2 Energy Security

Although the models that predict future vehicle sales and stock vary to some degree, the salient point is that China will experience an explosion of vehicles on the road over the next 40 years. Increases in vehicle stock also translate into increases in gross energy demand in the transportation sector. Since China is presently a net oil importer, then escalating future oil demand is not without geo-political and national security concerns. Presented in this section, alternative fuel vehicles, especially electric drive vehicles, offer China an opportunity to mitigate some of the security risks associated with acquiring what would otherwise be a completely oil import driven vehicle economy.

Since 1993, economic development, urbanization, and growth in vehicle transportation resulted in China importing more than half of its oil for domestic use, which is expected to continue into the future. According to analyst, oil consumption in the transportation sector has grown at a rate between 9.6 to 13 percent since 2000, which according to the 2007 IEA World Energy Outlook China's average oil consumption growth is 3.5 percent higher than other countries. It is projected to be between 808 and 1,152 million tce in 2030, depending on the forecast model.

Road vehicles in China will represent 70 to 80 percent of this increase [1].

One aspect of energy security for China is diverting the funds that would otherwise leave China to oil-producing regions of the world toward domestic industries to produce electricity and bio-fuels. The financial rationale is further supported by turmoil that arises from volatile oil prices that periodically impact China's industrial production. On average oil prices are expected to rise from an average of approximately $75 USD per barrel in 2010 to $110 USD per barrel by 2020, and then continue to increase into the future in relation to growth in world oil demand [7]. In particular, electric vehicles substitute domestic electricity generation for foreign oil imports, and they consume fewer gasoline-equivalents compared to conventional internal combustion engine vehicles. If China succeeds in growing a sizable electric vehicle market, they will have an opportunity to forgo a portion of oil import costs. The next section highlights the importance of revised fuel-economy standards for liquid fuel vehicles, which will also help to mitigate energy security concerns.

2.3 Environmental Improvements

Climate change and localized air pollution are unique symptoms of environmental externalities exacerbated by fossil fuel based energy consumption, yet they are both unmistakably threats. China's cities are often cited to be above the level of safe air quality, according to international standards. Poor urban air quality infringes on the health and welfare of city residents, and thus equates to losses in economic productivity. Moreover, China is now the largest gross emitter of greenhouse gases. Even though the concentration of greenhouse gases in the Earth's atmosphere is primarily the lingering contribution of the West since the industrial years, global warming will not decipher its judgment on relative historic pollution. Thus it is in China's own best interest to mitigate the emissions of greenhouse gases regardless of the lack of Western owner-responsibility on emissions that accumulated in the troposphere and beyond. Electric vehicles can gift China with cleaner urban air and fewer greenhouse gas emissions when compared to a business as usual case of conventional car ownership; however, to garner these benefits China must consider how electric vehicles are deployed today as well as in the future.

This section presents a synthesis of environmental lifecycle analyses for alternative fuel vehicles; however, the focus remains with vehicles that utilize an electric drive system, such PHEV and EV. Ultimately, the hypothesized benefits of electric drive and other alternative fuel vehicles are scenarios in which urban air quality is improved and road-transportation related greenhouse gases are reduced. This section excludes two-wheel vehicles, but they are discussed later in a section on consumer preferences.

Some studies indicate that electric vehicles might actually have a negative impact on the environment depending on the regional electric generation mix associated with the charging infrastructure in select cities. China's electric generation mix, the combination of power resources, primarily consists of coal, which has a high GHG emissions factor than gasoline or diesel. Therefore, some regions in China, mostly in the north, have greenhouse gas factors associated with their generation mix that theoretically could result in electric vehicles producing more emissions compared to conventional vehicles. These studies compare the energy efficiency of electric vehicles compared to internal combustion vehicles and argue that electric vehicles should only be deployed in certain geographic areas in order for them to produce net positive benefits.

Regional power grids utilize different mixes of resources for power generation. Regions with higher ratios of coal power will produce more pollution compared to regions with relatively more renewable, hydro, or nuclear power. Presently, China's electric generation consists of approximately 80% coal-fired plants on a national level, but the highest concentration of coal plants are located in China's northern provinces [11]. Electric vehicle deployment in some regions thus could produce more greenhouse gas emissions and coal-related air and water pollution compared to the externalities associated with conventional vehicles in these same regions. Regardless, the studies suggest that electric vehicle deployment in some cities in China will reduce the negative environmental externalities.

The aforementioned lifecycle analyses, however, are not entirely conclusive because they do not take into account the time of day demand curves, the potentiality of electric vehicle battery storage, and other variables such as battery technology improvements and the future deployment of carbon capture and storage for coal plants. Similar to projections in vehicle stock, each lifecycle model will produce different results based on the scope and data. Nevertheless, an environmental lifecycle analysis is the best way to evaluate if electric vehicle deployment will produce desired environmental benefits.

There are numerous methodologies to calculate the GHG lifecycle emissions associated EV, HEV, PHEV, ICEV, and other vehicles. A basic calculation of GHG emissions takes into account the different carbon dioxide equivalent factors for each type of fuel. A standard approach to compare the GHG emissions of vehicles is to conduct an analysis that includes the total fuel consumed (and GHG emissions related to other processes) throughout the lifetime of the value chain on a per unit basis. The most common lifecycle analysis is referred to as well-to-wheel, which includes the upstream supply chain and the vehicle fuel utilization. Other types of lifecycle analysis are limited to well-to-tank or tank-to-wheel, or they could be more inclusive of the downstream salvage emissions, which is a full cradle-to-grave analysis. Therefore, a lifecycle calculation can take into account all of the upstream and downstream processes, as well as the fuel utilization, which electric vehicles are estimated to have up to three times the fuel efficiency of gasoline powered vehicles of similar size [12].

An evaluation of a different lifecycle analysis suggests that a carbon capture and storage (CCS) scenario on coal-fired power results in the greatest reductions in GHG compared to an ICEV business-as-usual case. The CCS scenario suggests that GHGs would be mitigated to an extent even greater than a HEV/bio-fuel scenario. Regardless, even the worst-case coal-fired scenario with advancements in CCS demonstrates that GHGs could be reduced by 3-36 percent nationwide. On the contrary, CTL (coal to liquid) fuel will not produce reductions in GHGs compared to traditional vehicles unless CCS is also used in this process and then the net difference is almost zero [12]. This study also indicates that in 2015 with the national electric generation mix there is a possibility for 35 percent reduction in GHG emissions on a lifecycle basis as compared to conventional vehicle use. However, since this calculation uses a national electric generation mix rather than regional figures, these numbers are also skewed.

There is not yet a consensus on the full environmental lifecycles of electric drive vehicles compared to gasoline powered or bio-fuel vehicles. The scope of a single study to provide more conclusive results would require accurate historical and current data for numerous upstream, downstream, and vehicle fuel utilization processes at a regional level. In addition, it would require information regarding individual vehicle specifications. All of the data points would also need to be projected into the future, which necessitates assumptions on the evolution of specific technologies, consumer purchases, infrastructure, and related policies. Thus a genuine lifecycle analysis is nearly impossible, but there are good models that provide some insight into the opportunities for electric vehicles from which policy-makers are more informed, and all of the models reviewed for this paper conclude that there are net benefits for the application electric vehicles, perhaps depending on where they are deployed and perhaps not.

Furthermore, ICEV vehicles directly contribute to localize air quality degradation, but they also contribute to upstream pollution, which is caused by oil exploration and extraction, refining (a significant source of water pollution), and fuel transportation. Not to mention China has experienced numerous oil spills, which contribute to severe ecosystem damages, such as the Dalian Xingang Port oil spill in July 2010 that was one of China's largest disasters [7]. EV do improve the public health in urban areas by mitigating the air pollution caused from ICEV vehicles, but at the cost of displacing a portion of the pollution to more rural areas. Some lifecycle studies also take into account the non-GHG air pollution and water pollution; however, no conclusive studies were found for this paper.

3 Complex Challenges

As difficult as the benefits of electric vehicles are to quantify, albeit real, the obstacles for China to overcome are even more complex. The challenges, like the benefits, are not isolated to China, yet they have unique characteristics in regards to China. This section introduces three categories of challenges that encompass what other studies might divide into more or fewer topics. Successful electric vehicle deployment in China faces stern hurdles related to: 1) technology, intellectual property, and standardization, 2) consumer acceptance, and 3) power demand. Each of these categories of barriers include a myriad subjects, but they all have some relation to electric vehicle batteries.

3.1 Technologies, Intellectual Property, and Standardization

A competitive EV market in China relies upon the technology for lithium-ion batteries, motors, and other manufactured components for which China owns very little intellectual property. Although China has a competitive advantage in terms of natural resources and battery production history, they do not own the technology patents, which ultimately increases the cost of the EV supply chain. Japan owns more than 50% of lithium-ion patents, the US owns approximately 22%, and Korea has 15%. The remaining patents are divided primarily within Europe. Even though China has propelled its electric drive vehicle industry since 2004, she owns only 1% of current patents in lithium-ion battery production, which means that Chinese manufacturers have higher cost to lease the technology [13]. China is also limited by its patents in other EV components; for example, China does not have the intellectual property rights to the battery management systems that can affect the life of the battery and can account for up to 30% of the battery pack cost [9]. To reduce the total cost of ownership of EV produced in China, improvements in the production processes should reflect further research and development of domestic practices.

The market for lithium-ion batteries for EV began after the University of Texas invented the Lithium Iron Phosphate cathode in 1996, which is a lower cost alternative compared to the performance of lead-acid battery technology [9]. Lithium-ion batteries produce more power per mass compared to lead-acid and have the potential to be cost competitive with ICEV. Nevertheless, EV lithium-ion battery packs in 2010 cost nearly as much as a new gasoline powered car.

However, if China can continue to reduce battery costs through technology and process improvements, then it is possible that the battery cost could be reduced 60% by 2020 [7].

In addition to achieving technological prowess, the technology that is developed and deployed must have specific standards for usability and interoperability. Some standards are likely to become universal, while others may pertain to specific regions and/or vehicle classes. Presently there are numerous standards development organizations (SDO) attempting to create the rules that will drive this technology further into the consumer sphere. These organizations include, but are not limited to, the International Organization for Standardization (ISO) with ISO 6469, International Electrotechnical Commission (IEC) with IEC TC69, Standardization Administration of the People's Republic of China, and Society of Automotive Engineers (SAE) [14]. Examples of standardization that will affect the deployment of electric vehicles include the battery design, battery charging infrastructure, battery swapping infrastructure, charging information technology (IT), IT security, attachment plugs, and so on. There is some cross-pollination of standards, such as the joint US-China Electric Vehicles Initiative that aims to expedite the global deployment of electric vehicles [14]. Ultimately, however, without harmonization of standards across jurisdictions, then the uptake of EV could be delayed.

3.2 Consumer Acceptance

Consumer acceptance of electric vehicles is a function of the interaction between the three sets of actors – consumers, manufacturers, and policy-makers. In China, policy-makers affect decisions on funding for innovation and technology, consumer subsidies, and infrastructure development as well as other periphery aspects of the electric vehicle marketplace. Decisions by policy-makers are made with the intent to maximize the benefits aforementioned in this paper – energy security, economic development, and environmental improvements. Manufacturers are profit-maximizing organizations that attempt to navigate against their competition in the light of the direction of consumer demand. Consumers also behave to maximize their utility; however they are reliant on manufacturers and government to create an environment that entices a paradigm shift from conventional/mature modes of transportation. Without the right recipe, electric vehicles may not overcome the obstacles presented in this paper; however, there could be another alternative that arises that fits the consumer-demanded manufacturer-supplied government-encouraged interactions that indeed finds market equilibrium.

In order to overcome some of the technology, innovation, and standardization obstacles there must be a strong consumer market demand to drive revenue and to distribute innovation costs; however, consumers are somewhat reluctant to move quickly into a new ambiguous realm. Electric vehicle ownership generally disagrees with a rational consumer model. EV are not cost competitive compared to similar-class conventional vehicles or other modes of transportation such as buses, bicycles, and walking. To compete, EV will eventually need better capital efficiencies compared to substitute modes of transportation. The aim is to reduce the total cost of ownership, which is directly associated with the cost of the lithium-ion battery and components [9]. Furthermore, the EV industry must solve other consumer anxieties regarding battery performance and charging infrastructure.

Electric drive vehicles face competition from conventional ICEV vehicles, lightweight ICEV vehicles, public transportation, walking, bicycles, two-wheel electric bikes, and other alternative fuel vehicles. The competition is not only on the consumer-side, but there is also competition for innovation and infrastructure capital allocations by corporations and government institutions. Technology funds are limited, and the decisions by policy-makers and supply chain contributors will eventually favor the technologies that are most likely to produce the greatest benefits for the least cost. In parallel, consumers will also attempt to maximize their utility for the least cost. Therefore, the technology that receives the most innovation funding and consumer revenue will shape the future of alternative transportation.

The total cost of ownership (TCO) for EV is predominately in the upfront cost of the battery. The lifetime cost of an EV will result from fuel and maintenance costs, which, as technology improves, will be significantly lower than conventional vehicles. According to a World Bank study, the average lifetime cost for an ICEV vehicle compared to a comparable EV could provide a savings of approximately $10,000 by 2020; however, the upfront cost of the battery and other components might exceed these savings [7]. Therefore, in order to overcome the TCO barrier, EV manufacturers need to improve the battery and component manufacturing technologies in order to price them competitively [15].

Consumers also have anxiety about the battery replacement life, the range of each charge, charging infrastructure accessibility, and charging time. An EV lithium-ion battery life is presently about 160,000 kilometers (km) for typical applications. Comparable ICEV vehicles and their components have an original life of about 240,000 km. In terms of range, most EV can only travel about 160 km per charge [7]. This range is sufficient for most urban car owners; however, it could be a deterrent for applications such as corporate fleets, taxis, long-distance commuters, and often utilized fleets.

EV consumers also have anxiety about the uncertainty of the charging infrastructure. There are various types of charging stations. Some produce a full-charge within 30 minutes (rapid charge or Level 1), while other types of stations could take 4 hours (Level 2) or up to 8 hours (slow-charge or Level 3) to charge an EV battery. The cost for the technology and installation varies for each of these charging applications. There are also concerns about the security and billing with public charging stations, for which different policy models have been explored including subscription-fee based charging [16]. Some studies suggest that the majority of prospective EV consumers are likely to wait until services and standards are in place prior to investing in this new technology. Therefore, the consumer influence places new demands on manufacturers and policy-makers to create an operable environment for electric vehicles as a prerequisite.

The consumer demand for certainty about the technology and infrastructure for electric vehicles is similar to that of other types of alternative fuel vehicles. Only gasoline and diesel vehicles have a universal infrastructure already in place. Select cities have unique examples of alternative fuel infrastructure such as LPG in Shanghai, but a truly advantageous aspect for the development of electric vehicle infrastructure is that electric power transmission and distribution lines are nearly ubiquitous throughout China, especially in urban and highly populated regions. Thus, establishing the infrastructure for electric drive vehicles is more dependent on the technology and standardization than on building an entirely new logistics network for delivering alternative fuels.

According to a discrete choice probability model that assumes that consumers will attempt to maximize their utility, household income is one of the main driving forces for the decision to purchase alternative fuel vehicles. Larger households are also more likely to consider alternative fuel (especially electric) vehicles. This could be related to the aggregate disposable income from the cost efficiency that can be present in larger households. Moreover, younger households in particular those with a female head of household are more likely to purchase alternative fuel vehicles. Other factors that theoretically contribute to consumer utility maximization include daily commuting distance and previous vehicle ownership. Long commuting distances will negatively affected the probability for AFV purchases. Whereas consumers whom have previously owned a vehicle are less sensitive to the cost of electric vehicles compared to non-automobile owners [17]. An interesting insight from this study also revealed that previous car owners are have less concern about the infrastructure for electric vehicles because they are already familiar with their driving habits and can formulate a vision of their potential charging demand [17]. Regardless, the study of consumer vehicle preferences in China is still growing into a mature field. In part, the uncertainty resulting from the supply-chain contributors regarding the technology and infrastructure has potentially created a clouded image of this potential market for consumers, and thus a strong preference is not yet practical nor could it be analyzed.

Other factors identified in a separate study indicate that consumer preferences for vehicles are dependent on geography, which include the price of fuel, access to fuel, and environment, and supply chain [3]. This study utilized a survey methodology and also concluded that environmental benefits and low fuel cost were the two most important factors regarding consumer preference if upfront purchase cost were not an issue. However, consumers, according to this survey also had limited general knowledge of EV. They were less informed about the overall performance and operating procedures and costs. The survey analysis did find a correlation that indicated that respondents in families that have higher numbers of drivers are more likely to purchase an EV [3]. Other distinctive findings from three binary logistic regression models used on the survey data concluded that:

> (1) Whether a consumer chooses an EV is significantly influenced by the number of driver's licenses, number of vehicles, government policies and fuel price
> (2) The timing of consumers' purchases of an EV is influenced by academic degree, annual income, number of vehicles, government policies, the opinion of peers and tax incentives
> (3) The acceptance of purchase price of EV is influenced by age, academic degree, number of family members, number of vehicles, the opinion of peers, maintenance cost and degree of safety

An analysis of the various studies on consumer preference suggests that consumers do not yet have the information to create a strong preference for AFVs because the technology, infrastructure, and cost are difficult to predict. The direction of the substitute modes of transportation is also cumbersome to navigate for consumers, manufacturers, and policy decision makers. The result of this ambiguity does not derail the possibility of a strong electric drive (or alternative fuel) vehicle marketplace, but it does indicate that the industry is still in an embryonic phase.

Whilst the electric passenger vehicle marketplace is forming, electric two-wheel bikes are becoming omnipresent in China except in cities that have placed bans on this mode of transportation. A key factor for the growth of electric bikes is their national classification as a bicycle, which does not require a special license to own or operate [18]. Whereas most cities issue a limited number of passenger vehicle licenses, electric two-wheel bikes have served as a growing autonomous mode of transportation.

Electric bikes have the benefit of producing a small environmental footprint compared motorcycles, but they contribute to toxic lead pollution, which is currently not well controlled with recycling programs in China [18]. Furthermore, according to studies, electric bikes are not a likely substitute for automobile ownership. There is some thought that electric bikes are a precursor to electric vehicles, and aspects of this theory are correct. Sales, improved lithium-ion battery development for bikes, charging infrastructure, and consumer behavior trends from electric bike users do segue into a marketplace for electric vehicles; however, studies indicate that if electric bikes were removed from the decision-model of daily transportation, then public transportation is presently the preferable alternative [19]. This result is likely related to the cost of ownership of any automobile, and not simply the cost of ownership of electric vehicles.

The number of electric bikes on the roads in China has proven too difficult to estimate accurately; however electric bike stock is thought to be around 100-200 million, which is up from best estimates of around 50 million in 2007 [19]. Typically electric bikes utilize a lead-acid battery. The batteries function for this purpose for about 2 or 3 years depending on the number of charges and distances traveled. At the end of the useful life of a lead-acid battery, the ideal disposal is recycling. The recycle rate in most developed countries is more than 90%, and the result is very little lead pollution. About 3% of lead is lost in processing new batteries from recycled batteries, and only about 5% is lost in manufacturing new batteries from virgin lead sources. In China, however, the official recycle rate is about 31%. (Although some analyst believe that the rate is closer to 80% since recycling reports are not always well documented.) The manufacturing processes are also less efficient, and the lead loss rate is 27% and 18% for virgin and new recycled batteries respectively [19].

Electric bikes are just one substitute for consumers to choose besides traditional vehicles; there are also numerous types of other low-carbon alternatives including more efficient conventional vehicles. China, along with much of the developed world, is improving its fuel efficiency standards, leveraging lightweight materials (such as aluminum), and investing in bio-fuel options (especially high performance algae based fuels). The analysis to understand the best alternative for policy makers and manufactures includes, again, a lifecycle analysis of the environmental as well as the economic costs. This paper does not evaluate the various analyses that are in circulation, but rather informs that this type of analysis includes a vast amount of variables.

There are AFVs (bio-fuel, electric, hydrogen fuel cell, hybrid, plug-in hybrid, and electric bikes), low-carbon conventional vehicles (lightweight and advanced fuel economy), conventional vehicles (including motorcycles), public transportation, bicycles, and walking that should be analyzed and compared to one another in terms of environmental impact, economic impact, and consumer preference. There are hundreds of models of alternative fuel vehicles, and thousands of models of conventional and other types of transportation. Therefore, lifecycle analysis models must rely on assumptions used to determine average ownership, utilization, market growth, fuel economy, and distances traveled. These variables are often dissected into vehicle classes, such as light-duty, medium-duty, and heavy-duty (there also sub-classes within these vehicle types). Moreover, nearly all of these variables fluctuate overtime; therefore exogenous models that predict aspects like future vehicle stock by class category are theoretical econometric models (as described earlier in this paper), and thus a comparative lifecycle scenario analysis to determine utility maximization of all three actors in the present as well as to predicted the future is impossible to do so accurately. Therefore, as is being done in China today, the decision is to explore all of the options to various degrees and to continue to study the feasibility of deployment as well as the payoff of creating these markets.

3.3 Power Demand

Assuming that a robust electric vehicle market does come to fruition, then China must be prepared to handle the new power demand placed on its disparate regional electric infrastructure. China routinely experiences power shortages because of increased demand due from economic growth, global warming, and the decommissioning of older, less efficient, power plants. Furthermore, it likely that the vast majority of China's future power generation will continue to come from coal, yet it is possible that strategic deployment of carbon capture and storage and other cleaner coal technologies could mitigate some of the pollution associated with coal-fired power. Renewable energy is growing in China, but the transmission of renewable power is still in development as well as high-voltage transmission lines and smart grid, which will cumulatively help to reduce the environmental externalities associated with increases in electricity demand. Nevertheless, China is not equipped for an overnight mass adoption of electrified passenger transportation.

Theoretical optimization of power generation dictates that electric vehicle charging should take place during non-peak load times from the evening to early morning. In the event that electric vehicles are charged during the day, then they could greatly contribute to the peak demand, which would require approximately 10 TWh (terawatt hours) of new power generation capacity for every one million electric vehicles. This is roughly the same amount of energy that the present world aggregately consumes in 40 minutes. Although this number appears large, it is estimated as a small percent of China's total energy demand in 2020 [20]. Some studies suggest it will increase China's total energy demand by only about one percent, yet that amount is still sufficient enough to produce power outages. If electric vehicles are charged during the evening, on the other hand, they could increase nighttime energy demand by up to 40% (according a study of EV in Canada), but it would have little effect on overall daily peak demand [14]. In this scenario, electric vehicles would not elicit a need for substantial additions to the current power generation capacity.

Regardless of the energy capacity growth that might be required by the addition of electric vehicles, as the total vehicle stock continues to rise, gross energy demand will increase. Since electric vehicle battery performance for passenger vehicles is about two to three times more efficient than gasoline powered vehicles today, the introduction of electric vehicles will reduce the gross energy demand from the transportation sector [21]. The critical issue is to determine which path China will pursue to optimize its gross energy demand, and if China selects electrification because of its energy security and other benefits, then their plans must include some level of new capacity growth, new smart-grid infrastructure, and new electricity tariffs for end users.

4 Electric Vehicle Policies

China announced domestic sales targets of 500,000 EV by 2015 and 5 million by 2020, which is not likely to occur from organic market growth [22]. China's historic policies were focused on the technology and production processes for EV, and presently these initiatives are pursued in conjunction with city-centric pilot programs and limited consumer subsidies. Even the subsidies provided to consumers, which are not sustainable in the long-term, are an attempt to bolster revenue streams that induce manufacturers to continue with research and development. The inherent objective is to reduce the TCO without the use of subsidies in the future through advancements in EV battery technology and manufacturing processes.

The critical funding mechanisms to promote electric drive technology development are born from the 863 Program housed in the Ministry of Science and Technology (MOST). The late Deng Xiaoping created the National High-Tech Program, also referred to as the 863 Program, in March 1986 as a response to concerns from some of China's leading scientists at the time. The 863 Program initially had a wide mission to improve the science and technology of a number of industrial sectors, and in 2001 – the start of the 10th Five-Year Plan – a more robust vision was given to the program's ideals for clean energy technology advancement [23]. In accordance with the objectives of the program, China has been investing considerable sums of money in new energy vehicles, such as fuel-cell, PHEV, HEV, and EV. In 2001, the government invested RMB 800 million in fuel-cell projects. Five years later China created the "Energy-Saving and New Energy Vehicles Project", whereby MOST invested RMB 1.1 billion to establish a "technology roadmap" for EV [1]. In 2008 and 2009, China rolled out a collaborative EV pilot to deploy 1,000 EV in 10 select cities (discussed in-depth below). The next year the State Council allocated another RMB 3 billion for EV technology advancement. Then, in 2010 China initiated a further push for EV technology advancement, especially with battery technology, that received 42% of RMB 738 million in new research funding. That same year, the central government allocated funds for EV consumer subsidies in five of the EV demonstration project cities [9].

A cooperative initiative from the National Development and Reform Commission (NDRC), the Ministry of Finance (MF), the Ministry of Industry and Information Technology (MIIT) and MOST promoted 1,000 EV in 10 select cities (*Notice on Experimental Demonstration and Promotion of Energy Saving and New-energy Automobiles*), and two years later the pilot program was revised to a total of 25 cities in various stages. The original 10 cities were quickly expanded to the following thirteen cities in 2009: Beijing, Changchun, Changsha, Chongqing, Dalian, Hangzhou, Hefei, Jinan, Kunming, Nanchang, Shanghai, Shenzhen, and Wuhan. In June of 2010 another seven cities were added to the demonstration project: Guangzhou, Haikou, Suzhou, Tangshan, Tianjin, Xiamen, and Zhengzhou. At the same time, the central government began offering consumer subsidies (*Notice of Pilot Subsidies to Private Purchase of New Energy Vehicles*), on a kilowatt (kW) basis, of up to RMB 60,000 per vehicle for EV and RMB 50,000 per PHEV (which also utilize EV battery technology) for the following five cities: Changchun, Hangzhou, Hefei, Shenzhen, and Shanghai [3]. Most recently in 2011, the demonstration project at-large grew to 25 total cities with the addition of Chengdu, Hohhot, Nantong, Shenyang, and Xiangfan. Many of these cities already have plans to exceed the 1,000 EV targets with Shenzhen in the lead at 24,000 EV and PHEV planned by 2012 [9].

Deployment of electric drive vehicles and related technologies in the consumer sphere is, however, the mainstay for continuing research and development on EV batteries and other vehicle components because without actualization the industry would simply remain a lab experiment. In order to deploy electric vehicles, besides overcoming consumer anxieties related to cost and performance, a city must reach a certain level of readiness regarding infrastructure, specialized power pricing schemas, and other aspects of society and electric vehicle interaction.

Charging stations are a readiness factor for electric vehicles that has grown as a focal point for cities. Regarding the aforementioned challenge of creating standards for these technologies, in 2010 the MIIT released three standards: 1) *General Requirements for Electric Vehicle Charging Station*, 2) *Electric Vehicle Conductive Charge Coupler*, and 3) *Communication Protocols between Battery Management System and Off-board Charger for Electric Vehicles*. By the end of 2010, the number of charging stations (not charging poles) grew by approximately 140% over 2009. The number of stations is expected to grow to about 2,000 by the end of 2015. China's power grid companies and energy suppliers (such as Sinopec, CNOOC, and Petro China) are responsible for the vast majority of the installation of these stations primarily across the country's urban areas [24]. The number of charging poles installed by the State Grid on the other hand was estimated at around 6,200 in 2010.

Local governments are also implementing programs to drive the PHEV and EV industries beyond the aims of the national programs. Some cities have elected to supplement the national consumer subsidies. For example, Shenzhen has introduced local subsidies of RMB 60,000 for EV purchases and RMB 20,000 per PHEV. This city is also studying consumer acceptance of both rapid and slow charging stations with deployments of over 100 slow charge locations and two rapid charge locations (all equipped with authentication and billing systems). Shenzhen is also one of the first cities to specify a time-of-use charge for daytime charging based on commercial retail electric rate structures [24]. Moreover, based on the Shenzhen case, in 2010 the government installed slow-charge stations in 27 other cities [7].
Two other examples include Beijing and Shanghai, whereas both cities deployed a fleet of electric buses with battery swapping stations to keep the fleet operational throughout the day. These battery swapping stations require only 12 minutes; however, this option demands that the city purchase and maintain 60% more batteries [7]. Perhaps China's cities are competing for the benefits of becoming a leader within the leader for electric drive vehicles, but regardless of the motivation it is evident that local governments will play an intrinsic role in the potential creation of an electric passenger vehicle future in China.

In addition to the policies and examples aforementioned, there are numerous other policies to evaluate that are outside of the scope of this paper. Nevertheless, a short list of periphery policies is provided below.

- National Clean Vehicles Action implemented from 1999 and ethanol fuel promotion from 2004
- Industrial Policy for Auto Industry (2004)
- Medium – Long Term Planning for Energy Saving (2004)
- Renewable Energy Law (2005)
- Opinion on Encouraging Development of Energy-Saving and Environmentally Sound Small Displacement Automobile by State Council (2005)
- Outlines of 11th Five-Year Planning of National Economy and Society Development (2006)
- Rules on the Production Admission Administration of New Energy Automobile (Nov. 2007)
- Energy Law (Draft to Solicit Public Comments) (Dec. 2007).
- Denatured Fuel Ethanol'
- Vehicle-use Ethanol Gasoline
- Auto Industry Restructuring and Revitalization Plan
- Management Rules on Market Access of Manufacturing Companies and Product on New Energy Vehicles

Furthermore, two important policy areas in China that are not discussed herein, but deserve attention, are those regarding improvements in fuel economy standards for conventional vehicles as well as fuel taxes. Higher fuel economy standards are likely to reduce the total cost of ownership that will discourage the ownership for conventional vehicles in the long-run. Adversely, the introduction of a fuel tax, which has now been implemented in China after years of debate regarding the potential negative economic effects, will increase the total cost of ownership for conventional vehicles [13]. Generally both policies fit the recommendations environmentalists.

Although China's central and local governments' policies are in response to the market barriers, they are questionably insufficient to give birth to sustainable organic market growth. Research and development funding, through either direct sources or EV sales, will help to overcome the technological and hence intellectual property barriers. Subsidies, in the short-term, and improved technology, in the long-term, will reduce TCO to make EV financially competitive. Moreover, consumer anxieties should also dissipate if city demonstration projects become successful. Notwithstanding, there are still barriers that are not adequately addressed.

5 Policy Recommendations

The gaps in China's policies are a product of an equation with too many unknown variables to easily resolve, but deduction of many great minds that have not yet dismissed the notion of an electrified passenger vehicle future stands to reason that there is a solution. The quandary is in what order and to what extent should China pursue seemingly disparate yet interdependent courses of action. The three categories of barriers presented earlier were 1) technology, innovation, and standardization; 2) consumer acceptance, and 3) power demand. Addressing each of these barriers requires different sets of policies, yet at the same time one policy-set is dependent on the other. Without fully committing to a predetermined three-dimensional vision of electric vehicle cities in China, the policy approach will mimic policy strategies observed elsewhere in China's energy sector. Similar to the power structure reformations over the past 30 years, a trial-test approach is most likely.

Technology and innovation continues to receive direct research funding, and additional revenue from consumer purchases propped by subsidies should alleviate some pressure on the capital required to develop higher performance EV batteries at a lower cost. If this is achieved, then the total cost of ownership will reduce proportionately, and eventually consumer subsidies will fade and organic growth will prevail. Although there is reason to doubt that the pilot programs will reach their desired targets, and even if those targets are exceeded the revenue generated still might not propel battery advancements to a degree of competitiveness. Nevertheless, since the outcome of the city pilot and consumer subsidy programs will remain unknown until their 2012 expiration, this paper does not suggest any alterations.

Aspects of the electric vehicle marketplace that have not yet been adequately addressed relate more to the human-vehicle interaction. This section of the paper presents two policy areas to address with further research and analysis. Both sets of policy recommendations are found amongst other academic literature on the subject. This paper, however, provides a contextual element, modifications to these concepts, and in some cases adaptation from other models suggested for electric vehicle deployment in the US.

5.1 Combined Battery Leasing and Secondary Market

The leasing markets and post-EV markets for lithium-ion battery applications should be integrated because they will increase the value and lifespan of the batteries. There are examples of other markets that lease capital-intensive goods, and then resell the used goods into a secondary market. The same simple concept applies to electric vehicles with the slight, yet complex, difference that only a component of the vehicle is leased, which is the battery.

Based on current technology, lithium-ion batteries do not meet vehicle propulsion performance after their efficacy declines below 80 percent. Depending on driving behavior and the number of recharges, the efficacy could drop below the performance threshold anywhere between 3 to 8 years. Assuming a 160,000 km battery lifespan, and an average annual usage of 24,000 km, then battery replacement is about 6.5 years. That said, discarded vehicle batteries are still functional in a secondary market as stationary utility energy storage devices [7]. Furthermore, after the lifespan of the stationary batteries fall below a specified performance level, then the battery could be recycled in a tertiary market. The complete battery life scenario theoretically extends the value of lithium-ion batteries beyond original vehicle ownership. Therefore, if a consumer leased only the battery portion of their electric drive vehicle, then the consumer's total cost of ownership would reduce by the residual discounted value of the battery.

Electric battery leasing is not a novel idea for China. Ankai Bus, Zotye Auto, and Lifan Motors already have direct consumer and public leasing models in place [25]. Moreover, a California based company, Better Place, designed a for-profit model; whereby an electric recharge grid operator (ERGO) owns the battery, leases it to consumers, and helps build the infrastructure for city charging and battery swapping. In December 2011, Better Place did open a battery switching station with China Southern Power Grid (CSG) as the battery charging or switching operator (BCSO) in Guangzhou [26]. It is China's first fully automated battery switching facility, and it only takes about five minutes to complete the transaction. CSG is also committed to improving electric vehicle charging and battery swapping infrastructure in other areas including Shenzhen, Nanning, Haikou, and other cities. It is yet unknown, however, how CSG is planning to integrate these programs with its utility-level energy storage.

Energy storage systems offer the opportunity for batteries to charge during the hours of lowest demand on the grid, which also represents the lowest marginal GHG emission factors for the electric generation mix. During hours of low demand, often in the early morning, a number of coal-fired plants should cycle off while nuclear, hydro, and wind generation supply a relatively higher proportion of electricity. The post-EV batteries could store this lower GHG intensive electricity, and then during hours of peak demand, typically in the afternoon, the stored electricity could help curtail some of the load that would otherwise require more GHG intensive coal power. Together with the longer lifespan from introducing secondary markets, the concept of energy storage would also reduce the GHG lifecycle emissions for the lithium-ion batteries that were originally produced to serve only the EV market. As noted earlier, however, further research and analysis is required to determine the range of benefits. Such research should include a study of the marginal electric generation mix, city-specific demand curves, energy storage technology capabilities, battery-to-grid efficiencies, thermal losses, and other aspects of feasibility. Nevertheless, energy storage is likely a strong value-add throughout the life of lithium-ion batteries.

The recycling process, as the tertiary market, can mitigate some of the negative externalities caused from upstream lithium sourcing. The reuse of batteries for post-EV energy storage will increase the overall demand for virgin lithium resources and other materials compared to immediate recycling; thus, the lower GHG lifecycle per battery from the secondary market should take into account the environmental affects of this additional demand [10]. Regardless, the recyclability of lithium-ion batteries is a promising aspect about this technology, and such tertiary markets would have a business case for longevity insofar as the EV market is successful.

Aforementioned, the concept of creating the leasing and post-EV battery markets is not original; however, the research reviewed for this study did not suggest specific policy recommendations. The policy recommendation herein is for China to bifurcate its city-specific (pilot program) subsidy policies into two options for consumers. The consumer could elect for either a direct subsidy – if the EV battery system is not compatible with secondary market requirements – and retain ownership of the EV and battery, or the consumer could choose to lease the battery from the local government or SOE (perhaps the utility company like CSG) at a subsidized (by the secondary and tertiary market value) depreciated value. The consumer would own the EV, and at the end of the life of the original battery, the consumer would lease a new battery. This concept could extend the life of the EV, and may offer better leasing terms, longer battery life, and improved performance for the consumer in the long-run. In the leasing scenario, the local government or utility would own the batteries, which would later become energy storage units as part of the state-owned electric distribution grid network. If government directives initiate this type of market integration, it will relieve some uncertainties for private enterprises and consumers to perform more accurate risk and return analysis. Once the financial model for private enterprises is deemed feasible then the leasing, energy storage, and recycling markets could become competitive. In addition to the general benefits of improving the EV market for China this policy recommendation includes lower TCO for consumers, improved GHG lifecycles for lithium-ion batteries, and a partial solution for managing peak demand in urban areas.

5.2 Special Electric Rate Schedules

A complementary policy recommendation to energy storage in post-EV batteries is the creation of a time-of-use (TOU) utility rate schedule specific for primary market EV charging. Utilities have an opportunity to devise a billing structure that incentivizes EV owners to recharge their vehicles during non-peak hours. The benefits of this type of structure are similar to the secondary market energy storage benefits for charging the batteries with the lowest GHG intensive electric generation mix. If consumers charge their batteries during low-peak demand, then the GHG lifecycle could be improved during the primary market phase as well as the secondary market phase [24]. Furthermore, instituting a specific billing structure during the early adoption years for EV will help to construct a market that is more inclined to leverage the upcoming technology of vehicle-to-grid, whereby EV owners could also utilize their vehicles as mobile energy storage devices and independently resell electricity to the grid during peak hours. Some cities in China, such as Shenzhen, have already implemented some differentiated pricing mechanisms for electric vehicle charging; however, there is yet a ubiquitous understanding about how the rates should be designed for universal adoption. Therefore, China should conduct further research, as necessary, and consult cities on how to implement a TOU price for the EV market.

5.3 Licensing & Public Health Charges

Mass distribution of driver's licenses for passenger vehicles is relatively a new phenomenon in China. State and local governments previously owned the vast majority of non-commercial vehicles on the road. Today more and more private vehicle owners are clogging the roads, especially in urban areas. Yet, the number of available driver's licenses is limited [3]. China could implement a fast track license program for alternative fuel vehicles. Such a policy could encourage prospective vehicle owners to purchase electric vehicles.

Subsidies and licensing may not alone overcome competitive barriers for electric vehicles; thus, another policy suggestion is to discourage ICEV ownership through by increasing their TCO with the use of public health charges. Since a local public health cost is already built-in to EV – upfront cost for less localized air pollution, then municipal governments should also consider adding a public health fee to the ownership of ICEV vehicles. There are examples of cities implementing congestion charges, such as Durham City and London in the United Kingdom. A public health fee could resemble a similar type of initiative, but whereby EV, and to a lesser extent PHEV, would be exempt because they already incorporate the public health benefit of reduced local air pollution. Other policy mechanisms could also include special parking and driving privileges [7]. Moreover, a study of two-wheeled electric vehicles concluded that subsidies were not as an effective market mover mechanisms compared to penalties on their gas-powered counterparts. Some restrictions, such as limited licenses, were enforced for motorcycles to help improve safety and local air and noise pollution. The result was that more would-be motorcycle owners adopted the initially more expensive and less reliable electric versions.

Eventually the cost for two-wheeled electric vehicles decreased and the performance quality was improved [15]. Therefore, as a suggestion to help equalize the TCO between ICEV vehicles and EV, China should consider implementing municipal public health charges.

6 Conclusion

The potential for electric vehicles to flourish in China is tethered to the government's ability to level the playing field with the consumer market for substitute modes of transportation. Although the State is ardently pursuing policies to maneuver the electric vehicle (EV) marketplace into a competitive position, the future is still uncertain. The central, provincial, and local governments are attempting to steer the course to a successful EV marketplace, but the task of navigating through the obstacles is cumbersome. Similar to other clean energy and energy efficiency initiatives, China is taking an incremental policy approach.

Opportunities for China stir in the mist of a brewing electric vehicle marketplace. EV could reduce China's dependence on foreign oil, mitigate global climate change, spur economic development, and alleviate some urban air quality problems. These objectives are contingent, however, on China's policies to overcome the barriers facing a successful EV market. Unless China uncovers the policy solution to the electric vehicle deployment equation then consumers are likely to purchase other types of vehicles. Although certain policies are already in place to address the challenges, the outcome may not culminate in the desired results. Albeit further investigation is required, there are several policy options for China that could help to optimize EV potentials. If China can take the lead on integrating the EV and post-EV battery markets, institute TOU rate schedules, and require ICEV vehicle owners to absorb some cost for improved public health, then global EV leadership may well tip toward fruition.

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Author

Todd Edwards is research fellow at the Brussels Institute of Contemporary China Studies (BICCS) where he focuses on the deployment of electric vehicles in Chinese cities. He is also the Managing Director of TE SEMCO, an energy management consultancy.