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The China New Energy Vehicles Program

Challenges and Opportunities

Prepared by

PRTM

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The purpose of the report is to disseminate information on the implications of electric vehicle adoption in China.

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Preface

Urban Transport and Climate Change

Urban Transport and Climate Change

Reducing CO_2 emissions is a growing challenge for the transport sector. Transportation produces approximately 23 percent of the global CO_2 emissions from fuel combustion. More alarmingly, transportation is the fastest growing consumer of fossil fuels and the fastest growing source of CO_2 emissions. With rapid urbanization in developing countries, energy consumption and CO_2 emissions by urban transport are increasing quickly.

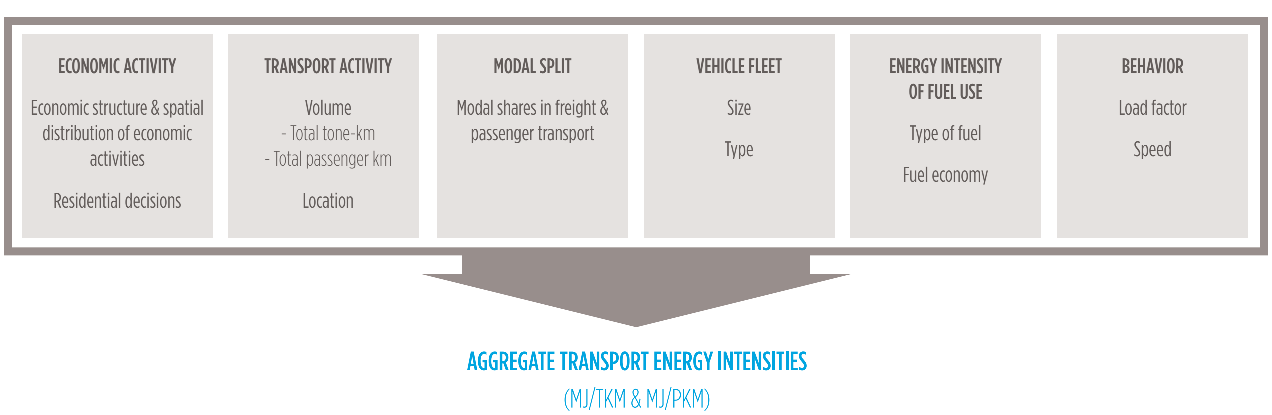
These growing emissions also pose an enormous challenge to urban transport in China. As a recent World Bank study of 17 sample cities in China indicates, urban transport energy use and greenhouse gas emissions (GHG) have recently grown between four and six percent a year in major cities such as Beijing, Shanghai, Guangzhou, and Xian.[1] In Beijing, CO_2 emissions from urban transport reached 1.4 metric ton per person in 2006, compared to 4.6 metric ton CO_2 emissions per capita in China in the same year. The numbers could be considerably higher in 2011.

A World Bank operational strategy for addressing greenhouse gases from urban transport in China (World Bank 2010), noted a strong alignment between the challenges associated with reducing such emissions and the other challenges faced by the sector. In many Chinese cities, there is an immediate need to address localized urban transport problems—congestion, accidents, and pollution. A slow and congested transport system stifles the efficiency of the urban economy which accounts for over 80 percent of the national economy. A car-oriented city particularly affects the mobility and safety of those who do not have access to a car—and who often have to contend with slow public transport and a road system that is inconvenient and unsafe for pedestrians and cyclists. Excessive conversion of farmland for urban development wastes scarce land resources and threatens the country's ecological systems. Excessive investment in urban transport through off-the-book borrowing by the municipal governments incurs heavy financial liabilities and threatens the country's financial stability. Rising fuel consumption endangers the nation's long-term energy security, even as growing CO_2 emissions from urban transport adds considerably to the difficulty of national CO_2 reduction.

Opportunities for Low-Carbon Urban Transport

This recognition of the alignment between local and global concerns was reflected in a strategy that sought a comprehensive approach to sustainable urban transport development. Figure P1 illustrates how a similar set of interventions both saves energy and reduces CO_2 emissions, and also addresses the important local problems related to urban transport. This figure provides a schematic of the drivers of emissions from urban transport and indicates entry points for urban transport policy interventions to save energy and reduce CO_2 emissions.

Figure P1: **Entry Points for Energy Saving and CO_2 Reduction**



The six entry points in Figure P1 all relate to the fact that, in essence, greenhouse gases from transport are emitted from the fuel used on motorized trips. The figure shows that increases in the level of **economic activity** in a city usually result in an increase in the total number of trips (i.e., the aggregate level of **transport activity**). These trips are distributed across the range of available modes (referred to as the **modal split**), depending on the competitiveness of the alternatives for any given trip maker. Every motorized trip emits GHG emissions and the amount of emission depends largely on the amount and GHG intensity of the fuel used, or the efficiency of the **vehicle fleet** and the **energy intensity of the fuel** used. Finally, **driver behavior** impacts the fuel use—after certain threshold speeds, fuel consumption becomes significantly higher. Further, activity location, modal choice and behavior are interlinked via often complex feedback loops. For instance, a common assumption is that location of activities drives the choice of mode—someone making a trip to work may choose between driving, using public transport or taking non-motorized transport. At the same time, there are also trips for which the choice of mode is fixed—a person may want to drive—and the choice of destination, for instance for a shopping trip, may be based on this choice. While this complex and distributed nature in which GHG emissions are generated makes transport a particularly challenging sector in which to dramatically reduce emissions, there are several strategy options for a city seeking to reduce the carbon footprint of its urban transport sector, all of which are highly relevant to Chinese cities today:

- *Changing the distribution of activities in space:* For any given level of economic activity, a city can influence the distribution of activities in space (e.g., by changing land use patterns, densities, and urban design) if it can have an impact on the total level of transport activity. Better land use planning and compact city development can lead to fewer or shorter motorized trips and a larger public transport share of motorized trips. It would also serve to address concerns related to excessive conversion of farmland and concerns related to the level of investment demanded by this sector.
- *Changing the relative attractiveness of different modes:* A city can also influence the way transport activity is realized in terms of choice of modes. Improving the quality of relatively low emission modes such as walking, cycling, and various forms of public transport can help a city attract trip takers to these modes and lower their carbon emissions per trip. Such actions would also increase the mobility and accessibility and address the concerns of the poor and others without access to a car. At the same time, a city can adopt demand management measures that would make the use of automobiles more expensive and less convenient. Such measures would have the impact of reducing automotive travel, and address concerns relating to congestion, local pollution, and safety.

- *Affecting the kinds of vehicle and fuel used:* Finally, government authorities can take a range of measures that directly influence what vehicle technologies are being used and the choice of fuel being used. This could include pricing policies that favor particular kinds of cars—such as differential tax rates favoring cars that have a higher fuel economy, as well as adoption of technological measures and fuels that reduce the carbon emissions of motorized vehicles per unit of travel. Such actions have the potential to directly lower not only greenhouse gas emissions but also local pollutant emissions.

This Report

This report is one of a series developed as part of an ongoing multi-year World Bank initiative focusing on this agenda. While this report focuses on the particular issue of electric vehicles, the overall initiative has supported a number of analytical studies, policy analyses, and pilots that have addressed other aspects of this challenge. Other reports in this series are listed below and can be accessed at the web site for the East Asia transport group at the World Bank (www.worldbank.org/eaptransport).

References and Other Relevant Reports

Strategy and Institutions

Darido, G., M. Torres-Montoya, and S. Mehndiratta. 2009. "Urban Transport and CO_2 Emissions: Some Evidence from Chinese Cities." World Bank Working Paper, World Bank, Washington, DC. [E, M]

World Bank. 2010. "CHINA: Urban Transport in Response to Climate Change. A World Bank Business Strategy," World Bank, Washington, DC. [E]

Papers published in Urban Transport of China, No. 5, 2010: [E, M]

Agarwal, O. P. "Dealing with Urban Mobility: the Case of India."

Chiu, Michael. "A Brief Overview of Public Transport Integration and Terminal Design."

Fang, Ke. "Public Transportation Service Optimization and System Integration."

Liu, Zhi and Shomik Raj Mehndiratta: "The Role of Central Government in Sustainable Urban Transport Development."

Liu, Zhi. "Urban Transport Infrastructure Financing."

Zimmerman, Sammuel. "The U.S. Federal Government and Urban Transport."

Carbon

ALMEC. 2009. "Guidelines for Preliminary Estimations of Carbon Emissions Reduction in Urban Transport Projects." Final report and calculators. May 2009. [E]

Walking, Cycling, and Participation

Chen, Yang and Shomik Mehndiratta. 2007. "Bicycle User Survey in Fushun, Liaoning Province, China." Proceedings of the Transport Research Board Annual Meeting 2007. [E]

Chen, Wenling and Shomik Mehndiratta. 2007. "Lighting up Her Way Home: Integrating Gender Issues in Urban Transport Project Design through Public Participation. A case study from Liaoning, China." World Bank Working Paper, World Bank, Washington, DC. [E]

Chen, Wenling and Shomik Mehndiratta. 2007. "Planning for the Laobaixing: Public Participation in Urban Transport Project, Liaoning, China." Proceedings of the Transport Research Board Annual Meeting 2007. [E]

Tao, Wendy, Shomik Mehndiratta and Elizabeth Deakin. 2010. "Compulsory Convenience? How Large Arterials and Land Use Affects Pedestrian Safety in Fushun, China." *Journal of Transport and Land Use.* Volume 3, Number 3. https://www.jtlu.org/. [E]

World Bank. 2009. "Inclusive Mobility: Improving the Accessibility of Road Infrastructure through Public Participation." Short Note, World Bank, Washington, DC. [E]

Accessibility and Land Use

Jiang, Yang, P., Christopher Zegras, and Shomik Mehndiratta. (in review). "Walk the Line: Station Context, Corridor Type and Bus Rapid Transit Walk Access in Jinan, China." [E]

Torres-Montoya, Mariana, Li Yanan, Emily Dubin, and Shomik Mehndiratta. 2010. "Measuring Pedestrian Accessibility: Comparing Central Business and Commercial Districts in Beijing, London, and New York City." World Bank Working Paper, World Bank, Washington, DC. [E]

Public Transport

Allport, Roger. 2008. "Urban Rail Concessions: Experience in Bangkok, Kuala Lumpur and Manila," EASCS Transport Working Paper No. 2, China Sustainable Development Unit, East Asia and Pacific Region, January 2008. Translated into Chinese as part of this initiative. [E,M]

Beijing Transport Research Committee. 2009. "Beijing Rapid Commuting Bus Transit Study." Final Report. [E, M]

Beijing Transport Research Committee. 2011. "Beijing: Metro-Bus Integration Study." Final Report. [E, M]

Gwilliam, Ken. 2007. "Developing the Public Transport Sector in China." World Bank Working Paper, World Bank, Washington, DC.

http://siteresources.worldbank.org/INTCHINA/Resources/318862-1121421293578/transport_16July07-en.pdf [E, M]

World Bank. 2009. "Urban Rail Development in China: Prospect, Issues and Options." World Bank Working Paper, World Bank, Washington, DC. [E, M]

Technology

World Bank. 2009. *China ITS Implementation Guidance.* World Bank Working Guide, 2009. [E, M]

Clean Air Initiative–Asia. 2010. "Guangzhou Green Trucks Pilot Project: Final Report for the World Bank–Truck GHG Emission Reduction Pilot Project." [E]

Zheng, Jie, Shomik Mehndiratta and Zhi Liu. Forthcoming. "Strategic Policies and Demonstration Program of Electric Vehicles in China." [E]

Training Courses (Presentation Slides)

Public Transport Operations, 2009. [E,M]

Urban Transport: Seoul's experience [M]

[E] – available in English

[M] – available in Mandarin

Acronyms and Key Terms

Acronym / Term	Definition
AC Charging	Used to refer to the charging method when a vehicle is recharged by connecting to a vehicle charging point that provides the vehicle with one of the standard alternating current (AC) voltage levels available in a residential or commercial setting (e.g., 240V AC).
Battery Cell	The individual battery units that are then combined with multiple cells into a battery pack which is then installed in an electric vehicle (EV).
Battery Pack	The combination of many individual battery cells to provide sufficient energy to meet the needs of an electric drive vehicle.
Battery Management System (BMS)	The electronics required to monitor and control the use of the battery to ensure safe, reliable operation.
C-Class Vehicle	The term C-Class vehicle is used to refer to a vehicle that is similar in size to a BYD e6 or VW Golf. It is also sometimes referred to as a compact vehicle.
Charge Point	Used to refer to a special electrical outlet with a special plug that is designed to allow safe and reliable charging of an electric vehicle.
DC Charging	Refers to a vehicle charging method where the vehicle is plugged into a battery charger that provides a direct current (DC) voltage to the vehicle rather than the typical AC voltage. DC charging is the emerging approach being used for high power "fast charging" of vehicles.
Discharge Cycles	Refers to the number of times that the battery in an electric drive vehicle provides the full amount of energy that it can store.
Drivetrain	The drivetrain consists of the components in the vehicle that convert the energy stored on the vehicle to the output to deliver power to the road. In a conventional gasoline powered vehicle, the drivetrain consists of the engine, transmission, driveshaft, differential, and wheels. In an electric vehicle, it consists of the motor, driveshaft, and wheels.
Electric Vehicle (EV)	In this document, an EV is a vehicle that is powered completely by an electric motor with the energy being supplied by an on-board battery.
Grid to Vehicle Interface	Used in this document to refer to the communication link between an electric drive vehicle and the power grid when the vehicle is connected for charging. It is intended to enable vehicle charging while minimizing the potential of electrical overload when vehicles are charging.

Acronym / Term	Definition
Hybrid Electric Vehicle (HEV)	Refers to a vehicle that uses both an electric motor and a gasoline engine to power the vehicle.
Internal Combustion Engine (ICE)	An internal combustion engine in this document refers to a gasoline engine used in conventional vehicles today.
Inverter	Part of the electric drivetrain, the inverter is a high power electronic control unit that supplies the voltage and current to the electric motor in an electric drive vehicle.
Kilowatt Hour (kWh)	Unit of energy commonly used in electricity.
Load Management	Means of controlling the amount of electrical power being consumed on the power grid to prevent overload conditions.
New Energy Vehicles (NEV) Program	China's program to foster the development and introduction of vehicles that are partially or fully powered by electricity.
Plug-in Hybrid Electric Vehicle (PHEV)	The PHEV refers to a Hybrid Electric Vehicle that is capable of storing energy from the power grid in the on-board batteries. This differs from an HEV, which does not have the ability to connect to the power grid to store additional energy.
Power Grid	The network of electrical transmission and distribution equipment that delivers electricity from the power generation plant to the individual consumers.
Smart Battery Charging	Used to refer to EV battery charging where the time and speed of charging is managed to ensure that grid resources are used efficiently and that the electric power capacity of the grid is not overloaded.
Smart Grid	Used to refer to a power grid with the ability to electronically communicate with individual electric meters and electrical devices that consume electric power.
Electric Drive Vehicle (xEV)	Used to refer to any vehicle that is driven either partially or fully by electric motors. This includes HEV, PHEV, and EV.

Executive Summary

The China New Energy Vehicles Program
Challenges and Opportunities

The Driving Forces

Within the last decade, the emergence of four complementary megatrends is leading vehicle propulsion toward electrification. The first of these trends is the emergence of global climate change policies that propose significant reduction in automotive CO_2 emissions. The second trend is the rising concerns of economic and security issues related to oil. A third driver for vehicle electrification is the increase in congestion, which is creating significant air quality issues. The fourth trend—rapid technology advancement—has resulted in battery technology advancements to a point where electric vehicles are now on the verge of becoming feasible in select mass market applications.

The industry forecasts suggest that the global electric vehicle sales will contribute between 2 percent and 25 percent of annual new vehicle sales by 2025, with the consensus being closer to 10 percent. As a result of such a transition, there will be a significant shift in the overall value chain in the automotive industry.

Observations on China's New Energy Vehicle Program

In June 2010, the World Bank organized a team of international experts in urban transport, electric vehicle technologies, and policy and environment to carry out a survey study of China's New Energy Vehicle (NEV) Program. The team met Chinese government and industry stakeholders in Beijing and Shenzhen to acquire a better understanding of the Program. The preliminary findings of the study indicate that the scale of China's Program leaves the country well poised to benefit from vehicle electrification. Vehicle electrification is expected to be strategically important to China's future in the following four areas: global climate change; energy security; urban air quality; and China's auto industry growth.

In 2009, the Chinese government initiated the Ten Cities, Thousand Vehicles Program to stimulate electric vehicle development through large-scale pilots in ten cities, focusing on deployment of electric vehicles for government fleet applications. The Program has since been expanded to 25 cities and includes consumer incentives in five cities. Significant electric vehicle (EV) technology development in China is occurring in industry as well as universities, focusing primarily on batteries and charging technology. The new EV value chain is beginning to develop new businesses and business models to provide the infrastructure, component, vehicle, and related services necessary to enable an EV ecosystem.

Identified Challenges for China Going Forward

By comparing the observations on China's New Energy Vehicle Program with other global programs across several dimensions—policy, technology, and commercial models—the World Bank team has identified several challenges for China going forward in the vehicle electrification program.

Policy. The implemented policies related to EV in China mainly focus on the promotion of vehicle adoption by way of introducing purchase subsidies at a national and provincial level. Meanwhile, policies to stimulate demand for EV, deploy vehicle-charging infrastructure, and stimulate investment in technology development and manufacturing capacity also need to be developed. China's recently announced plan to invest RMB 100 billion in new energy vehicles over the next 10 years will need to include a balanced approach to stimulating demand and supply.

Integrated Charging Solutions. Since the early vehicle applications have been with fleet vehicles such as bus/truck or taxi, charging infrastructure technology development in China has focused on the need for fleets. However, as private cars will be fully involved eventually, integrated battery charging solutions need to be developed to cover three basic types: smart charging, standardized/safe/authenticated charging, and networked and high service charging.

Standards. China has not yet launched its national standards for EV. The first emerging standard is for vehicle charging. The full set of such standards should not only govern the physical interface, but also take into consideration safety and power grid standards. To facilitate trade and establish a global market, ideally standards would need to be harmonized worldwide to minimize costs.

Commercial Models. The EV value chain is beginning to develop new business models to provide infrastructure, component vehicle, and related services. It is essential to build a commercially viable business model which bears the cost of charging infrastructure, as the industry cannot indefinitely rely on government funding. It is also likely that revenue collected from services can help offset the cost of infrastructure.

Customer Acceptance. In the long run, consumers will only commit to EVs if they find value in them. Even when the lifetime ownership costs become favorable for EVs, the upfront vehicle cost will still be significantly higher than a conventional vehicle with a significantly longer payback period than most consumers or commercial fleet owners are willing to accept. While leasing could address this issue, a secondary market for batteries would have to be established, in addition to a vehicle finance market, to enable the leasing market to be viable.

GHG Benefits. The biggest challenge faced by China is that the current Chinese electricity grid produces relatively high greenhouse gas (GHG) emissions and is projected to remain GHG-intensive for a significant period of time, due to the long remaining lifetime of the coal-fired generation capacity. A new framework for maximizing GHG benefits in China has to be developed to fully realize the low emission potential of electric vehicles.

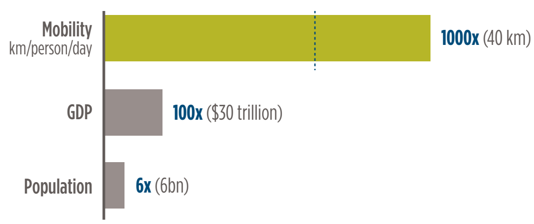
1. Introduction

The China New Energy Vehicles Program

Challenges and Opportunities

The last 200 years have seen a disproportionate growth in human mobility when compared to GDP and population growth. The early 21st century has also experienced marked acceleration in the urbanization of the world's population centers, particularly in the developing world.

Figure 1: **Historic Mobility Growth Factor (1800-2000)**



Source: Diaz-Bone 2005, after Nakicenovic, 2004

With rapid urbanization, travel demand in the cities has grown considerably. This travel demand is increasingly being met by personal motor vehicles while the share of sustainable modes like walking and cycling or the use of public transport has been declining. Today, many cities have to battle traffic congestion and air quality in parallel as urban air quality has deteriorated from the increase in travel demand and an increase in the use of personal motor vehicles.

For many countries that depend on imported petroleum fuels, energy security has also become an important issue. The non-renewable nature of petroleum fuels has resulted in concerns on the long-term availability of oil as well as its price.

More recently, climate change concerns are becoming of primary importance. This is placing further pressure on cities, where a significant portion of transportation-related GHG emissions emanate, to find alternatives to public and personal vehicles that are based on the internal combustion engine.

At one level, efforts are being made to bring about a modal shift toward sustainable forms like walking, cycling, and public transport. Meanwhile, at another level, attention has been focused on using alternative sources of propulsion that have lower emission characteristics, both GHG

Figure 2: **Challenges Facing EV Commercialization Worldwide**

Supply Side	Demand Side
• Large investments will be required in new R&D, industries, and facilities; some by the private sector, some by the public sector • Power distribution and generation capacity increases and "smart charging" will be required • Industry segments that have not traditionally worked together will now have to forge partnerships (e.g., utilities, auto makers, battery makers) • New standards will be required (e.g., charging, safety, disposal of batteries, etc.)	• The high cost of the battery can make an EV 1.5X-2.0X the price of a gasoline vehicle—but the operating cost is 3-4X less, as electricity is cheaper than gasoline • EVs need frequent charging and most can travel ~100 miles or less on a single charge • Charging requires hours not the few minutes required for fuel gasoline vehicles • Not clear whether EVs will be accepted by broad customer segments or remain a niche
Policy	
• Government incentives required to achieve financial viability and break-even volumes/prices for users to shift to EVs	

and criteria pollutants such as particulate matter, than conventional vehicles. The EV has been gaining worldwide momentum as the preferred solution for addressing many of these concerns. Electrification of vehicle propulsion has the potential to significantly ameliorate the local pollution caused by automobiles, and address both energy security and the GHG concerns—albeit not as fully or as quickly as may be needed. Accordingly, China has launched possibly the world's most aggressive program to transition its public and private vehicle fleet to fully electric and electric-gas hybrid vehicles.

Despite significant global activity toward vehicle electrification, commercialization of EVs faces a number of supply, demand, and policy dimension challenges (Figure 2).

In June 2010, a World Bank mission consisting of experts from the Bank's Transportation sector, and outside experts in EV technology, policy, and environment visited China to better understand the Chinese NEV program. This report reflects the learning from several weeks of discussions and workshops with government and industry representatives in China. It details the measures China has adopted in meeting these challenges and identifies future challenges and possible new opportunities associated with a well organized and executed EV program.

Based on this report, possible areas for further strengthening China's EV program have been identified. This report is also intended to help guide other countries in developing similar strategies for a more sustainable future. The following sections are organized in three areas. The first section discusses megatrends that are driving the global trend toward vehicle electrification. The second section addresses the policy, technological, and commercial implications of the NEV program currently being deployed in China. The last section draws comparisons to other programs being implemented around the world and the challenges for China going forward.

2. The Megatrends Behind Electrification of Transportation

Over the last 100 years, the dominant form of automotive propulsion has been the internal combustion engine. While battery electric vehicles have been piloted several times in this period, technology has not historically been able to meet the needs of the mass market consumers and fleet customers. However, within the last decade, the emergence of several complementary megatrends has begun to drive a change toward the electrification of automobiles.

The first megatrend toward vehicle electrification involves the economic and security issues related to oil. Oil prices are expected to rise to approximately US$ 110[2] per barrel by 2020 up from the 2010 price of approximately US$ 75 per barrel.[3] While a sustained increase in price certainly has an impact upon national economies, the greater risk is the volatility in oil prices, which has a significant economic impact, as was experienced during the oil price run-ups in 2010. Meanwhile, several governments have rising concerns regarding the national security implications of importing greater than 50 percent of their oil consumption. As a result, countries are adopting policies favoring new vehicle technologies that reduce fuel consumption. For example, energy security was one of the objectives of the recent US$ 2.4 billion in U.S. stimulus grants targeting alternative propulsion technologies.

A second driver of vehicle electrification is the potential to reduce local pollution caused by vehicles. Reduction in local air pollution in urban areas is a primary benefit in this regard. Electrification shifts local pollution away from distributed mobile sources, which are difficult to regulate and control, and toward point sources, which can be located to minimize human exposure and are more susceptible to policy and technological fixes. In addition, electric drive vehicles are not subject to emission-related deterioration or tampering, which can dramatically increase in-use emissions as vehicles age. To realize these significant air quality benefits in California's polluted urban areas, the California Air Resources Board has maintained since 1990 a "Zero Emission Vehicle" (ZEV) regulation. Under this regulation the major automobile manufacturers, beginning in 2001, have been required to place increasing numbers of battery electric and/or fuel cell electric vehicles in California as a means to accelerate technology development toward commercialization. Similarly, a series of policies have been enacted in London to reduce the air quality impact of vehicles in urban areas by driving the adoption of electric vehicles. These policies include the elimination of congestion tax for EV owners, providing dedicated parking spots for EVs, and investing GBP 20 million for recharging infrastructure.

In addition to their beneficial effect on air quality, electric vehicles reduce or avoid many other environmental impacts caused by conventional vehicles and their fuel. Petroleum production, refining, and distribution create the risk of environmental contamination. For example, in July 2010 a pipeline explosion at Dalian Xingang Port resulted in China's biggest oil spill in recent history, leading to new safety requirements at the nation's ports.[4] Refineries also are estimated to generate 20 to 40 gallons of wastewater for every barrel of petroleum refined.[5]

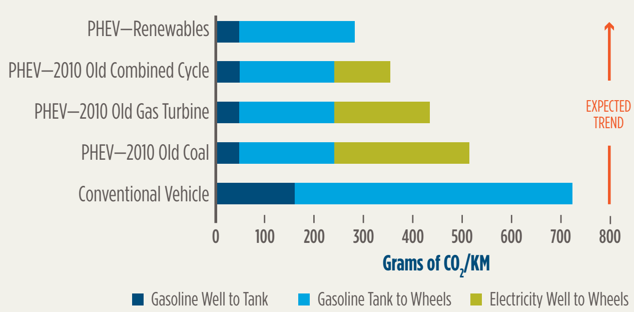
Refineries generate petroleum coke and other waste materials such as spent catalyst. Nuclear and coal-fired electric plants also generate waste. Lithium batteries have the potential for reuse as stationary power storage after they have exceeded their automotive service lifespan, and lithium batteries can also be recycled.

The third trend is the emergence of global climate change policies. For example, as a result of the Kyoto Protocol, significant automotive CO_2 emissions reductions have been proposed around the world. In the EU, the goal is for the average CO_2 emissions for the new vehicle fleet to be below 95g CO_2 / kilometer by 2020[6], which represents a 30-40 percent improvement from today's emission levels.[7] Existing analyses of GHG emissions suggest that actual savings from electric vehicles will depend on a combination of many factors, mainly future improvements in the GHG performance of the conventional internal combustion engine and the carbon intensity of the power generation mix. Issues related to the efficiency of the vehicle and the impact of EVs on the generation mix also have an impact. Preliminary analyses (see Box 1 for results) all suggest that significant GHG savings can accrue from the electrification of the vehicle fleet, particularly with improvements in the carbon intensity of the underlying generation mix, but realizing these benefits will require a deliberate and consistent policy framework combined with a consistent measurement and monitoring system. In this regard, electrification is also in a position to take advantage of the momentum within China, in terms of targets, policy incentives, and consequent investments to decrease the carbon intensity of power generation.

Box 1: **Electric Vehicles and Green House Gas (GHG) Benefits**

For many years, electric vehicles have been viewed as an important element in combating local pollution caused by automobiles. However, as climate change has grown in significance in the sustainability debate, electric vehicles are also increasingly considered to be crucial elements of a climate change mitigation strategy for the transport sector. However, despite this, the estimated GHG impacts of electrification vary significantly across available analyses—most of which are based on U.S. data and assumptions. Figure A summarizes the results of a joint study by EPRI and the NRDC in the United States that found that even with a heavy coal generation mix, there are still CO_2 emissions improvements from plug-in vehicles compared to conventional vehicles in 2010. This study, which evaluates a typical U.S. sized vehicle weighing approximately 1,600 kilograms, assumes fuel economy performance of 10.6 liters/100 kilometers[8] for the conventional vehicle while the electric drivetrain energy efficiency performance is approximately 5.2 kilometers per kWh. The assumed GHG emissions for the "Old Coal" power plant are 1,041 g CO_2 / kWh.

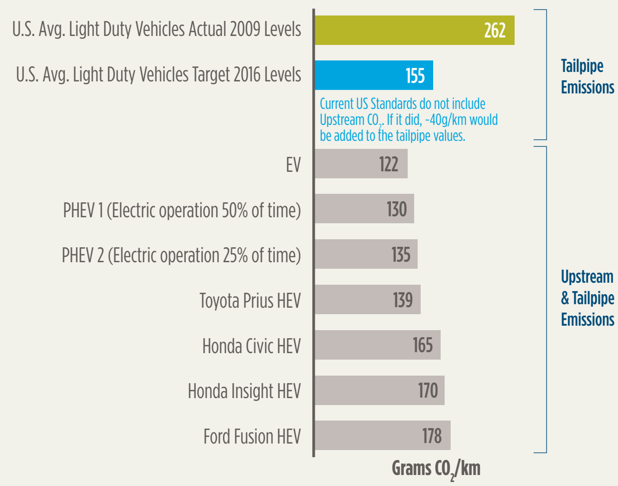
Figure A: **2010 Emissions by Vehicle Technology**



Source: EPRI, NRDC

In all cases, there is an improvement in CO_2 emissions per mile: "well to wheel." While a PHEV that uses renewable electricity (e.g., wind or solar energy) affects a CO_2 reduction of two-thirds, a coal intensive power generation source reduces the well to wheel CO_2 emissions by one-third.

Figure B: **U.S. ICE Tailpipe Emissions vs. xEV [Upstream and Tailpipe] Emissions**



Source: Light Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975-2009, EPA

Federal Register: Light Duty Vehicle Greenhouse Gas Emissions Standards and Corporate Average Fuel Economy Standards Final Rule, May 7, 2010, EPA and NHTSA

Federal Register: Revisions and Additions to Motor Vehicle Fuel Economy Label, Proposed Rule, Sept 23, 2010, EPA and NHTSA

Upstream CO2 levels based on a US national average electricity GHG emissions

Figure B summarizes the results of analyses conducted by the United States Environmental Protection Agency and the Department of Transportation in connection with the recently announced 2012–2016 vehicle emissions laws. Their studies indicate that the current ICE dominated U.S. light duty vehicle fleet average in 2009 had significantly higher tailpipe CO_2 emissions than both EVs and PHEVs of more than 260 grams of CO_2/km. The target set in the new laws for 2016 is a value of 155g of CO_2/km for the fleet average, a significant reduction.

As upstream CO_2 for ICE fleets is not included in the current U.S. 2009/2016 standards, the values exclude them. If they included them, it is estimated that approximately 40g/km would be added to the tailpipe values.

By comparison, xEVs offer a distinct advantage when compared to the ICE fleet average ranging from ~15 percent better than the 2016 target for EVs to some 15 percent worse than the average for Hybrids. This study assumes that the electricity generation CO_2 emissions are equivalent to the 2005 U.S. average of 642 g CO_2 per kWh and that the electric vehicle efficiency is 8 kilometers per kWh.

An analysis with Chinese data[9] suggested that, in China, as elsewhere, the GHG benefits of EV vehicles depended on the energy efficiency of coal-fired power plants and the coal share of the generation mix. Assessing the current generation mix and plant efficiency, the study suggests that currently EVs are likely to realize carbon benefits relative to conventional vehicles in the south, central, and northwestern regions of China, where coal accounts for 65 percent to 77 percent of the mix. However, as plant efficiency (the study uses 32 percent nationwide) and the renewable share of the generation mix increase (and there are considerable policies, investments, targets, and programs in place toward these ends), the study suggests that the GHG benefits of vehicle electrification could be considerable.

In general, the assumptions underlying this analysis are similar to the U.S. studies. However, there are differences in the assumptions for vehicle efficiencies. For example, the 2008 gasoline vehicle fuel efficiency of approximately 9.2 liters/100 kilometers is higher than the first U.S. study above, while the electric vehicle energy consumption of approximately 4.2km per kWh is lower than the first study above. Taken together those assumptions tend to reduce the estimated GHG benefits of electrification as compared to the U.S. study.

Building on the Tsinghua University work noted above, the Innovation Center for Energy and Transportation (iCET) has calculated, for seven electrical grids in China, the GHG emissions per mile that would result from operation of a Nissan Leaf™. Their results are as follows:

Power Grid	Lbs CO_2/MWH at plug	Leaf g/km
North China	2723	261.0
Northeast	2712	260.0
East China	1960	188.1
Central China	1810	173.5
Northwest	2022	193.8
South China	1863	155.3
Hainan	2124	178.6

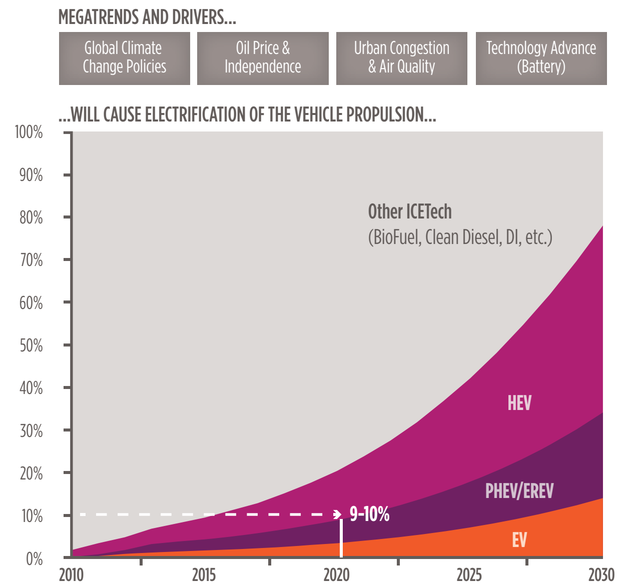
Source: iCET Analysis

Based on calculations from iCET, the Chinese fleet average GHG emission rate for 2009 for major domestic and multinational car manufacturers was about 179g/km or about 219 g/km assuming that upstream emissions account for 18 percent of total GHG emissions. Thus, in five of the seven regions shown above, the Nissan Leaf GHG emissions are lower than the 2009 Chinese fleet average.

The first three trends create a need for clean, efficient vehicles. Meanwhile, a fourth trend of rapid technology advancement has resulted in battery technology progressing to a point where electric vehicles are now on the verge of becoming feasible in select mass market applications. The advent of lithium-ion batteries has driven a significant increase in energy density from the Lead Acid batteries used in the first generation of EVs in the 1990s. As a result, a Nissan Leaf battery at 24 kWh and 218 kilograms has more capacity and less than half the mass of the Gen1 EV 1 battery at 19 kWh and 595 kilograms. Furthermore, the cost of batteries is expected to drop by more than 50 percent by 2020, which will enable electric vehicles to rival gasoline vehicles on a total cost basis.

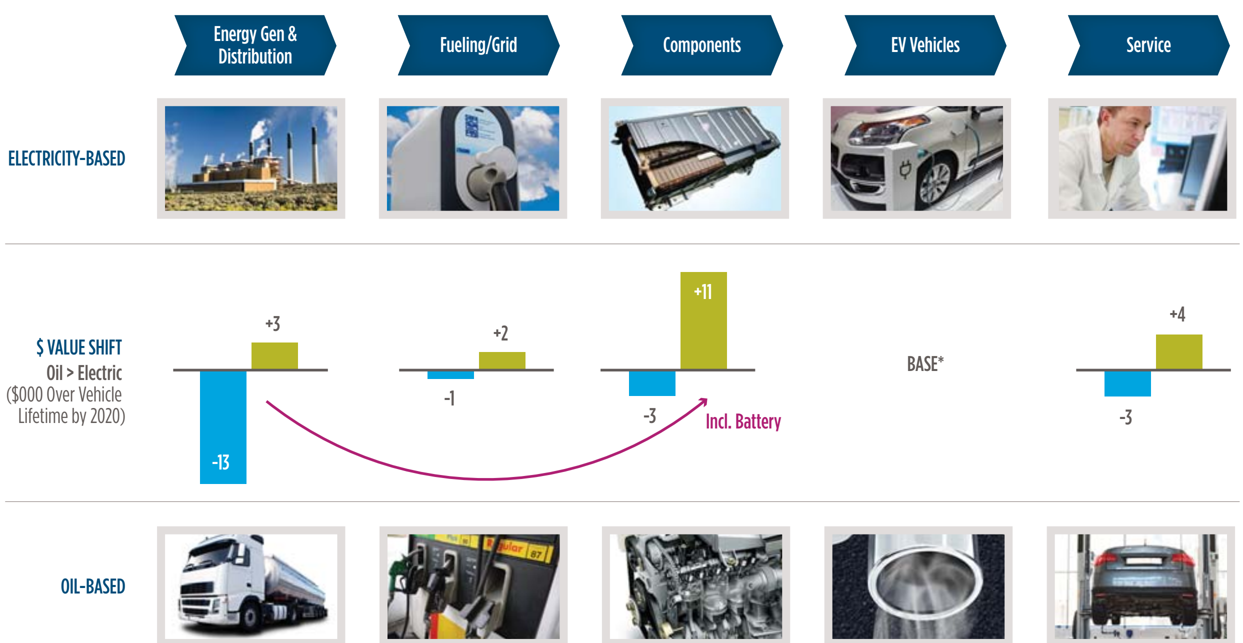
As a result of these trends, the growth of electric vehicles over the next 10 years is expected to be significant. The industry forecasts suggest that global plug-in vehicle sales will contribute between 2 percent and 25 percent of new vehicle sales. The consensus is that it will be closer to 10 percent but, while the forecasts vary widely in magnitude, they all represent a significant shift from the current industry powered almost exclusively by fossil fuels (Figure 3).

Figure 3: **Forecast Mix of Vehicle Technologies through 2030**



Source: PRTM Research, OICA (International Organization of Motor Vehicle Manufacturers), various analyst reports, interviews

Figure 4: **The Value Chain Displacement from Oil to Electric Power (2020)**



Source: PRTM Analysis

As this transition to vehicle electrification occurs, there will be a significant shift in the overall value chain. In the traditional automotive value chain, as shown in Figure 4, the majority of the value is created upstream in the energy generation and distribution element of the value chain.

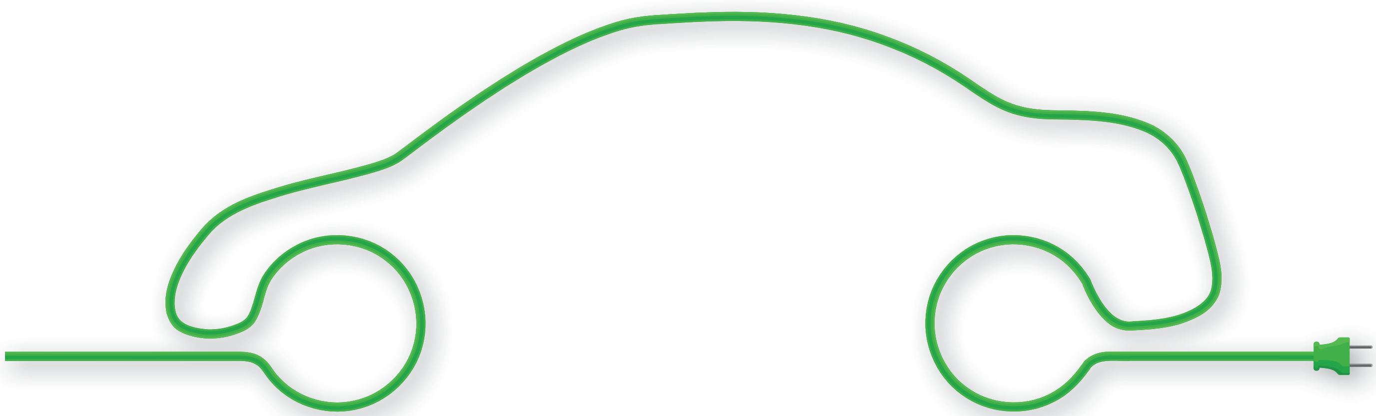
The lifetime value capture for a typical C-Class vehicle sold in 2020 will be about US$ 13,000 from sale and distribution of gasoline. For the same vehicle with an electric drivetrain, the lifetime energy and distribution costs reduce significantly to approximately US$ 3,000 over the life of the vehicle. In this case, the value capture will shift to the drivetrain components where there will be approximately US$ 11,000 per vehicle spent on the battery, motor, and inverter.

The amount of change electrification will cause in the engineering of vehicles will go beyond the creation of a new value chain (Figure 5).

Vehicles that are 70 percent mechanical and 30 percent electronic in value today will likely become the inverse—20 percent mechanical and 80 percent electrical/electronic. Primarily, steel structures will undergo large-scale substitution of composite, aluminum, or other lightweight materials. Vehicles will become more networked and connected while intelligent transportation systems will become the foundation of sustainable transportation solutions. These shifts in technology and the overall value chain will likely have significant impact on the industry structure and possibility for mobility paradigms in future cities (Box 2).

Figure 5**: The Automotive Industry Changes Driven by Vehicle Electrification**

TODAY		2020+
70% Mechanical/30% Electrical and Electronic	→	20% Mechanical/80% Electrical and Electronic
Primarily Steel Structures	→	Composite and Lightweight Materials
Limited Vehicle to "X" Communications - Navigation - Telematics (Accident Notification/Concierge)	→	Significant Vehicle to "X" Communications - Vehicle to Grid - Traffic Management/Vehicle Guidance - Car to Car Accident Avoidance - Interactive Entertainment and Productivity Systems



Box 2: **Sustainable Electric Mobility: a Paradigm Shift for Vehicle Technology and Urban Mobility**

The widespread introduction of electric vehicles will address a number of problems related to current automobile-dependency in cities, such as excessive fossil fuel and energy use, local air and noise pollution, and carbon emissions contributing substantially to climate change. However, a number of problems related to urban congestion, peripheral sprawl, and inefficient land-use will not be addressed without a more radical reinvention of urban personal mobility systems.

The shift from combustion to electric vehicle technologies provides a unique opportunity to rethink mobility issues within cities and foster the introduction of a new generation of mobility options that reflects innovation both in terms of technology and business models relative to the current dominant mobility paradigms. While very much speculative at present, academics as well as corporations are investigating the possibilities of an EV powered world. Small electric vehicle parking facilities could be developed at transit stations and other major destinations around an urban area. Vehicles automatically recharge while at these facilities and could be easily picked up with a simple swipe of a card and dropped off at locations close to any destination. Information on vehicle availability could be shared through widely available wireless networking systems and the energy for these vehicles could be generated with solar-friendly, wind-friendly, fuel-cell-friendly smart electrical grids. There are a number of attractive business models being proposed and the current socio-economic climate is increasingly promising for the introduction of an integrated electric vehicle and sustainable mobility systems in cities.

Variations range from GM's "electric networked vehicle,"[10] a small lightweight future vehicle showcased at the Shanghai 2010 Expo, conceptually envisioned to be integrated with public transport and neighborhood mobility constraints, to a vision developed by researchers at the University of California[11] of developing a stand-alone lightweight mobility system on a city-wide scale with both infrastructure and vehicles completely separated from the traditional, heavier weight automobile and heavy vehicle infrastructure. In all cases, the prospects for change rest on a combination of technological and business innovation—building mobility-on-demand systems using smaller, well-designed, and more efficient lightweight electric vehicles, such as mini cars, scooters, and electric bicycles that are effectively integrated with mass transit systems and focus on providing neighborhood-level access to key services and destinations.

3. Observations on China's New Energy Vehicles Program

A significant amount of activity is focused on EVs in China. From policy development, to technology development, to new business models, China is very well advanced in the deployment of electric vehicles. The following summary of China's status in EV deployment is based on a World Bank mission undertaken to better understand China's New Energy Vehicle program. A team of experts commissioned by the World Bank in transportation, electric vehicle technologies, policy, and environment visited Chinese government and industry stakeholders in Beijing and Shenzhen in June 2010. The two-week mission concluded with a workshop attended by many public and private sector stakeholders. As such, the study reflects the understanding gained by the mission team and is not intended to be a comprehensive summary of all EV related activity in China.

3.1 A policy framework for considering public support for electric vehicles

Many would consider the development of electric vehicles a completely commercial phenomenon, akin to the evolution of color or high-definition televisions and query why governments or institutions like the World Bank should focus at all on this sector. Undoubtedly, private commercial players motivated by market interests will be critical to any meaningful deployment of such vehicles. However, there are at least three kinds of reasons to consider policy, and possibly financial support to accelerate and support the deployment of electric vehicles:

- *External "Pigouvian" benefits.* Substituting internal combustion vehicles running on fossil fuels such as diesel or gasoline with electric vehicles has the potential to reduce the emission of local pollutant and green house gas emissions. Economic theory suggests that vehicles generating pollution should be charged with a "Pigouvian"[12] tax to the equivalent of the local and global pollution burden they generate.[13] To the extent that electric vehicles do not generate these costs, public support—ideally an appropriately lower Pigouvian tax (or an equivalent level of support)—would not be unreasonable under such circumstances. Ideally the support should be structured in ways that promote the development of markets, address market failures, and complement rather than substitute for private initiatives.
- *Impact on other public infrastructure.* Electric vehicles will interact with regulated (and, in many cases, publicly provided) infrastructure in ways that will require careful planning and management. In particular, there are significant opportunities and issues related to the interaction between electric vehicles and the electric grid. On one hand, there is potential for significant benefits: For instance, off-peak charging of EVs could smooth out the overall demand for electricity, thus increasing efficiency of the grid. At the same time, there are significant risks associated with not planning the transition carefully. In the worst case, if significant numbers of EVs charge during peak periods, it would stress the electric grid, and reduce grid efficiency by exacerbating peaking.
- *Transformative effects on public infrastructure.* EVs also offer an unusual opportunity to potentially transform the manner in which urban mobility is configured. As Box 2 discusses, EVs offer a rare opportunity to transform urban street and road infrastructures —facilitating the development of specialized, lower-impact vehicle-street systems for neighborhoods, commuting, and so forth—with associated benefits for safety, mobility, and accessibility.

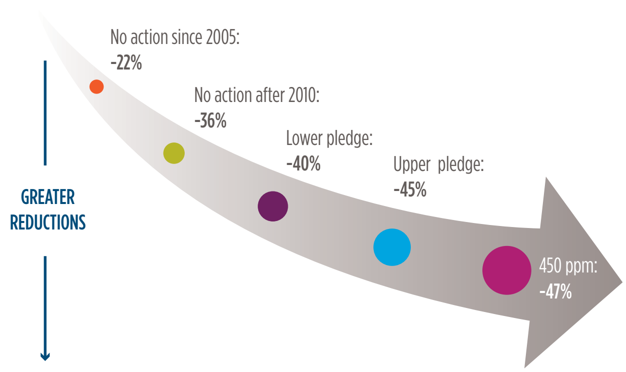
In addition to these kinds of public benefit rationales, governments may take into account other considerations, such as energy security policy and automotive industrial policy. In China, such considerations are particularly relevant given the combination of a large, fast-growing market for automobiles combined with the sizeable and increasing automotive manufacturing capability in the country.

3.1.1 Strategy

China has indicated that vehicle electrification is a strategically important element to its future development in four areas: (i) global climate change; (ii) energy security; (iii) urban pollution; and (iv) auto industry growth.

- *Global Climate Change:* China is committed to policies to address climate change and has announced a target to lower its carbon intensity, the amount of carbon dioxide emitted per unit of GDP, by 40-45 percent by 2020 compared to a 2005 baseline (Figure 6).

Figure 6: **China's Carbon Intensity Reduction Plans**



Source: CHINA NDRC

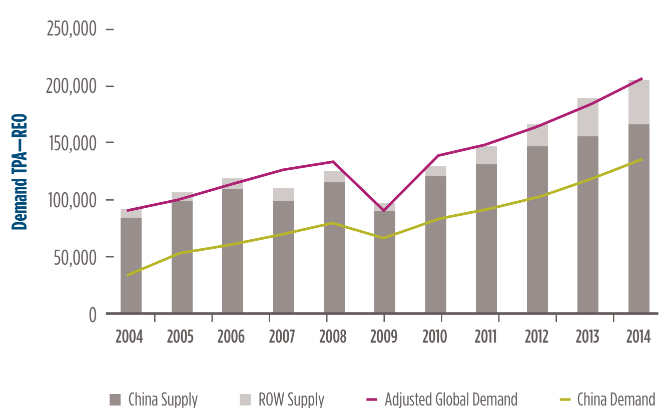
- *Energy security:* Half of China's oil is imported. In 2007, China's oil consumption was 7.6 million barrels of oil per day. By 2020, this is expected to increase to 11.6 million barrels of oil per day. In this same period, global oil consumption will increase from 85 million to 92 million barrels per day.[14]
- *Urban pollution:* While power generation accounts for a large portion of the CO_2 emissions in China, large cities such as Beijing have significant transportation-related air quality issues. For example, in Beijing, it has been estimated that more than 70 percent of CO and HC emissions are caused by transportation.[15] This issue, which put significant restrictions on motor vehicles in the city during the 2008 Olympic Games, is expected to worsen as the number of vehicles in Beijing increases.
- *Auto Industry Growth:* Chinese automotive production in China in 2009 was 13.6 million vehicles,[16] making China the largest auto producing nation in the world with continued production growth expected to reach 30 million vehicles per year by 2030. While this production growth is significant, its bulk currently feeds domestic demand. Although there have been recent acquisitions of niche global brands such as Volvo and Rover by Chinese automakers, it is unlikely that these brands will transform China into a large-scale exporter. Due to the significant technological and scale advantages that the established global automotive manufacturers have in internal combustion engines, it is also unlikely that Chinese automakers will be able to organically establish a strong global presence.

While high barriers to entry will likely prevent Chinese automakers from developing a significant global position in an industry where internal combustion engines are the dominant propulsion source, electric propulsion will introduce a value chain shift that could favor China from both a technological and supply chain perspective.

China is likely to benefit in the EV drivetrain components value chain. This is largely due to China's strength in batteries and motors. For example, as one of the major players in lithium batteries for cell phones, China has established the production capability and value chain to cost-effectively produce lithium batteries in scale.

In addition, China also possesses an advantage in electric motors, which is partly due to its position as the dominant producer of rare earth, as shown in Figure 7. Rare earth materials, specifically neodymium, contribute approximately 30 percent[17] of the material cost of permanent magnet motors, one of the key motor types used in electric propulsion systems. This raw material dominance, along with China's relative labor cost advantage, has resulted in an emerging extended supply chain in motor technology and production.

Figure 7: **Global Rare Earth Material Production**



Source: D. Kingsworth, Industrial Miner

The result of these advantages in batteries and motors could provide an overall advantage for Chinese companies in electric drivetrain components and may position Chinese automakers to assume global leadership in electric vehicles.

3.1.2 Program Scope

In 2009, the Government of China initiated the Ten Cities, Thousand Vehicles Program. The intent of this program was to stimulate electric vehicle development through large-scale pilots in ten cities that would identify and address technology and safety issues associated with electric vehicles. The ten cities included in the initial program rollout were: Beijing, Shenzhen, Shanghai, Jinan, Chongqing, Wuhan, Changchun, Hefei, Dalian, and Hangzhou. In this program, each city was challenged with rolling out pilots of at least 1,000 vehicles. To manage the early driving range and infrastructure issues of EVs, the initial focus for the program was on government fleet vehicles with predictable driving patterns such as buses, garbage trucks, and taxis. Following the rollout of the initial ten cities, the program was expanded twice—first to Changsha, Kunming, and Nanchang and then to Tianjin, Haikou, Zhengzhou, Xiamen, Suzhou, Tangshan, and Guangzhou.

Building on the Ten Cities, One Thousand Vehicles program, which was focused on deployment of electric vehicles for government fleet applications, the program was expanded to include consumers in Shanghai, Changchun, Shenzhen, Hangzhou, and Hefei in June 2010. To encourage EV adoption by consumers, the central government of China has also introduced purchase subsidies of RMB 60,000 per vehicle for Battery Electric Vehicles (BEV) and RMB 50,000 per vehicle for Plug-in Hybrid Electric Vehicles (PHEV). These subsidies are being enhanced for consumers by additional subsidies at the state level. For example, in Shenzhen, additional subsidies of RMB 60,000 for BEV and RMB 20,000 for PHEV are being offered, resulting in total consumer purchase subsidies of RMB 120,000 for BEV and RMB 70,000 for PHEV.

The New Energy Vehicles program continues to grow and evolve virtually daily. Most recently, it has been announced that these programs will be backed by RMB 100 billion in central and local government investment. This is a significant increase from earlier statements and sets a new threshold on the world stage.

3.1.3 Standards

Development of common national standards for charging infrastructure, vehicle charging methods, vehicle/charger connectors, battery cells, charging network communications, charging network billing, and standards development were not initial areas of focus during the Ten Cities program. In the absence of national standards, local approaches were developed in the different pilot implementations.

The local approaches that were developed are beginning to be evaluated for the development of national standards with the first to emerge being the standard for vehicle charging. Led by the Ministry of Science and Technology, infrastructure companies, automotive component suppliers, and automakers are collaborating to develop a national standard for the charging method and connector. While not yet finalized, State Grid has joined with industry to develop a seven-pin vehicle/charger connector that will enable both AC and DC charging. Other standards for battery cells and network communications are yet to be developed.

3.2 State of Technology

Significant EV technology development in China, focused primarily on batteries and charging, is occurring in industry as well as universities. However, technology is also being developed for motors, power electronics, and overall vehicle integration.

3.2.1 Battery

As one of the global leaders in lithium-ion batteries for cell phones, China has a strong foundation for lithium-ion battery technology, which is being used to generate solutions to the key issues in the application of lithium-ion batteries in EV traction drive systems. The primary issues being addressed, as in the rest of the world, are battery cost and life.

Based on the industry stakeholder discussions held in June 2010, the 2010 production costs for lithium-ion battery packs in China appear to be between RMB 3,400 and RMB 5,000 per kWh. For a typical C-Class vehicle with a 25 kWh battery, this will result in new vehicle battery costs between RMB 84,000 and RMB 125,000—close to the cost of a typical C-Class car with a gasoline engine. Since this upfront expense will be a significant purchase barrier for most consumers, emphasis is being placed on reducing battery costs through material development and operations optimization. Through these developments, battery manufacturers in China expect costs in 2020 to be reduced by approximately 60 percent to between RMB 1,300 and RMB 2,000 per kWh. This will reduce the cost of a typical new vehicle battery to between RMB 34,000 and RMB 50,000.

Due to the high cost of batteries, battery life is also a critical consideration. In-vehicle battery life is currently expected to be approximately three to five years, or around 160,000 kilometers. Since the typical life expectancy of the major components in conventional vehicles is more than 240,000 kilometers, battery life will likely need to be improved by approximately 50 percent to meet the needs of most vehicle owners.

3.2.2 Vehicle

One of the key areas of vehicle technology development, as a result of the Ten Cities program, has been electric transit buses (Figure 8). These buses, which are currently operating in cities such as Beijing and Shanghai, have been developed to meet the high energy and high duty cycle requirements of the transit bus market. For example, the 50 buses operating in Beijing, produced by Zhongtong Bus Holding Co., Ltd., have seating capacity for 50 passengers and a 200 kilometer nominal range with a maximum speed of 70 kilometers per hour. To meet the needs of this application, the buses have 171 kWh lithium-ion batteries.[18]

Figure 8: **Beijing EV Bus**

Source: Zhongtong Bus Holding Co., Ltd.

Figure 9: **BYD E6**

Source: BYD

Another area of vehicle technology development has been the development of passenger cars targeted for use by consumers as well as use in fleets such as taxis.

One example is the BYD E6 (Figure 9). While most electric vehicles being developed globally have a driving range of approximately 160 kilometers, the E6 has a driving range of 300 kilometers.[19] This driving range, which approaches the 480 kilometer range of a typical gasoline car, will enable use for many taxi applications as well meet the expectations of a large number of consumers. The enabler for such a driving range is the vehicle's large 62 kWh battery. While such a battery is cost prohibitive for most vehicle manufacturers, it is likely that BYD is leveraging its cost position as a large volume lithium-ion battery producer to provide a vehicle that addresses one of the biggest EV consumer concerns—range anxiety.

3.2.3 Infrastructure

Since the early vehicle applications in China have been with fleet vehicles, the charging infrastructure technology development has focused on the needs of fleets. Due to their high utilization rate, many fleet applications will drive more than the standard range that the current batteries will allow on one charge. For example, the EV buses in Beijing have a maximum driving range of 200 kilometers on a full charge. However, with a safety margin they are currently limited to driving 100 kilometers on a full charge. As a result, since many of the buses exceed this on a daily basis, they need to be recharged throughout the day. To ensure that the buses maintain a high operating up-time, these buses must be recharged quickly.

One approach being utilized in Beijing to achieve high operating up-time is a rapid battery exchange system whereby the bus pulls into a battery swap station and robotic battery removal systems locate and remove a battery pack on each side of the bus. Next, the system locates and returns the batteries to an open spot in the vertical battery charging banks positioned along walls facing each side of the bus. Following this, the next available fully charged battery pack is located from the charging bank, removed, and placed in each open battery bay on the bus. The entire battery exchange takes approximately 12 minutes from the time the bus enters the station to the time it can return to service.

To ensure that fully charged batteries are always available when a bus returns to the battery swap station, the supply of extra batteries maintained at the station equals 60 percent of the number of the batteries in the field. For example, for 50 buses, 80 batteries are needed in the swap stations. To charge these batteries, the battery swap station consists of 240 9 kW chargers to simultaneously charge the batteries returned from the field. To manage the large amount of power consumed by the chargers and the impact on the electrical grid, a load management model has been employed to optimize charging speed and balance load power.

Figure 10: **180kW Fast Charger in Shenzhen**

Figure 11: **220V Charger in Shenzhen**

In addition to rapid battery exchange, another approach being utilized to meet the needs of fleet applications is fast-charging. In Shenzhen, for example, there are two public fast charging stations in operation with plans for an additional station to be completed by the end of the year. Each of the two stations currently operating has three chargers, each with a power capacity of 180 kW, which will be capable of recharging a taxi in 10-30 minutes (Figure 10). Plans have been announced for similar charging stations across the country, with 75 charging stations to be installed in 27 cities by the end of 2010.[20]

There is also deployment of slower, lower power charging infrastructure suitable for overnight charging. In Shenzhen, 100 charge points with standard 220V outlets have been deployed around the city (Figure 11). These charge points have network communications to allow authentication, billing, and diagnostics. Currently, they are being installed in clusters at charging stations.

3.3 Commercial Models

To accomplish the Ten Cities, Thousand Vehicles Program, there has been a significant level of development and coordination across the value chain. This is beginning to develop new businesses and business models to provide the infrastructure, component, vehicle, and services necessary to enable an EV ecosystem.

In order to deliver electric vehicles to the market in China, new vehicle value chains are emerging to address the technology and manufacturing gaps that the existing automotive value chain holds for EVs in China. One example of such an emerging value chain is being developed by China's fifth largest automaker, Beijing Automotive Industry Holding Corporation (BAIC). To drive the development of electric vehicle technology, BAIC has created a separate company, Beijing New Energy Vehicle Company, focused solely on electric vehicles. This company, which has plans to build 150,000 EVs and HEVs by 2015, has established relationships with global companies and is developing new local companies to enable these plans. For example, the company's announced acquisition of vehicle platform designs from Saab is now serving as the basis for its mid- and high-level EVs. Beijing New Energy Vehicle Company is internally developing the control and electric drive systems and has formed a separate company, Beijing Pride Power System Technology Co., for the development of battery systems. Beijing Pride Power System Technology Co. is responsible for developing the integrated battery systems, including the full pack and battery management system.

In parallel with the development of the vehicle and component value chain elements, it is essential that a new value chain be built for the development, deployment, and operation of the vehicle recharging infrastructure

Figure 12: **Extended EV Value Chain**

(Figure 12). Such a value chain requires involvement of many stakeholders. First, the utility is required to ensure that the introduction of new electrical loads on the grid does not create disruptions. Second, smart grid technology providers need to be involved in the development and production of the new recharging equipment and network backbone. Additionally, the original equipment manufacturers (OEMs) and battery management systems suppliers need to manage the tradeoffs between the infrastructure and vehicle battery system necessary to optimize the battery charging system. An example is the Beijing bus battery exchange stations, which included multiple value chain stakeholders. A bus operator, Beijing Public Transport, was involved in determining the new operating modes for the EV bus fleet. A utility, State Grid, managed the overall impact on the grid from charging the large bus batteries. A battery supplier, CITIC Guoan MGL Battery Co., assessed the overall impact on the battery life of different charging methods. Battery management systems architect, Beijing Technology University, determined the approach for charging the batteries that balanced the local grid load constraints with the operating requirements for bus up-time. Finally, bus manufacturer Zhongtong Bus Holding Co. determined how to package the batteries in the bus so that they could be removed automatically and be packaged to allow the bus safety and comfort requirements to be achieved (Figure 13).

Figure 13: **Beijing EV Bus Exchangeable Battery Pack**

Source: Lithium Force Batteries

In addition to the vehicle and infrastructure, new service business models will emerge in the value chain. The Beijing bus pilot also serves as an example of such new service models. Due to the significant upfront cost of the batteries for buses, a leasing model was deployed by the battery manufacturer, CITIC Guoan MGL Battery Co, in conjunction with the bus operator, Beijing Bus Group. The batteries are leased from CITIC Guoan MGL Battery Co, based on the distance driven. In addition to the battery supplier and the bus operator, this model also requires the involvement of other value chain stakeholders. For example, since the battery management and recharging systems are critical determinants of how the battery will age over time, collaboration with the technology provider, Beijing Technology University, was required to determine how the battery would age and the likely rate of depreciation.

4. Discussion and Conclusions

4.1 Comparison with Other Programs Worldwide

Arguably, the scale of the New Energy Vehicles Program leaves China well placed in the context of worldwide vehicle electrification. Yet, significant efforts underway elsewhere have put many electric vehicles on the road around the world. This section details some of those competing initiatives across several dimensions, including policy, technology, and commercial models, and compares them with the Chinese program to help define areas of opportunity.

4.1.1 Policy

From a policy perspective, China is very developed in the implementation of policies to drive electric vehicle adoption. However, there is now strong momentum in policy development in many other countries to stimulate demand for electric vehicles, deploying vehicle recharging infrastructure, and stimulating investment in technology development and manufacturing capacity. These policies are emerging in several forms. One form involves government spending for manufacturing and research through grants, loans, and tax credits. A second emerging form consists of infrastructure deployment with governments providing grants and loans for the deployment of charging infrastructure. To stimulate demand for the vehicles, several national and local governments are implementing policies providing government subsidies or tax credits toward the purchase of such vehicles. In addition to monetary policies, several non-monetary policies are emerging targeting vehicle manufacturers and consumers. These policies include extra credit for vehicle manufacturers in calculating fuel economy for meeting national requirements as well as preferred parking and driving lane access.

The United States provides one example of a comprehensive set of such policies. As shown in Figure 14, more than US$ 25 billion in loans for advanced auto manufacturing and more than US$ 2 billion grants for batteries have been deployed.

Additionally, US$ 100 million is being distributed for infrastructure deployment in a five-city electric vehicle pilot program. Furthermore, federal subsidies of up to US$ 7,500 per electric vehicle are in place with additional incentives available in some states.

In the United States, a large portion of the policymaking has been at the national level with some additional policies at the state and city level. The focus of these policies has been to stimulate consumer demand, provide a catalyst for infrastructure deployment, and to drive U.S. auto industry investment to maintain global competitiveness. In

Figure 14: **U.S. Government EV Policy Summary (2010)**

	Incentives	Financial	Non-Financial
Manufacturing/ R&D Investment	• $25 billion for an Advanced Technology Vehicle Manufacturing Incentive program to technology that achieves 25% higher fuel economy • $2.4 billion in grants for electric vehicle development in March 2009	X	
Infrastructure Investment	• $400 million for demonstration projects and evaluation of plug-in hybrid and electric infrastructure • $54 million for tax credits on alternative refueling property, including charging • $100 million grant for 5-City “EV Project” infrastructure deployment	X	
Vehicle Purchase	• $7,500 consumer tax credits for new purchase of PHEV/EV • Additional state level purchase incentives up to $5,000 for PHEV/EV	X	
	• Many states provide HOV lane access, designated parking space programs		X

Figure 15: **UK EV Policy Summary (2010)**

	Incentives	Financial	Non-Financial
Manufacturing/ R&D Investment	• £350 million for research and demonstration projects	X	
Infrastructure Investment	• Planned £20 million procurement program, 25,000 charging points in London	X	
Vehicle Purchase	• Private electric vehicles are exempt from annual circulation tax • Company electric cars are exempt for the company car tax for first five years after purchase • Starting from 2011, purchasers of electric and PHEVs will receive a discount of 25% of vehicle list price with a cap of £5,000; the government has set aside £230 million for the incentive • Electric vehicles are exempt from congestion charging	X	
	• Planned dedicated bays for electric cars in London		X

other countries, such as the UK, there is a much stronger policy emphasis at the city level (Figure 15). In London, for example, there have been a number of policies deployed that are developed to drive EV adoption and fund the local infrastructure deployment. London has announced a plan to invest GBP 20 million for deployment of 25,000 charging points within the city. To drive consumer demand, London has waived the congestion charge for EVs driving within the city.

Policies aimed at reducing GHG and criteria pollutant emissions from electricity generation are also important in order to fully realize the potential of NEVs. Here the global track record is mixed. The EU has in place an emission cap covering GHG emissions from the power sector. There is no similar comprehensive GHG policy in place in the United States, although individual regions and states have moved forward with power sector emission caps or requirements for increased use of renewables.[21, 22] As noted above, China has announced a target to lower its carbon intensity by 40-45 percent by 2020 compared to a 2005 baseline. Achieving this ambitious goal will help to reduce the carbon intensity of the electricity used to power NEVs.

4.1.2 Technology

China's relative position in EV technologies, as compared to the United States, Europe, Japan, and Korea, parallels its overall position in the global automotive industry.

Battery Technology. China has clearly become the leader in Li-ion battery manufacturing for consumer products. Probably more than half of the world's supply of Li-ion phone, smartphone, and laptop batteries are manufactured in China.

In large form factor automotive batteries, the challenge is greater in the "upstream" materials, such as the cathode materials and the process controls in preparing the materials (Figure 16). That technology has historically been perfected by the Japanese and, more recently, the Korean chemical industries.

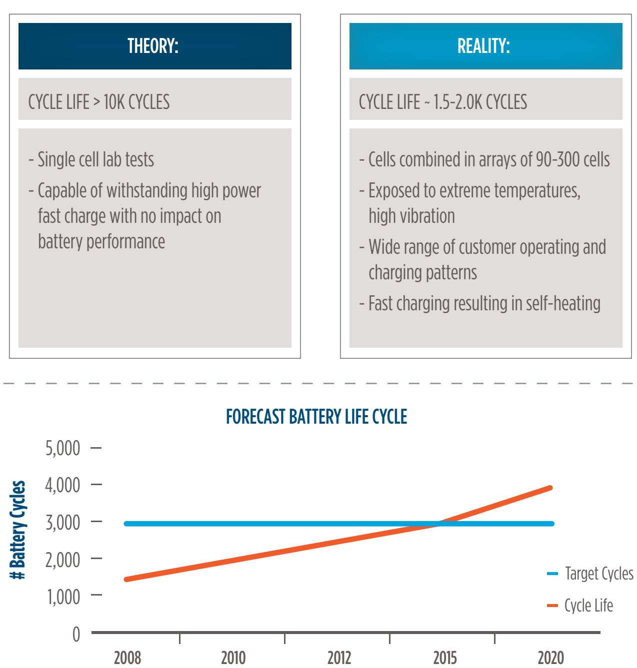
Higher levels of quality in the upstream materials have a large bearing on the life of the battery, as represented by the number of discharge cycles a battery can tolerate before losing its ability to fully charge. In automotive applications, the goal is ~1,500-2,000 discharge cycles to support 8-10 years of use in a typical car. The Chinese battery manufacturers aim to achieve these targets and there are not yet sufficient vehicles on the road to validate these levels.

While Li-ion battery technology is progressing, achieving OEM battery life targets of 10 years/240,000 kilometers (~3k battery cycles) will likely take further development and it could require another decade before those levels are achieved (Figure 17).

Figure 16: **Upstream Li-ion Battery Advanced Materials Supply Chain**

Source: PRTM Analysis

Figure 17: **Outlook for Li-ion Battery Life Cycle Performance**



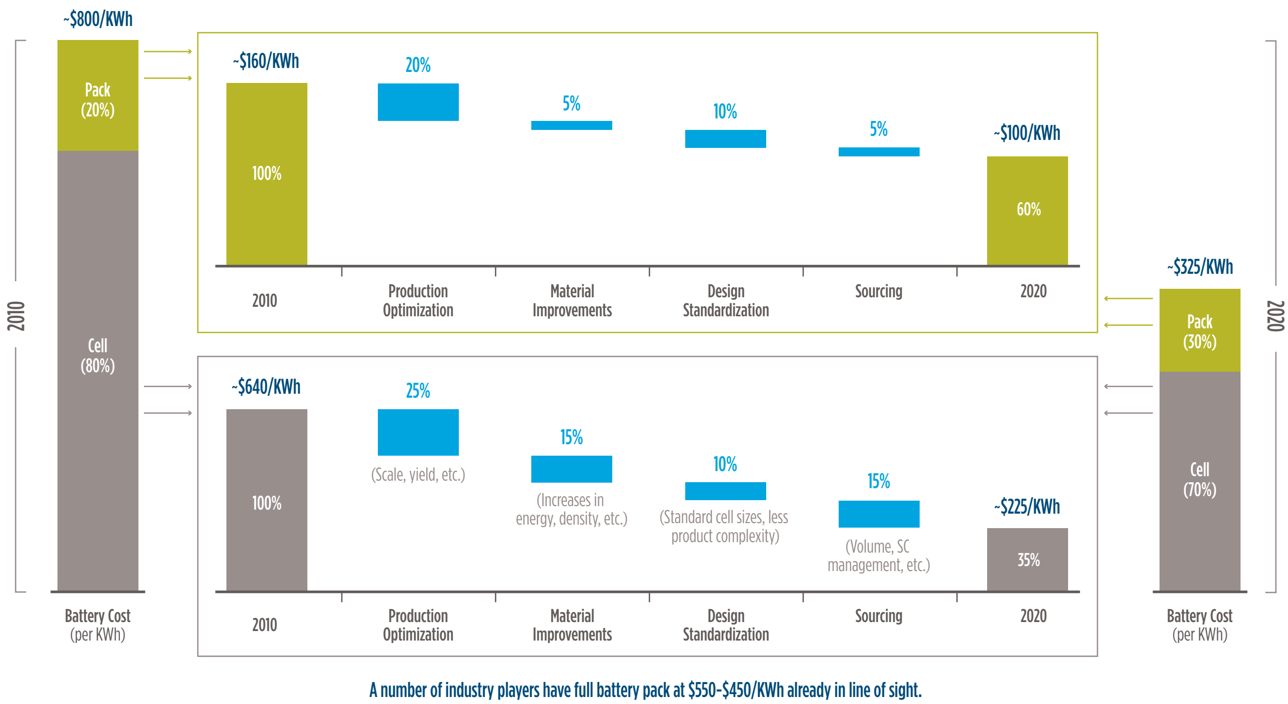
Source: PRTM Analysis, OEM Interviews

The next issue to be addressed after battery life is battery costs. As discussed earlier, battery costs currently may be 50 percent of the cost of a vehicle. China has been among the leading sources of competitive cost batteries as the industry scales up for mass production of large form factor batteries for EV applications.

Though there is much debate, there is growing consensus that Li-ion battery costs should be 50 percent lower than they are today within the next decade. Some sources argue that the cost reductions will in fact be closer to 70 percent. As shown in Figure 18, this cost reduction will come from a combination of improvements in production processes, materials, design standardization, and supply chain actions.

These forecasts are corroborated by the cost-down curves that have been experienced in the last 20 years in the photovoltaic sector for solar applications, as shown in Figure 19. Photovoltaic technology costs have been reduced by 70 percent in the last 20 years as volumes have scaled, with some two-thirds of the cost reductions occurring in the first 10 years.

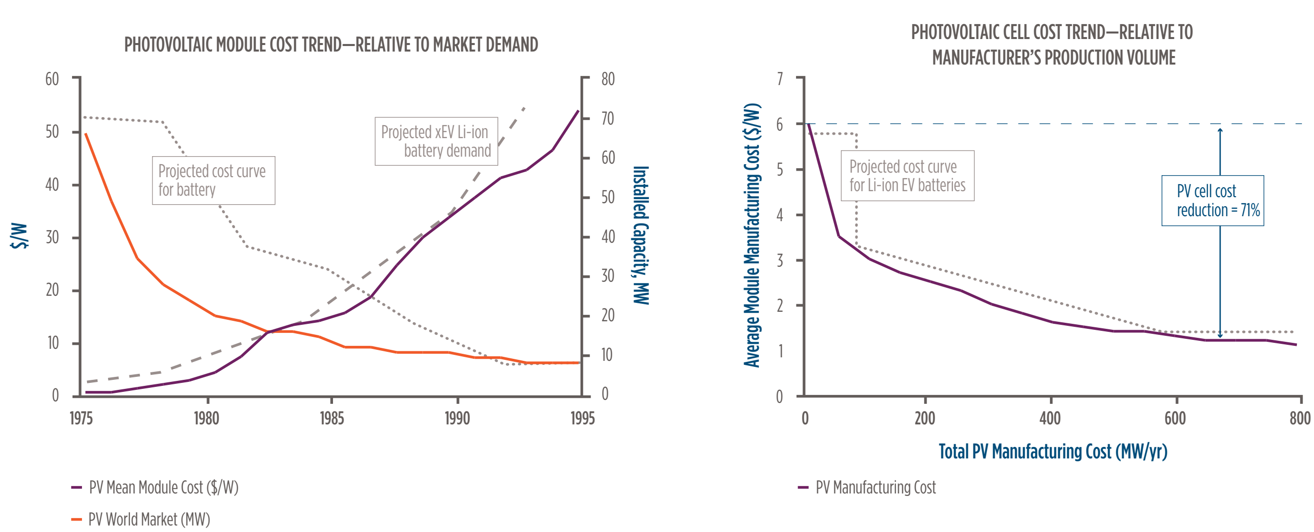
Figure 18: **Battery Cost Forecast**



Note: All figures in 2010 dollars

Source: PRTM Analysis, Industries Interviews

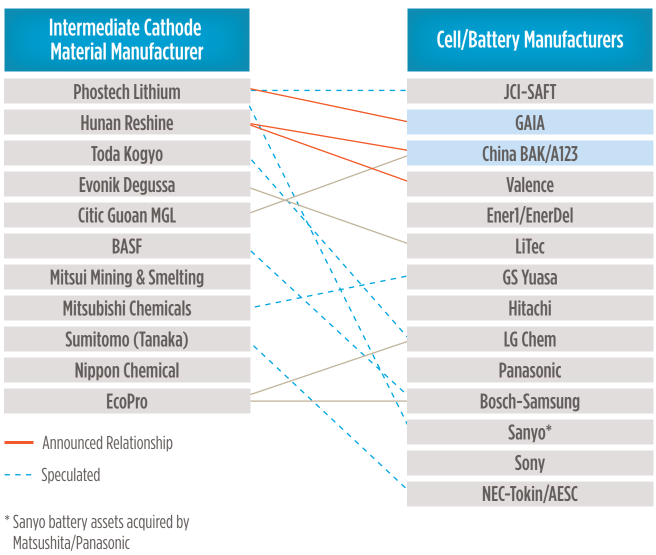
Figure 19: **Comparison of Battery Cost Reduction Forecasts with Actual Results in Photovoltaic Technology**



Source: NREL, DOE, United Nations University, PRTM Analysis

The development of the longer life batteries has become a "team effort" as the upstream and downstream battery manufacturers, and, in some cases the OEMs, have built strong supply relationships/partnerships to pool resources and accelerate their development timelines. Figure 20 shows an example of these emerging relationships between the upstream and downstream Li-ion battery value chain manufacturers.

Figure 20: **The Relationships between Upstream and Downstream Li-ion Battery Makers (June 2010)**



Source: Public Announcements, PRTM Analysis

Another issue with battery development in China is that a vast majority of technology patents are owned outside of China. Japan owns more than half of international patents in lithium-ion battery related technology, the United States nearly a quarter, and South Korea and Europe owning about 20 percent—leaving China with only about 1 percent of international patents in this field.

Battery Management Systems. After battery quality, the next critical determinant of battery life is the battery management system (BMS). The systems not only manage the use of the charge to maximize distance but also manage the variables (e.g., temperature) that have an impact on the life of the battery (Figure 21).

BMS systems can account for 20-30 percent of the battery systems' final cost. Those costs are expected to diminish rapidly as scale is achieved and China should have an advantage with its extensive electronics sector and its competitive cost position.

As the overall BMS sector is in its infancy, it is not clear who could be classified as the leader. The know-how is critical and most of the western OEMs have been developing the capabilities in-house. Chinese OEMs will likely find the need to do the same in the future.

Infrastructure. One of the most debated aspects of the EV industry is the infrastructure. The three main issues are:

- What type?
- How much?
- To which standards?

The first question typically addresses the mix of home versus public charging and the mix of slow versus fast charging. There is no single answer as the type of vehicles, the level of urbanization, and government policies all play a major role.

For example, as shown in Figure 22, the nature of the EV fleets and the nature of the pilot activity are somewhat different in Asia, Europe, and the United States.

Figure 21: **The Function of BMS Systems**

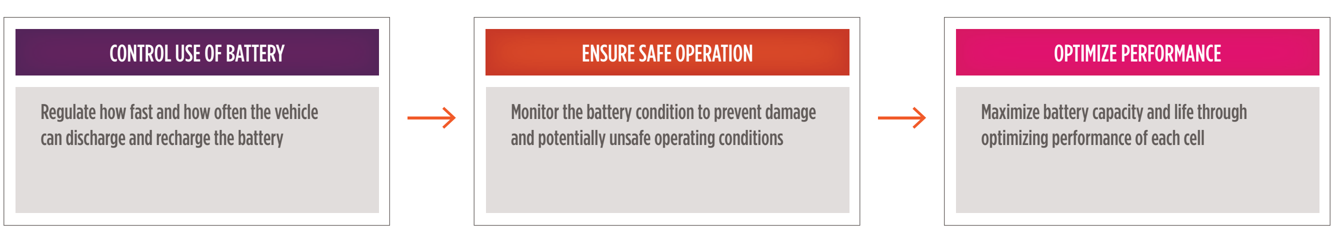
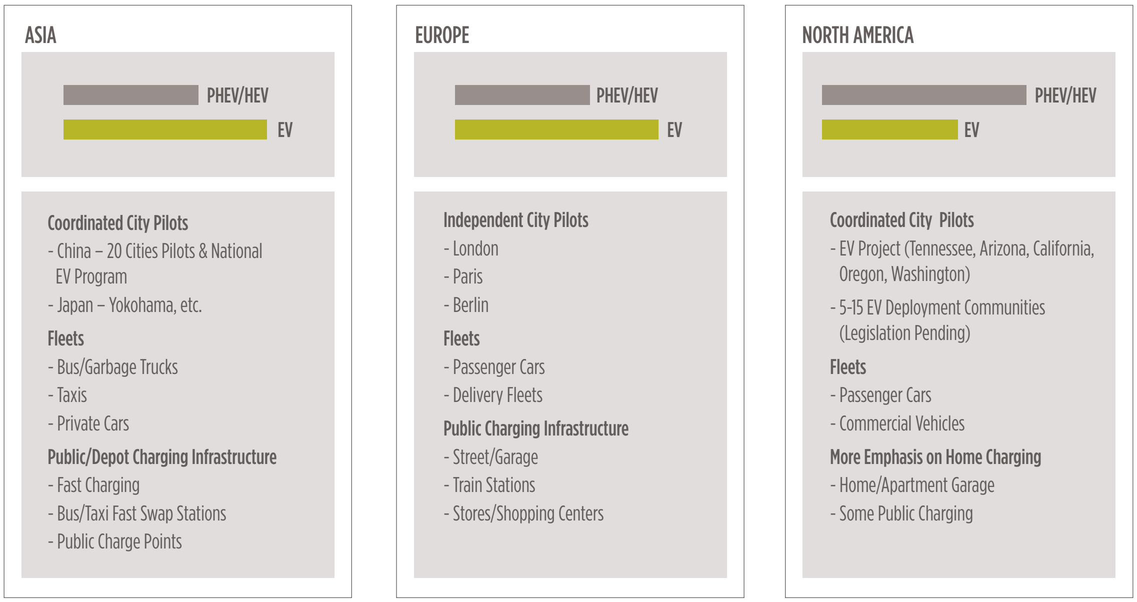


Figure 22: **Comparison of Infrastructure Deployment Globally**



China is pursuing an ambitious EV pilot program and in 2011 this has now grown to 25 cities. The latest estimates suggest the program will be supported by RMB 100 billion in government investments. Some cities, like Beijing, are focused on buses and municipal trucks while cities like Shenzhen are directing their attention to cars. As described earlier, the Beijing Bus Pilot is reliant on a highly automated battery swapping infrastructure. Shenzhen, however, is working on placing up to 24,000 electric cars on the road in 2012 and is actively seeking to position public charging lots close to the apartment buildings where most of the residents live. This has resulted in complex land use planning and coordination with the urban planning authorities.

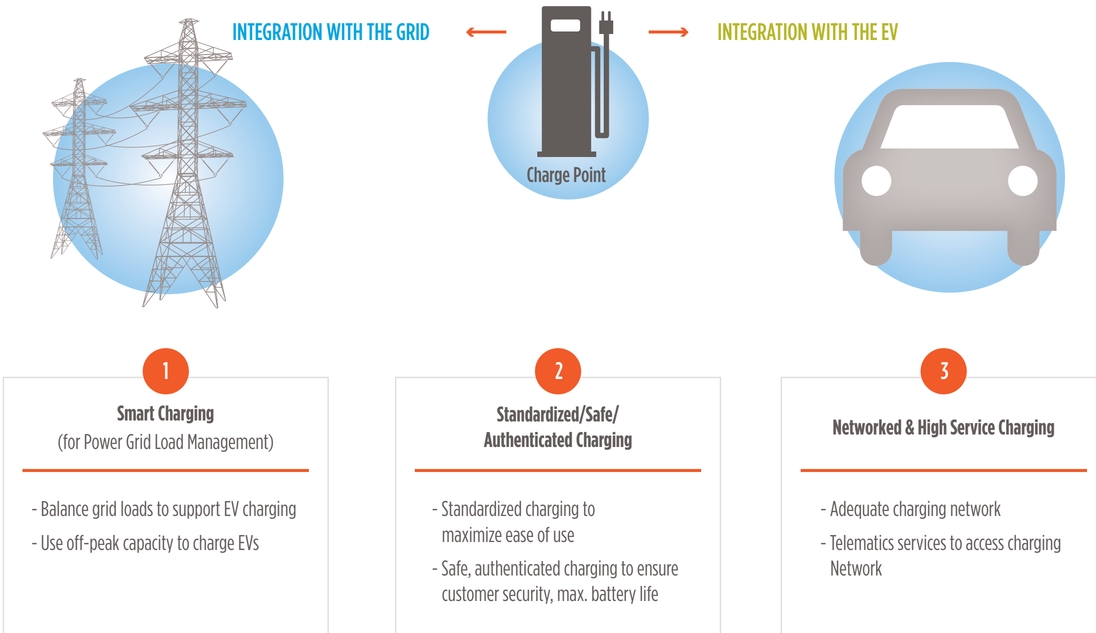
In Europe, EV activity has been led by cities like London, Paris, and Berlin, largely at the local level. The mayor of London advocated the incentive schemes to reduce taxes and fees on EVs to reduce congestion and clean the air. Paris, where Renault and Peugeot already have some 30,000 battery powered EVs in use, worked with the local utility EDF and the local government to develop a plan that includes more than US$ 2.5 billion in investments in charging infrastructure. Berlin has been following a similar path, but the key driver has been utilities like RWE that see major dividends in electric vehicles for future revenues and in capacity investment reduction through the use of the vehicle's batteries for storage.

The U.S. Government has been promoting EV technology and has invested approximately US$ 2.4 billion in electrification grants. This has included US$ 1.5 billion in battery manufacturing, US$ 500 million in electric vehicle components and US$ 400 million in infrastructure projects. In many respects, the U.S. program is similar to the Chinese model where there is top-down funding and coordination, albeit on a smaller scale. Infrastructure pilots are being deployed under the EV Project Program across several states, including Tennessee, Arizona, California, Oregon, and Washington. Cities like San Diego, Los Angeles, San Francisco, Chicago, New York, and Washington D.C. are all preparing for deploying charging infrastructure.

However, as the solutions are configured to meet local needs, the infrastructure will need to provide for three basic types of charging as shown in Figure 23:

- *Smart Battery Charging:* Ensures that demand is met by customers to charge when they need to without compromising the integrity of the distribution system. This will require "smart grid" technology

Figure 23: **The Three Types of Charging for an Integrated Solution**



Source: PRTM

as well as measures such as time of day pricing to manage the load.

- *Standardized/Safe /Authenticated Charging:* There must be common standards to minimize complexity, safe charging systems that prevent accidents during charging and authentication of the vehicle for the appropriate charging speed/power. A seamless integration of the technologies that support these capabilities will be required to produce a "hassle free" experience for the driver.
- *Networked and High Service Charging:* The EV driver will require a higher level of service (e.g., reserving a charging spot) while also spending more 'dwell" time around the charge point than a gasoline vehicle driver spends at a gas station. This provides opportunities for innovative new services that could add to the revenue line for the providers.

To help visualize the integrated charging solutions, it is useful to explore how they may be configured to meet the needs of different "use case" environments as shown in Figure 24.

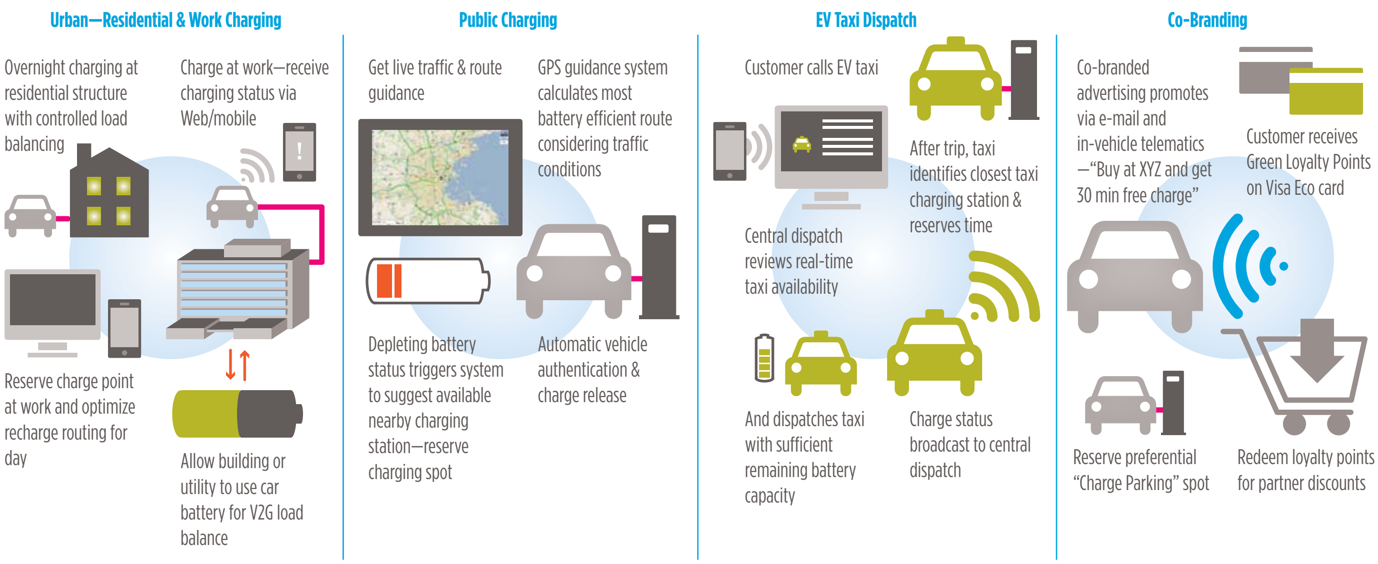
The urban drivers with a garage, as in many parts of the U.S., will be able to largely rely on overnight home charging for their needs. In Chinese cities where high rises dominate, authorities in cities like Shenzhen are exploring parking centers close to residential buildings where owners can charge vehicles overnight. Public charging will also be required for drivers who wish to travel beyond the reach of their batteries' charge. In this situation, fast charging, and the ability to reserve charging spots for especially rapid charging, will be critical.

There is a likelihood that taxi fleets will become users of EVs in the near future and this is being actively promoted in cities like Shenzhen. It will require a stronger IT communications infrastructure to ensure drivers are recharging during idle times rather than "roaming" for customers.

The EV driver's needs for service are likely to create innovative business models to help pay for the services. For example, department stores may provide free charging to attract customers. The charge spots could generate additional revenue through advertising, as drivers interact with them more frequently. Loyalty programs may offer charging time in place of other incentives.

The second major question under debate is how much infrastructure is needed, how much will it cost and,

Figure 24: **Examples of Different Use Cases for EV Charging Requirements**



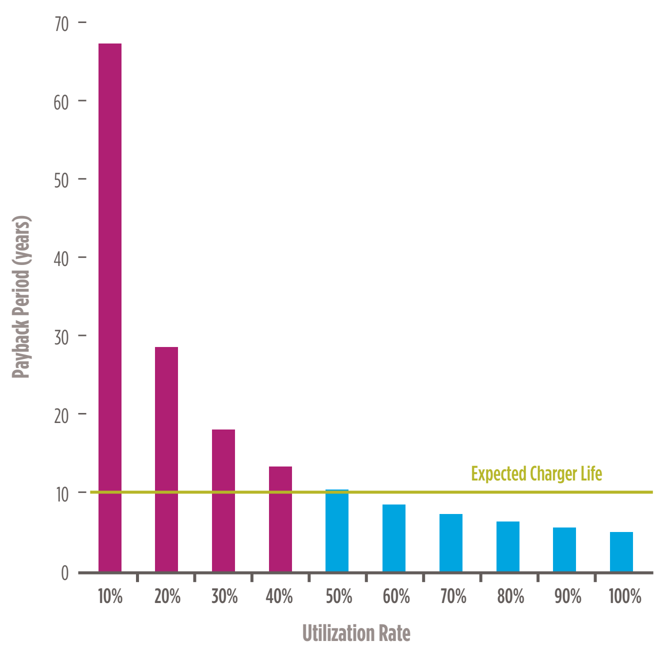
Source: PRTM Analysis

perhaps most significantly, who will pay for it. There are no clear answers but the debate on the importance of public charging infrastructure was best illustrated by the study conducted by the Japanese utility, Tokyo Electric Power Company (TEPCO) in 2007 and 2008, as shown in Figure 25.

Initially, TEPCO installed chargers at the homes of the EV owners. Due in part to what is commonly referred to as "range anxiety," the drivers returned home with batteries typically less than half depleted. Later in 2008, TEPCO installed a number of public charging stations. Curiously, although the public chargers were not used extensively, drivers began to return home with batteries significantly more depleted than in 2007—they knew the public chargers were available even if they did not need to use them.

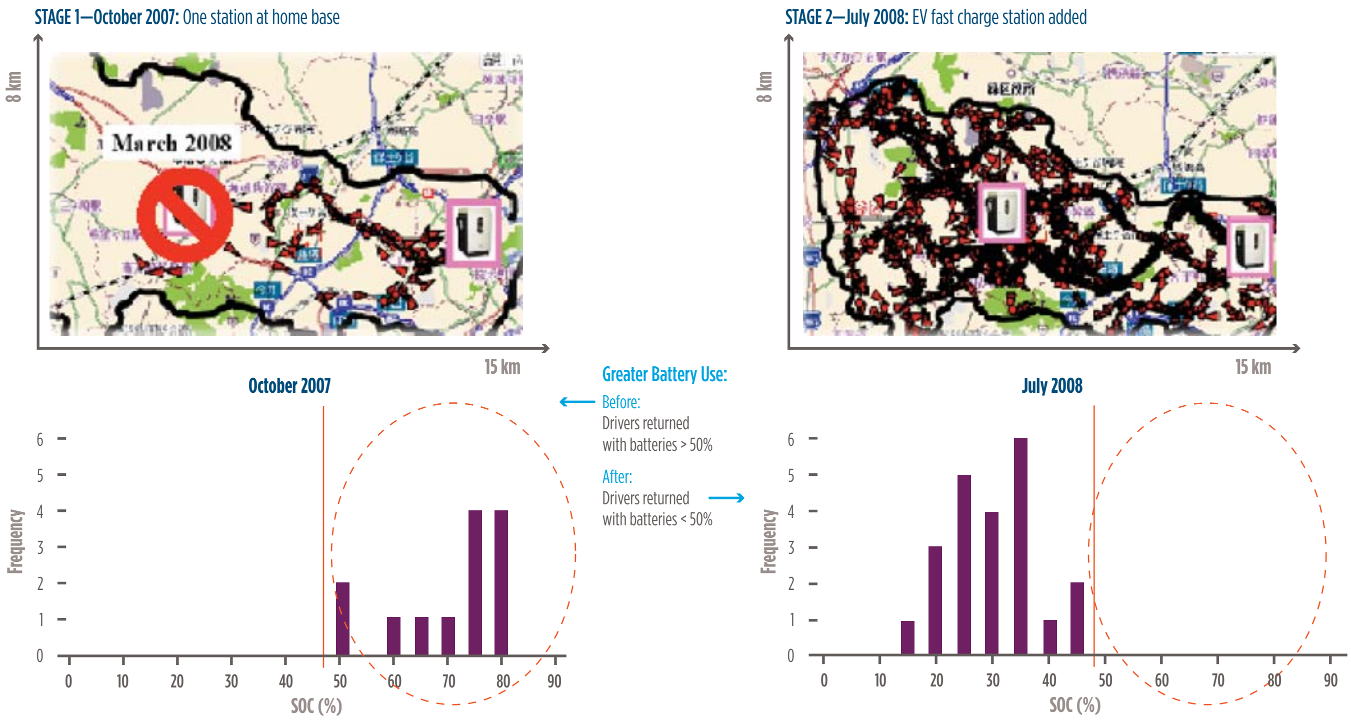
Therefore, it is generally accepted that some amount of public charging infrastructure will be required, even if it is not clear how much precisely. The amount of infrastructure is not an insignificant question as the return on investment on a typical charger is not attractive, as seen in Figure 26.

Figure 26: **Charge Point Payback**



Source: PRTM Analysis

Figure 25: **TEPCO Infrastructure Study Results**[23]



Source: TEPCO

Currently, most of the costs have been borne by governments but, over time, those costs will shift increasingly to the private sector. Utilities are likely to be players in the provisioning of charging infrastructure in many parts of the world but whether one party will own/operate and maintain the charging public infrastructure is unclear.

What is clear is that there will need to be commercially viable solutions to the infrastructure questions:

- Do utilities do more than sell electricity—for example provide EV services?
- Is there a need for independent, third-party EV power + service companies?
- Do the vehicle manufacturers need to provide the infrastructure for their vehicles?

It will be several years before the answers to these questions are answered by the marketplace as the focus for the immediate future is centered on the technical/operational and policy issues that will provide a basic infrastructure for supporting the first wave of EVs in the next several years. 2010 and 2011 represent the "GEN1" years, as shown in Figure 27, where such issues will displace the business, or commercial, aspects. But the commercial viability of the infrastructure and the overall EV value chain will grow in significance as governments begin to pull back funding and expect the industry to find viable business models to pay for the infrastructure in the "Gen 2" timeframe from 2012 to 2014. That is when the EV production volumes will begin to exceed the million units mark, and when worldwide and large-scale deployment is likely. China, like the rest of the world, will have to fashion its own business models that sustain the ramp-up.

Standards. The EV industry is struggling with the issue of EV charging standards. As with many industries in their infancy, there are a multitude of standards emerging. For example, the Society of Automotive Engineers (SAE) has undertaken development of the primary standards for the charging-related wired and wireless interfaces such as J1772, which governs the physical interface ("the plug") that connects to the vehicle. However, as seen in Figure 28, the full set of standards that connects the vehicle to the grid, including safety and power grid standards, have to be considered in creating an integrated solution.

The unfortunate fact is that the United States and Europe, which took the lead in developing the EV charging standard, have now developed two different charging plugs

Figure 27: **The Emerging Priorities for EV Deployment**

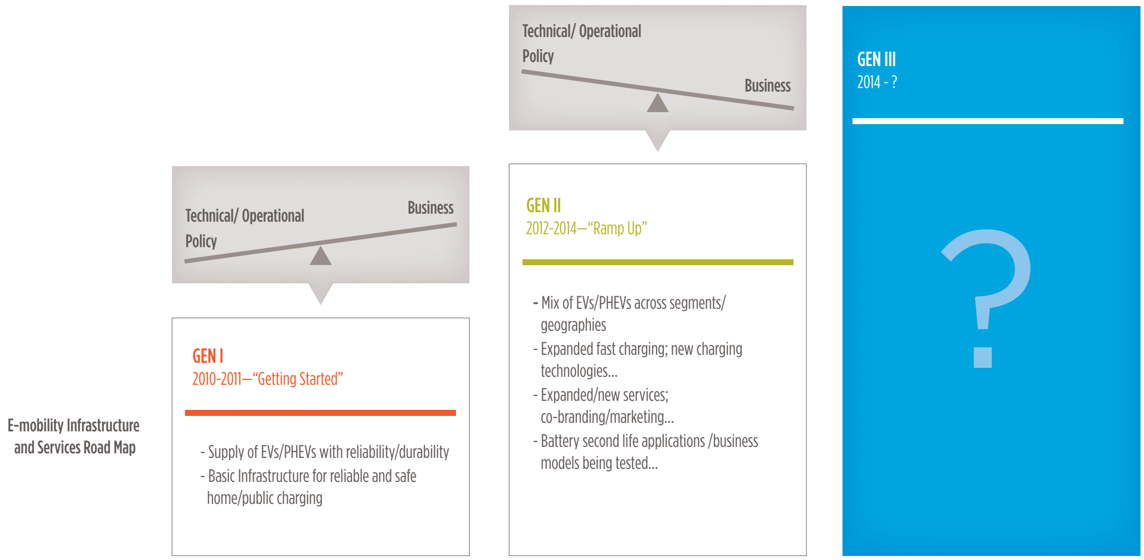
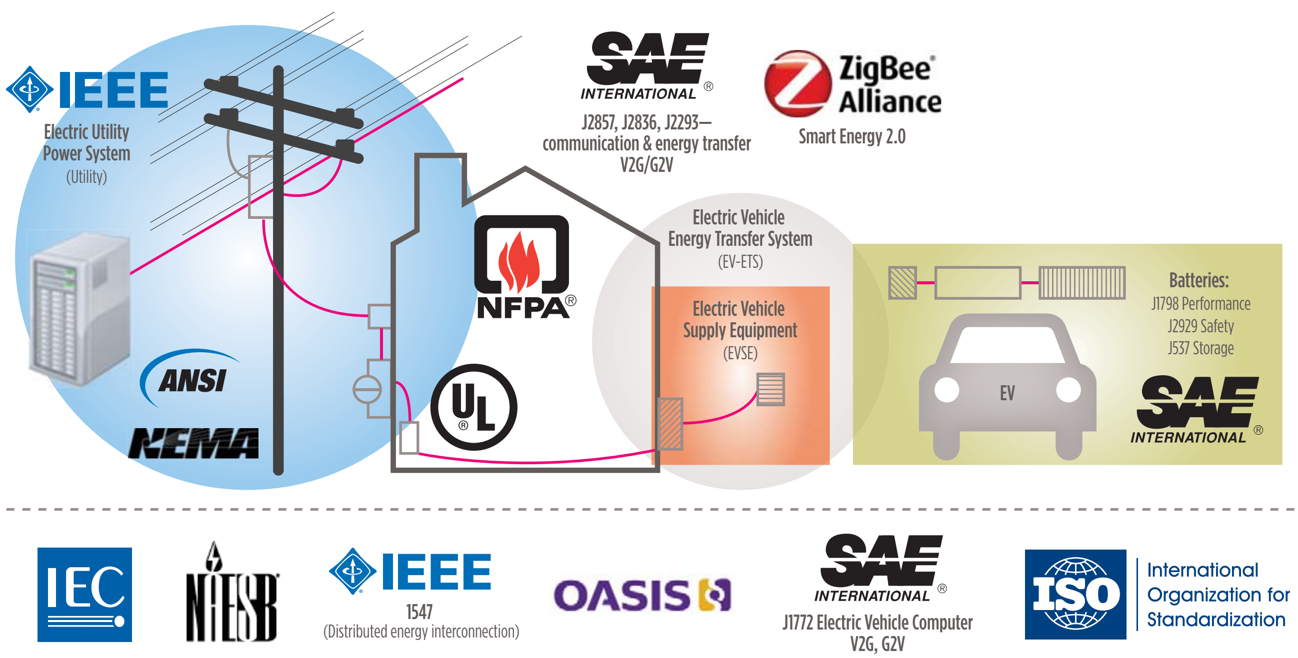


Figure 28: **The Full Spectrum Of Standards Required For an Integrated Charging System in the U.S.**



Source: SAE

(Figures 29 & 30). The U.S. plug developed by the SAE is called the J1772 plug. It can support 120V and 240V charging. In Europe, the manufacturers have selected a different plug that is often referred to as the Mennekes plug, after the manufacturer. It can support 240V and 360V charging. They have different numbers of connectors, and vary in size.

Figure 29: **European Mennekes Plug**

Figure 30: **J1772 EV Charging Plug**

Source: Mennekes, SAE

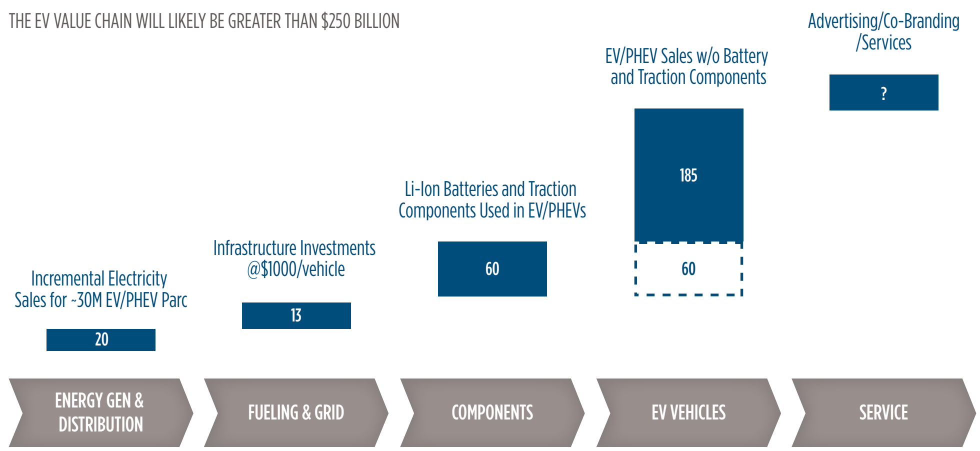
For fast charging, the Japanese TEPCO standard, which can go as high as 500V, is emerging as the dominant solution in Asia (Figure 31), as well as on the west coast of the United States, but Europe is continuing with the Mennekes standard for fast charging.

Figure 31: **Japanese TEPCO Fast Charging Plug**

Source: TEPCO

China has not yet formally launched its standards. In May 2010, it was announced that a four-tiered standard was being developed and would be launched later in the year. Ideally, those standards would incorporate some of the standards already developed to minimize the costs of complexity as the Chinese manufacturers eventually begin to export their vehicles.

Figure 32: **Global EV Value Chain in 2020**



Source: PRTM Analysis

4.1.3 Commercial Models

The EV value chain that is developing is likely to be greater than US$ 250 billion worldwide by 2020, as per the analysis shown in Figure 32.

The utilities will play a major role in this new value chain as the suppliers of the "power" required. Though they are the primary contenders for a role in the infrastructure business that delivers the power to the vehicles, it is not clear if they will be the only ones doing so or if they will be providers of the services whose revenues can help offset the cost of the infrastructure (e.g., driver services, charging station operation and maintenance and so forth). As seen in Figure 33, independent, third-party players (like Project Better Place) could take a role in providing the electricity and services, as has been occurring in the United States and Europe.

Figure 33: **Potential Business Model Owners in the Emerging EV Value Chain**

	EMERGING BUSINESS MODEL "OWNERS"			
	NATIONAL/UTILITY-BASED OPERATOR	3RD PARTY OPERATOR	STATE MUNICIPALITY	OEMs
Emerging Models	- Participating in Tech. Pilots with OEMs and Technology Providers - Some Plan to Own and Operate Infrastructure	- Planning to Own and Operate Infrastructure - Explore Broad Business Models to Include Service and Battery Business	- Some Planning to Own and Operate Infrastructure	- Establishing Technical Pilots with Utilities and Technology Providers - Developing Services
Pro	- Electricity/Grid - Federal/State Role	- Integrated Business Model	- Local Regulations	- Vehicle, Customer - Battery
Cons/Gaps	- U.S. Too Fragmented to Cost Effectively Develop Services and Infrastructure - Regulatory/Regional/Capital Constrained	- Access to Capital - Hesitant to "Open" Network - Not Currently Multi-OEM	- Lack of Scale to Be Cost Effective - Financial Limitations	- Capital Constrained - Single OEM, Not Likely to Provide Multi-OEM Solution
Success Probability	MED	MED-HIGH Based on Partnership	LOW	LOW (MED if Partner)

Most Likely Model Candidates: NATIONAL/UTILITY-BASED OPERATOR and 3RD PARTY OPERATOR

Source: PRTM Analysis

4.2 Challenges for China Going Forward

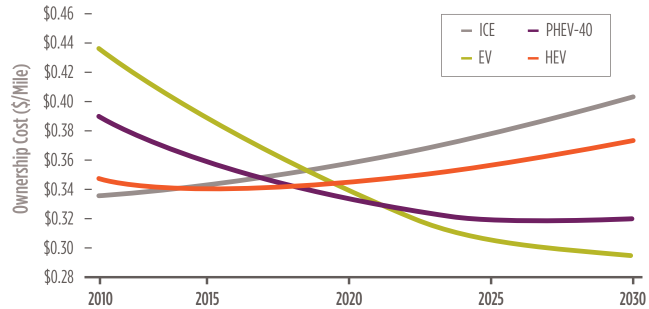
China is pursuing an ambitious electrification program. Yet the challenges it faces are similar to those faced elsewhere in the world. Many of them have already been discussed in this paper and they have centered on the supply side issues surrounding the provisioning of the charging technology and the batteries.

A framework for organizing these barriers around demand and supply is presented in Figure 34. Those shown in yellow are potential solutions, whereas those in red still require development of solutions. On the demand side, customer acceptance is still a significant unknown. Although it is generally accepted that however successful the EV sector is, it will not satisfy much more than the demand of the "early adopters" in the next 10 years, through 2020. The costs of ownership will be a central issue throughout the decade as costs have to be reduced significantly as government subsidies and incentives will be phased out.

Even the reported RMB 100 billion dedicated to the China New Energy Vehicles program will not be sufficient to subsidize purchases for the entire decade. If consumers do not find value in EVs, it will be very difficult to convince buyers to commit to them.

Figure 35 compares the Total Cost of Ownership (TCO) model for EVs, PHEVs, and HEVs for the next 20 years. Today, gasoline and HEVs offer somewhat comparable TCOs. EVs and PHEVs are not yet competitive without government incentives and subsidies, and will not be until the latter half of the decade. As shown in Figure 36, one of the key enablers for cost competitiveness of EVs and PHEVs is vehicle price reductions of 15-20 percent while gasoline vehicle prices remain relatively constant.

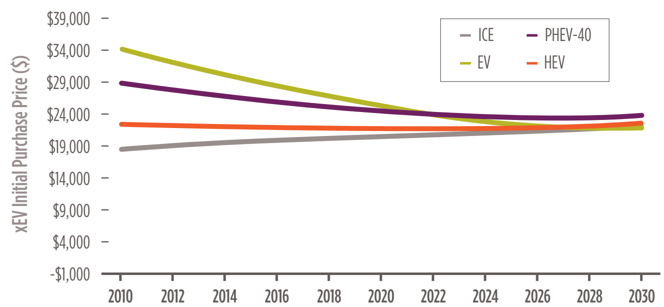
Figure 35: **China xEV Total Cost of Ownership Comparison**



KEY ASSUMPTIONS	2010	2030
Gasoline ($/Gallon)	$2.93	$5.81
Electricity ($/kWh)	$0.10	$0.15
Battery (Li-ion) • HEV – 1.5kWh • PHEV – 12kWh • EV – 24kWh	 $1,250/kWh $690/kWh $625/kWh	 $400/kWh $220/kWh $200/kWh

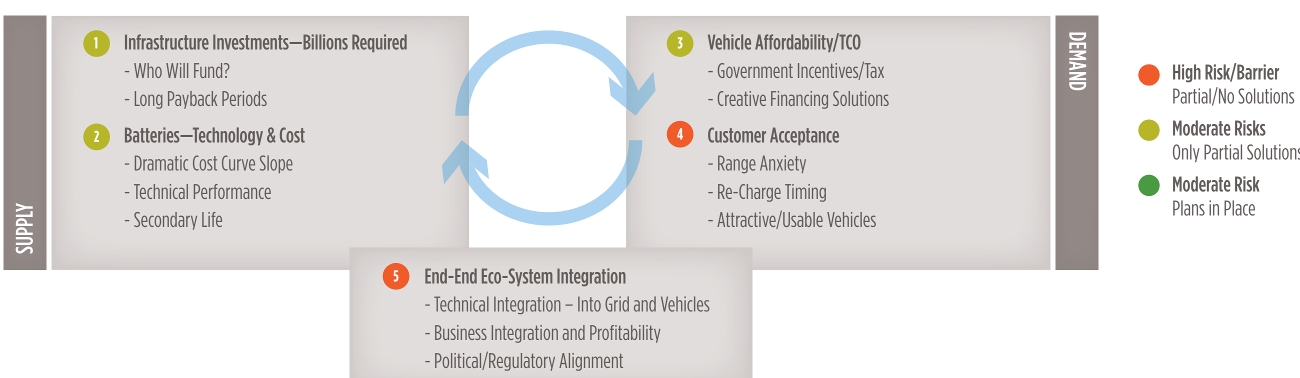
Source: PRTM Analysis

Figure 36: **China xEV Initial Purchase Price Comparison**



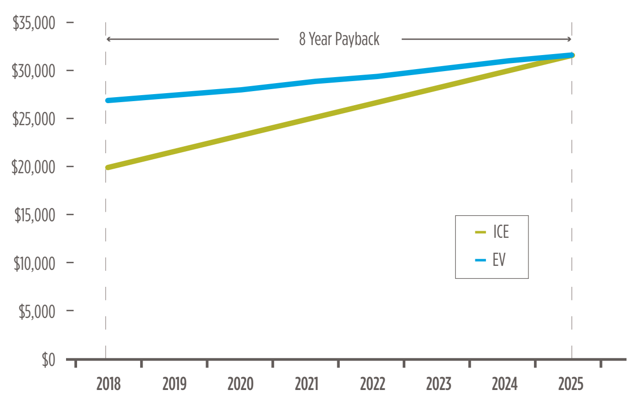
Source: PRTM Analysis

Figure 34: **A Framework for Organizing the Barriers to EV Adoption**



Further compounding this challenge is that fact that even when the lifetime ownership costs become favorable for EVs, the upfront vehicle cost will still be significantly higher than a conventional vehicle with a gasoline engine (Figure 37), while the payback period is significantly longer than most consumers or commercial fleet owners are willing to accept. While leasing could address this issue, two key barriers need to be addressed for EVs to become a viable alternative in China. First, a vehicle financing market, which is not a widely established market, would need to be developed. Second, a secondary market for batteries, a critical enabler for the leasing market to be viable, would need to be established. Currently, there is no downstream market to place used batteries from vehicle applications into new secondary markets for other applications, such as renewable energy storage.

Figure 37: **Cumulative Ownership Cost Comparison for Vehicle Purchased in 2018**



Source: PRTM Analysis

The one other "red" barrier is the creation of an integrated solution that addresses both the technological and commercial issues. Each region faces different challenges in this regard. Potentially, the biggest challenge is faced by the United States, where the aging grid is viewed as weak. Further compounding the issue in the U.S. is the number of utilities—some 3,000 by one count—that are subject to the 50 Public Regulatory Commissions (PUCs) for each state. The PUCs' aim is to ensure rates stay low and they do not favor business cases that show poor rates of return, as the charging infrastructure is likely to have. In Europe, there are fewer utilities and they cut across countries. They are not subject to the U.S. style regulatory issues.

China may have the least complexity, as there are only two large utilities, State Grid and Southern Grid. This offers distinct advantages for China, especially from a common standards approach. However, the current Chinese electricity grid has relatively high GHG emissions and analysts have projected that, due to the long remaining lifetime of the existing and newly installed coal-fired generation capacity, this could remain the case for a considerable period.[24] Electrification of the Chinese vehicle fleet clearly will help achieve energy independence objectives (due to reduced reliance on imported oil) and will reduce GHG emissions in some regions even with the current grid. But China faces a significant challenge in fully realizing the low emission potential of NEVs and indications are that realizing such benefits will require a deliberate policy framework supported by a consistent monitoring regime (Box 3).

Box 3: **A Framework for Measuring and Maximizing Carbon Benefits**

Three critical factors determine the well-to-wheels GHG intensity of an electric vehicle:

a. The carbon intensity of the generation mix. This is the dominant factor and is determined by the share of coal (versus renewable) in the generation mix and the efficiency of the coal power plants. China has committed to aggressive targets on both—increasing the efficiency of coal power plants (from 32 percent in 2010 to 40 percent in 2030) and in increasing the share of renewables in the mix. Achieving these targets will be key to realizing the potential GHG benefits from electrification.

b. The efficiency of the vehicle and associated charging mechanism—how much electricity is required to travel a given distance. This will vary depending on the weight of the vehicle and its specific design features.

c. The impact of EVs on the generation mix, (i.e., EVs can "soak up" excess renewables at night and thereby allow for a higher percentage of renewables in the overall mix than would otherwise be the case). A deliberate policy environment (peak versus off-peak pricing, administrative requirements guiding charging) and facilitating technology environment (such as the availability of smart grid applications) can have significant impact on actual GHG emissions.

Even within a given technology context, there are considerable analytical and methodological issues that need to be clarified in order to accurately and consistently measure the carbon impact of a vehicle electrification strategy. Issues of particular concern include:

a. Using the average versus marginal generation mix. Until EVs become a mainstream solution, the marginal mix is more accurate (the generation source supplying the marginal demand). However, this is quite complicated to measure in practice.

b. Geographic factors. The carbon intensity of the generation mix will vary by region. Estimates of EV carbon impact will vary depending on whether one assumes the national, regional, or local mix. For regulatory purposes, it is simpler to use the national mix but this is less accurate.

c. Future grid changes. The grid is getting cleaner over time. Thus, the electricity used by a vehicle in year 10 of its life will be cleaner than that used in year one. Estimates of the lifetime carbon impact of EVs need to take this into account.

From an institutional standpoint, work is needed to build a more direct linkage between generation and consumption, in order to better measure the carbon impact of EVs and allow for dedicated use of renewables. The ability to purchase electricity from specific generation sources and assign it to EVs will vary from system to system. In most places at present, for example, there is no "direct access" so a consumer cannot directly purchase renewable sources.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Endnotes

[1] Darido et al. 2009.

[2] U.S. Energy Information Administration Annual Energy Outlook 2010. Washington, DC: U.S. Department of Energy; http://www.eia.doe.gov/oiaf/aeo/

[3] http://www.eia.doe.gov/dnav/pet/pet_pri_wco_k_w.htm

[4] http://articles.cnn.com/2010-07-23/world/china.oil.spill_1_oil-spill-crude-dispersants?_s=PM:WORLD

[5] From a water consumption standpoint the situation is less clear. A recent study using the U.S. 2005 electricity generation mix found that displacing gasoline miles with electric miles resulted in more water being consumed and withdrawn, primarily due to water cooling of thermoelectric power plants (King, Carey W and Michael E. Webber. 2008. "The Water Intensity of the Plugged-In Automotive Economy," Environ. Sci. Technol. 42, 4305–4311). Much less water is used by fossil power plants with dry cooling systems, and renewable resources such as wind and PV solar. In general there is a trend in China to reduce water use in electricity supply (http://www.circleofblue.org/waternews/2010/science-tech/climate/chinese-power-plant-develops-advanced-coal-technology/).

[6] http://ec.europa.eu/environment/air/transport/co2/co2_home.htm

[7] http://www.jato.com/Consult/Pages/co2.aspx

[8] Fuel consumption conversions are conducted according to the factor defined in An, Feng and Dianne Sauer, "Comparison of Passenger Vehicle Fuel Economy and Greenhouse Gas Emission Standards Around the World," Pew Center on Global Climate Change. December 2004. According to An and Sauer's analysis, due to the differences between the NEDC and US-CAFE (and other) testing cycles, direct unit conversions from mpg to L/100km are not accurate and need to be modified by a multiplier.

[9] Huo Hong, Qiang Zhang, Michael Wang, David Streets and Kebin He, "Environmental Implication of Electric Vehicles in China," Environmental Science and Technology, May 2010.

[10] GM's vision for 2030 Urban Mobility," Automotive Engineering International, November 16, 2010.

[11] Delucchi, Mark and Ken Kurani, "How we can have safe, clean, convenient, affordable, pleasant transportation without making people drive less or give up suburban living," Institute of Transportation Studies, University of California Davis, CA.UCD-ITS-RR-02-08 rev. 1. October 2010.

[12] A Pigovian subsidy (tax) is a term for subsidies (taxes) imposed on individuals or firms who are taking actions that have positive (negative) social consequences. The subsidy (tax) corresponds to the social benefit (burden) associated with the action, so that the total "cost" to the individual or company reflects the costs they impose on society. A Pigovian subsidy (tax) equal to the positive (negative) externality (or impact on society) is thought to correct the market outcome back to efficiency. A typical example of such a tax would be to charge polluters for air or water pollution emissions.

[13] Conceptually, there is a distinction between local and global externalities. For a global issue such as climate, the Pigouvian argument makes most sense if the rest of the world is addressing the issue with the same level of commitment as China.

[14] U.S. Energy Information Administration International Energy Outlook 2010, July 2010. Washington, DC: U.S. Department of Energy. http://www.eia.doe.gov/oiaf/aeo/

[15] Qizhong Wu, Zifa Wang, A. Gbaguidi, Xiao Tang and Wen Zhou. 2010. "Numerical Study of the Effect of Traffic Restriction on Air Quality in Beijing," SOLA, Vol. 6A, 017−020, doi:10.2151/sola.6A-005.

[16] http://www.businessweek.com/news/2010-05-29/china-automobile-production-may-grow-by-15-this-year-update1-.html

[17] http://www.science.doe.gov/sbir/solicitations/FY%202010/06.EE.Electric_Drive_Vehicles.htm

[18] http://www.zhongtongbuses.com/8-electric-buses-b-LCK6120EV.html

[19] http://www.byd.com/showroom.php?car=e6&index=6

[20] http://www.canadiandriver.com/2010/04/11/china-builds-45-car-electric-charging-station.htm

[21] For examples of regional US power sector greenhouse gas emission caps see the Regional Greenhouse Gas Initiative, http://www.rggi.org/home, and the California Air Resources Board cap and trade program, http://www.arb.ca.gov/cc/capandtrade/capandtrade.htm

[22] U.S. Department of Energy, Energy Efficiency and Renewable Energy, EERE State Activities and Partnerships, http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm

[23] TEPCO R&D Center Study 2008

[24] Huo, Hong, Qiang Zhang, Michael Q. Wang, David G. Streets, and Kebin He: Institute of Energy, Environment and Economy, Tsinghua University, Beijing, China, Center for Earth System Science, Tsinghua University, Beijing China, Center for Transportation Research, Argonne National Laboratory, Argonne, Illinois, Decision and Information Sciences Division, Argonne National Laboratory, Argonne, Illinois, and State Key Joint Laboratory of Environment Simulation and Pollution Control, Department of Environmental Science and Engineering, Tsinghua University, Beijing, China. 2010. "Environmental Implication of Electric Vehicles in China," Environ. Sci. Technol. 2010, 44, 4856–4861.