Case Study 1

HIGH FUEL EFFICIENCY MOTOR VEHICLES

Case Study of the Summary Report:

Policy and Technology Pathways to a Low Carbon Economy: Electric Vehicles and Energy Efficient Air Conditioners in China

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Acronyms

ADB	Asian Development Bank
BAU	Business as usual
CAS	Chinese Academy of Sciences
CDM	Clean Development Mechanism
CEACER	China Energy and CO_2 Emissions Report
CME	Carbon Market Economics
CO_2	Carbon dioxide
$CO_{2\text{-}e}$	Carbon dioxide equivalent
COP	Coefficient of performance
CSES	Centre for Strategic Economic Studies
ECS	Energy Conservation Scheduling
EER	Energy Efficiency Rating
EIA	United States Energy Information Administration
ERI	Energy Research Institute
EU	European Union
EV	Electric vehicle
FYP	Five Year Plan
GDP	Gross Domestic Product
GHG	Greenhouse gases
GW	Gigawatts
IEA	International Energy Agency
kW	Kilowatts
kWh	Kilowatt hours
LCE	Low carbon economy
MEPS	National Bureau of Statistics, China
NBSC	National Bureau of Statistics, China
NDRC	National Development and Reform Commission, China
NEA	National Energy Agency, China
NEC	National Energy Commission, China
NPC	National People's Congress, China
OECD	Organisation for Economic Co-operation and Development
PV	Photovoltaic (solar cells)
RAC	Room air conditioner
RMB	Renminbi or Chinese National Yuan
SGCC	State Grid Corporation of China
TCE	Tons of standard coal equivalent
TPY	Tons per year
US	United States
VAT	Value added tax
WTO	World Trade Organisation

1. Introduction

This report is one of a series produced by the Centre for Strategic Economic Studies at Victoria University and the Energy Research Institute of the National Development and Reform Commission on the implications for the Chinese automotive industry and the economy, more broadly of a move by the Chinese government to promote a greater use of motor vehicles that produce less greenhouse gases and other pollutants and are more fuel-efficient. This transition is occurring against a background of increasing knowledge of the impact of greenhouse gases on climate change and the desire to improve air quality within China's cities. Concerns about resource security and the rising real cost of fossil fuels is another important motive for improving fuel efficiency. A further more critical consideration is the desire to establish a globally competitive motor vehicle industry in China that shares market leadership in terms of fuel economy and new energy vehicles.

The Chinese Government through a number of major policy announcements over recent years has decided that the principal initiative that it will undertake to lower greenhouse gases and address greater fuel security for passenger vehicles is to promote the greater development and uptake of electric vehicles. Accordingly, this report concentrates on what the central and sub-national Governments have done in China to promote the development of electric vehicles, and describes and discusses a technological roadmap and set of policy instruments to achieve this.

The report provides background on both the rapid rise in the number of motor vehicles in China during the past decade, and the corresponding rapid growth in the output of the domestic automotive production industry. It describes how national, regional and municipal governments within China have promoted the growth of the industry through joint ventures among foreign automotive manufacturers, domestic manufacturers and government, and more recently have encouraged the development of automotive technology, such as electric cars. The government has introduced policies and programs to address pollution, congestion, fuel costs and climate change associated with motor vehicle use, and these are described in terms of their impact on the industry and consumers.

Although established in automotive component export markets for some time, the Chinese motor vehicle industry is poised to make a serious attempt to become a global presence in the automotive trade. As the Japanese and Korean examples illustrate, this is necessarily a long-term program which will require Chinese manufacturers to meet environmental, safety and engineering and other standards in developed economies, as well as the quality and other expectations of consumers. Therefore, manufacturers will increasingly need to adopt world's best practice manufacturing and supply chain management techniques and invest in the innovation necessary to achieve this, either within their own organisations or in collaboration with private and public technology organisations.

The challenges faced by the Chinese Government in reducing carbon emissions from transport are illustrated in this report by comparing growth in the Chinese passenger vehicle fleet with that in

Australia as an example of an advanced economy. The anticipated strong growth in the number of cars in China is used as a justification by the Chinese Government for prioritising the development of electric and hybrid diesel vehicles. It remains unclear, however, how significant any shift towards electric and hybrid diesel vehicles will be in reducing China's carbon emissions. Instead, a technology neutral policy driven by a range of policy and regulatory measures specifically aimed at carbon emission reductions, such fuel efficiency standards for motor vehicles would be more appropriate. Moreover, as Green-Weiskel (Rivkin, 2011) concluded, "as long as China is addicted to coal, one million new electric vehicles a year won't amount to any positive climate impact". As such, the development of electric vehicles in China and elsewhere must accompany a significant shift away from coal and towards cleaner and preferably renewable sources of energy (Earley et al., 2011).

There are a range of policies that can be adopted to encourage low carbon transport suggested in this report including stronger emissions standards for vehicles, fuel taxes, vehicle purchase taxes, support for infrastructure for electric vehicles and encouragement of alternative transport modes. One such program that has already been implemented in a number of European countries that is gaining wider attention is the so-called "feebate" which provides rebates for vehicles with lower emissions than a benchmark rate and fees for vehicles exceeding the rate. The feebate is described in some detail as a supplement to the setting of stronger emission standards.

The concern about carbon emissions from transport has prompted governments and other bodies to develop roadmaps setting out goals and timelines for achieving lower emission vehicles. These are reviewed and illustrated using the UK Consensus Technology Roadmap.

The Energy Research Institute has developed a technology roadmap for the introduction of electric vehicles in China, along with a roadmap for the introduction of associated charging infrastructure and a range of policies and programs to implement the roadmap. The roadmap found that the success of electric vehicles in penetrating the market will be dependent upon three key factors: advances in battery technology; the widespread deployment of charging facilities; and pricing parity between electric vehicles and conventional vehicles. Each of these issues is discussed to provide a picture of how China intends to develop policies to advance electric vehicle technology and deployment so that they make up a significant proportion of the Chinese motor vehicle fleet within twenty years. The Appendix provides a review of fuel efficiency and emission standards in various countries.

2. The Chinese Automotive Sector

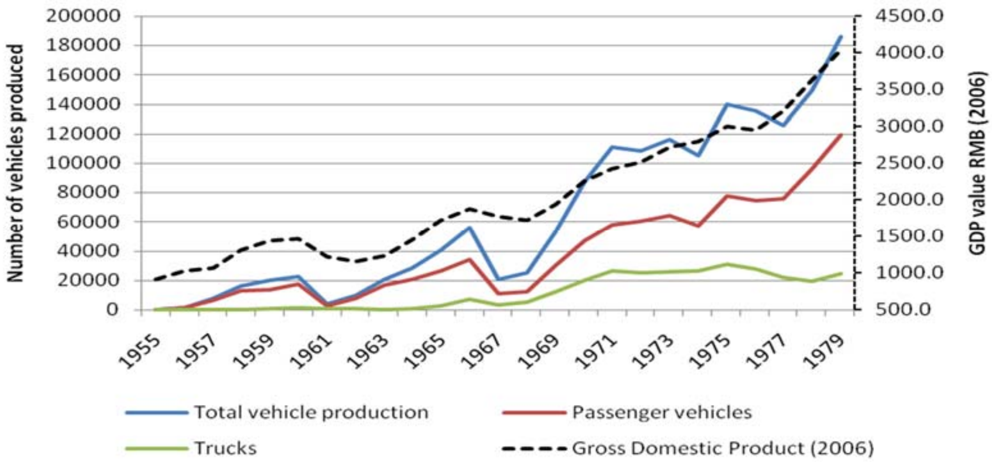
2.1 Historical Background

Although China had a modest automotive manufacturing sector prior to the Second World War, the industry is usually described as originating with the establishment by the national government in 1956 of the First Automobile Works (FAW) in Changchun in Jilin Province, North-East China. Producing medium-size trucks, the FAW factory was based on a Soviet design and was built with the help of Soviet technicians. In the following few years, automotive manufacturers were set up by provincial and municipal governments in Nanjing (now the Nanjing Automobile (Group) Corporation), Shanghai (now the Shanghai Automotive Industry Corporation – SAIC), Jinan (China National Heavy Truck Group) and Beijing (Beijing Automotive Industry Holding Corporation). The first passenger car, the 'Hongqi' (Red Flag), was launched by FAW in 1958. However bicycles provided the chief form of personal transport for much of the period after 1949.

Following the difficulties of the Great Leap Forward and the demise of Soviet-China friendship, the central government set up the Second Automobile Works (SAW, later Dongfeng Automotive Group) with the support of the Shanghai municipality and FAW. For strategic reasons however, the plant was located in Shiyan, a remote location in Hubei province.

During the Cultural Revolution regional authorities set up new factories in Tianjin, Shenyang and Wuhan, all of which became major producers. However the isolation of China and the turmoil during the period of the Cultural Revolution meant that the growth of the local automotive industry was constrained and consisted overwhelmingly of trucks rather than passenger vehicles.

Figure 1. Vehicle Production and GDP, China, 1955-1979



Source: NBSC, 2009.

Figure 1 shows that the average annual growth from 1955 to 1979 was nearly 12% (Liu and Yeung, 2008), and production rose rapidly between 1967 and 1971 before reaching a plateau and then rapidly growing after 1974. Vehicle production grew from 61 vehicles in 1955 to 185,700 vehicles in

1979 (Arnold, 2003; NBSC, 2009). The growth in vehicle production mirrors the changes in China's gross domestic product (GDP) during the 25-year period.

The economic reforms and greater openness beginning in 1978 provided a major stimulus to the Chinese automotive industry. There was strong growth in the importation of cars and the Government responded by promoting joint ventures between domestic and foreign manufacturers to increase local production. The first of these was a small venture involving American Motors Corporation and Beijing Automotive called Beijing-Jeep to produce a local version of the Jeep Cherokee.

In 1987 the Government decided as part of its overall industrial strategy to nominate the automotive industry as one of its key 'pillar industries'. An important aspect of this was the decision to divide the leading manufacturers into major and minor assemblers. The three major joint ventures were:

- Shanghai Automotive Industry Corporation and Volkswagen (1985)
- First Automobile Works and Volkswagen (1990)
- Dongfeng Motor Corporation and Citroen

The three smaller ones were:

- Beijing Automotive Industry (BAI) – AMC (later Chrysler, then Daimler Chrysler, then Hyundai)
- Guangzhou Automobile Industry Group and Peugeot (later Honda) (1985)
- Tianjin Automotive Industry and Daihatsu (later merged with FAW and Toyota joint venture)

Of these early joint ventures, the most successful were those involving Volkswagen, which took advantage of its first-mover status and through its Santana and Jetta models quickly reached a dominant position in the market. Guangzhou-Peugeot was closed in 1997, while Beijing-Jeep never flourished.

From their beginnings in 1983, joint ventures proliferated and now involve all the major international automotive manufacturers, including the Japanese car companies that had earlier been reluctant to commit to joint ventures because the initial ones had many teething problems. The more recent and key joint ventures include: Jinbei-General Motors, Chang'an-Suzuki, Nanjing-Iveco, Changhe-Suzuki, Shanghai-General Motors, Guangzhou-Honda, Nanjing-Fiat, Yueda-Kia, Tianjin-Toyota (later FAW-Toyota), Chang'an-Ford, Beijing-Hyundai, FAW-Toyota, Dongfeng-Nissan, Guangzhou-Toyota, BMW-Brilliance and Beijing-Benz (Liu and Yeung 2008).

While initially concentrated heavily in Changchun and Shiyan and later in Beijing, Nanjing and Shanghai, the creation of new companies and factories lead to a decentralisation of production and spread the geographical distribution of the industry to other cities such as Chongqing, Harbin and

Tianjin. Figure 2 shows the distribution across provinces of Chinese automobile production in 2001 and 2009 and it is clear that the distribution of shares has become more uniform.

Figure 2. Provincial Shares of Chinese Automobile Production, 2001 and 2009

	2001	2009
Beijing	6.5	9.2
Shanghai	12.4	9.1
Chongqing	10.2	8.6
Guangxi	5.8	8.6
Guangdong	2.4	8.2
Jilin	16.7	8.0
Hubei	10.3	7.8
Anhui	3.8	6.3
Tianjin	2.5	4.4
Shandong	0.5	4.0
Hebei	0.6	3.7
Liaoning	3.4	3.7
Shaanxi	0.8	3.7
Jiangsu	4.6	3.7
Jiangxi	6.8	2.1
Heilongjiang	5.9	2.1
Zhejiang	0.9	2.0
Other	5.8	4.9

Source: CEIC database, 2011.

Figure 3. Concentration (Herfindahl) Index for Provincial Shares of Chinese Automobile Production, 1995 to 2009

Year	Index
1995	0.899
2000	0.858
2001	0.870
2002	0.754
2003	0.766
2004	0.703
2005	0.648
2006	0.637
2007	0.650
2008	0.657
2009	0.653

Source: CEIC database, 2011.

A commonly used measure of concentration is the Herfindahl index, and calculating this across all provinces shows declining concentration particularly in the first part of the initial decade of the 21st century (Figure 3).

The Government's policy to build the local automotive industry through the transfer of technology, skills and capital from foreign car companies via majority ownership of joint ventures was formally recognised in the 'Automotive Industry Policy of China' in 1994. This policy aimed at tripling local production over a 15-year period, beginning the process of making the automotive industry internationally competitive. It instituted some formal protection barriers by raising the import duty on completely built-up vehicles and components and provided subsidies for exporters. The policy required the industry to reach 80% local content within three years or face higher import duties. Importantly it permitted only one major new venture during the period of the 9th Five Year Plan

(FYP) from 1996 to 2000 (SAIC-General Motors) and promoted the rationalisation and consolidation of domestic manufacturers. From this emerged the major producers in the market today (Figure 2).

China's decision to seek membership of the World Trade Organisation (WTO) which took place in December 2001, necessitated a change in some of the protectionist aspects of industrial policy. The 10th Five Year Automotive Development Plan (2001-2005) included a number of measures stimulating the vehicle market in China, including reducing tariffs on imported complete built units (CBUs) and vehicle components, as well as abolishing local content requirements. The Plan reiterated the policy of favouring selected large firms both among the assemblers and parts manufacturers and encouraging further consolidation among smaller producers.

Figure 4. Shares of Chinese Automobile Sales, Major Manufacturers, 2005 and 2010

Company	2005	2010
Shanghai Auto Industry Group	16.0	19.7
Dongfeng Automobile Co., Ltd	12.7	14.7
China FAW Group Corporation	17.1	14.2
China Changan Automobile Group	21.0	13.2
BAIC Group	10.4	8.3
Guangzhou Auto Industry Group	4.1	4.0
Chery Automobile Co., Ltd	3.3	3.8
BYD Company Limited	0.0	2.9
Brilliance Auto Group Co., Ltd	2.1	2.8
Anhui Jianghuai Automobile Co., Ltd	2.7	2.5
Zhejiang Geely Holding Group	2.6	2.3
Great Wall Motor Co., Ltd	1.1	2.2
China National Heavy Duty Truck Group Co., Ltd	0.3	1.1
Chongqing Lifan Passenger Car Co., Ltd	0.0	0.6
Shaanxi Automobile Group Co., Ltd	0.0	0.6
Dongnan (Fujian) Automobile Industry Co., Ltd	1.0	0.5
Hunan Jiangnan Auto Mfg Co., Ltd	0.0	0.5
Shandong KAMA Automobile Manufacturing Co., Ltd	0.0	0.3
Hawtai Motor Co., Ltd	0.0	0.1
Ziyang Nanjun Automobile Co., Ltd	0.0	0.1
Qingling Motors Group Co., Ltd	0.0	0.0
Hafei Motor Co., Ltd	4.0	0.0
Changhe Aircraft Industry Company	2.1	0.0
Yuejin Motor Group Co., Ltd	0.1	0.0

Source: CEIC database, 2011.

In 2010, the top five manufacturers accounted for 70% of sales while the top 10 made up 86%. Figure 4 lists the major car makers in China in 2005 and 2010, which hold a combined market share of 94.4%. The remaining 8% of the market is divided amongst a further 100 or so manufacturers. At the end of 2008 there were some 117 car manufacturers in China (China Association of Automobile Manufacturers, 2009).

While joint ventures with foreign manufacturers producing domestic versions of foreign cars dominate, an interesting feature of Figure 4 is the increasing market share held by a number of private domestic manufacturers – namely Zhejiang Geely Automobile, Chery Automobile, Brilliance and BYD. These companies began producing cars quite recently in 2000 (Geely), 1998 (BYD) and 2002 (Chery), and they have emerged to gain a significant market share without being a preferred manufacturer within the automotive industry plan. More recently, BYD has made major commitment to electric and hybrid vehicles. Other independent producers include Great Wall Motors, initially a truck manufacturer which began making SUVs in 1996, but is producing an increasing number of smaller private vehicles today.

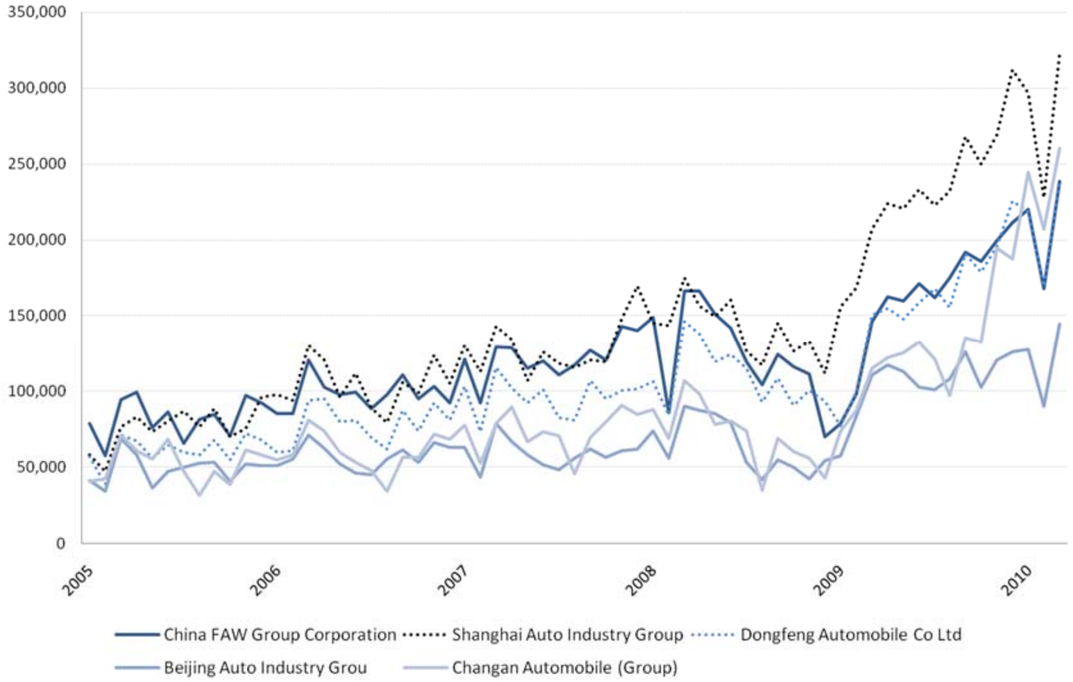
In summary, Chinese government policy with respect to the automotive industry has been to build a domestic production capability by encouraging joint ventures with foreign car companies and a few selected domestic manufacturers. The foreign car companies would have a minority share in such ventures, but would transfer skills and design and manufacturing technology to China to form the basis of domestic capabilities in these areas.

In a review of the Chinese automotive industry, Liu and Yeung (2008) assert that this desired development of technological capacity in the favoured domestic manufacturers – FAW, SAIC and Dongfeng – has not occurred, and they remain reliant on their foreign partners for new models and associated technology. They cite the case of Dongfeng which closed its technical centre for new car development in 2002. As noted earlier, it is those manufacturers that emerged outside the formal automotive plan that have been successful in developing their own cars and technologies.

In January 2009, the Chinese Government announced a range of measures to stimulate the economy in light of the global recession and financial crisis. Included in this package was the *Automotive Industry Restructuring and Revitalisation Plan,* which among other things called for a further rationalisation of the 14 major domestic manufacturers into around 10 which would account for 90% of the market and be organised into two tiers by 2012. The first tier would consist of SAIC, FAW, Dongfeng and Chang'an with annual sales volumes above 2 million units and another 4 to 5 companies including BAIC, GAIG, Chery and China Heavy Duty Truck Corporation with annual sales volumes above 1 million units. It is interesting to note that Chery is now acknowledged officially as a leading automotive company in China. Another outcome of the rationalisation plan has been an acceleration of overseas acquisitions in 2008 and 2009. However, domestic mergers are expected to dominate 2010 and 2011 (Yu, 2010).

Figure 5 shows the monthly production figures of China's top five automobile manufacturers between January 2006 and March 2010. The past three years clearly highlight the role of domestic policy and economic conditions on vehicle production. For example, in early 2008 there is a brief slowdown in car production, due to the government's monetary and fiscal policy tightening, followed by a rapid surge in production following the RMB4 trillion stimulus package, which was released in January 2009. Production was only possible to grow so rapidly, because the manufacturers have been building up the manufacturing capacity of their plants since 2005, as well as consolidating their control of the market by merging smaller plants.

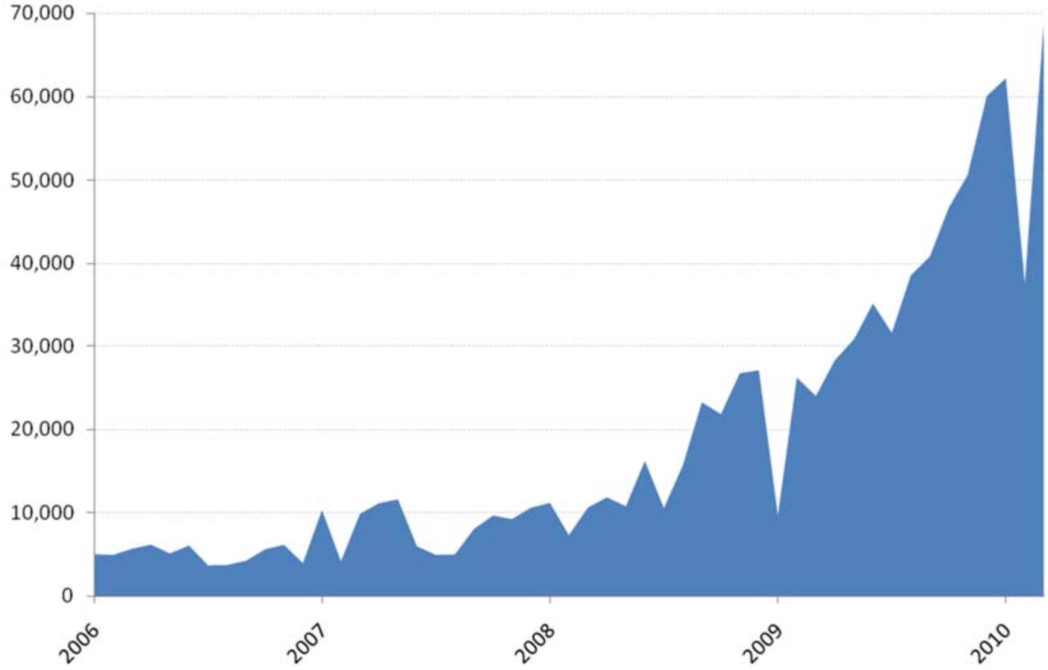
Figure 5. Monthly Production of China's Top Five Automobile Makers, number of vehicles



Source: CEIC Data (2010) from China Association of Automobile Manufacturers; January 2005- March 2010.

One of China's motor vehicle stand-outs is the sudden rise and success of the Shenzhen-based BYD. Figure 6 highlights the dramatic increases in BYD vehicles from 2008 when it introduced its low cost F3 model, which has gone on to become the most popular small car on the domestic market in 2009. The company plans to sell 800,000 vehicles in 2011. BYD has been very successful in marketing its brand both domestically and internationally and will be one of China's first vehicle manufacturers to sell hybrid and electric vehicles on the international market. The company grew on the back of its cell phone components and laptop battery plant, but today auto sale revenues have soared to the front. In 2010, BYD announced plans to spend US3.3 billion on battery development over the next five years. BYD's plug-in E6 entered the Chinese market in 2010 and was planned for launching in the US market in 2011 after ongoing delays. During 2010 and 2011, BYD started encountering a slowdown in sales and a run of domestic media criticism.

Figure 6. Monthly BYD Automobile Production, number of vehicles, 2006-03.2010



Source: CEIC Data (2010) from China Association of Automobile Manufacturers.

2.2 Market Characteristics

During 2009 and 2010, China's motor vehicle market has seen a shift away from the traditional dependence upon foreign-branded vehicles to a more diverse market. The largest market share is still held by global automaker joint ventures, such as Volkswagen (16%), Hyundai (10%) and GM (9%). And yet, privately-owned indigenous manufacturers are increasing their share with Chery Automobiles holding 5.5%, closely followed by the private BYD at 5.1%. In total, China's domestic brands hold a 32% market share with predictions this will rise to 37% by 2015. Assisting this transition is a greater level of dispersed control of the industry with the top-five companies making up 50% of market share compared with 87% in Japan and 65% in the US.

The reduction in tariffs and duties in 2006 to 10%-13% for components and 25% for cars has reduced the price of both imported and domestic cars contributing to a major expansion in the market for cars in China (Figure 7).

In the first quarter of 2009, the number of automobiles sold in China exceeded that in the United States for the first time, making China the largest automotive market in the world. In 2009, passenger cars accounted for about 72% of both output and sales of all automobiles (NBSC, 2010). The total number of motor vehicles on the road in 2009 grew by 45% to reach 76.2 million, including over 13 million low-speed trucks and tri-wheel motor vehicles. Passenger vehicles totalled 52.2 million, half of which are private cars (NBSC, 2010). By 2010, China motor vehicle production made up almost a quarter of global production and almost half of new motor vehicle sales growth.

Figure 7. Automotive Output in China, 1978-2010, thousand units

Year	Motor vehicles	Passenger cars
1978	149	100
1980	222	135
1985	443	237
1990	509	269
1995	1,453	572
2000	2,077	618
2001	2,342	704
2002	3,251	1,092
2003	4,444	2,071
2004	5,091	2,276
2005	5,705	3,932
2006	7,238	5,197
2007	8,873	6,380
2008	9,324	6,729
2009	13,764	10,364
2010	18,243	13,887

Source: NBSC, 2009, CEIC database, 2011.

Over the period 2005 to 2010 the average annual growth rate for passenger cars was 28.7%, while for trucks it was 19.4% and for buses 15.4% (Figure 8).

Figure 8. Output of Cars, Buses and Trucks in China, 2005-2010, thousand units

	Cars	Buses	Trucks
2005	3,932	175	1,170
2006	5,197	195	1,313
2007	6,380	242	1,515
2008	6,729	244	1,623
2009	10,364	276	2,319
2010	13,887	359	2,843

Source: CEIC database, 2011.

Figure 9. Automotive Market in China, Share of Market by Country of Origin of Manufacturer

Year	2000	2007
China	19.8	30.0
Germany	46.5	18.1
Japan	17.1	27.2
Korea	0.0	7.2
USA	6.7	13.1
Others	9.1	4.4

Source: Liu and Yeung, 2008.

While domestic manufacturing provides most of the supply for the Chinese automobile market, China does import some vehicles – in 2007 about 314,000 units with a value of about US$10 billion. In 2010, this figure rose 93% year on year to 813,600 vehicles worth around US$30.64 billion, which included 343,700 SUVs. Japan, Germany and South Korea have been the principal suppliers of imported vehicles for the past five years (Figure 9). Figure 10 shows the composition of Chinese external trade in vehicles and automotive parts from 2000 to 2007. While imports of trucks have remained relatively constant, there has been a major expansion of truck exports to other developing nations, particularly since 2004. By 2009, China produced almost half of global demand for heavy and commercial vehicles with growth in emerging markets (Algeria, Syria, Brazil, Vietnam and Iran) bringing exports to more than 435,000 in 2010.

Similarly, while imports of cars jumped in 2002 and 2003, the growth since then has been modest. Again however, exports have increased rapidly from a low base and now outnumber imports. Imports of automotive parts have been increasing – doubling in recent years – but this has been more than outweighed by a rapid rise in the export of parts. Exports of motor vehicles have been largely constrained by the rapid growth of domestic demand.

Figure 10. Chinese Automotive External Trade, Trucks, Cars and Parts, 2000-2008

Year	Trucks		Cars		Parts	
	Import No.	Export No.	Import No.	Export No.	Import US$m	Export US$m
2000	3,085	7,093	21,620	523	2,112.8	1,125.4
2001	3,138	8,527	46,632	763	2,617.7	1,632.2
2002	6,692	10,520	70,329	969	2,312.4	1,661.3
2003	9,862	26,142	103,017	2,849	7,384.3	5,420.4
2004	8,078	52,796	116,085	9,335	8,679.6	7,946.0
2005	3,032	100,153	76,542	31,125	7,684.9	9,889.5
2006	5,582	163,064	111,777	93,315	10,525.2	19,248.4
2007	7,980	260,311	139,867	188,638	14,215.2	28,691.2

Source: Liu and Yeung, 2008.

The principal destinations for the export of motor vehicles from China have been to relatively unsophisticated markets in the Middle East and elsewhere (Figure 11) although some exports have occurred to developed countries. By contrast automotive components and parts have been sold predominantly to developed countries. This includes exports by foreign companies such as Bosch and Delphi producing parts in China through joint ventures.

Figure 11. Top 10 Destinations for Chinese Automotive Exports, 2008

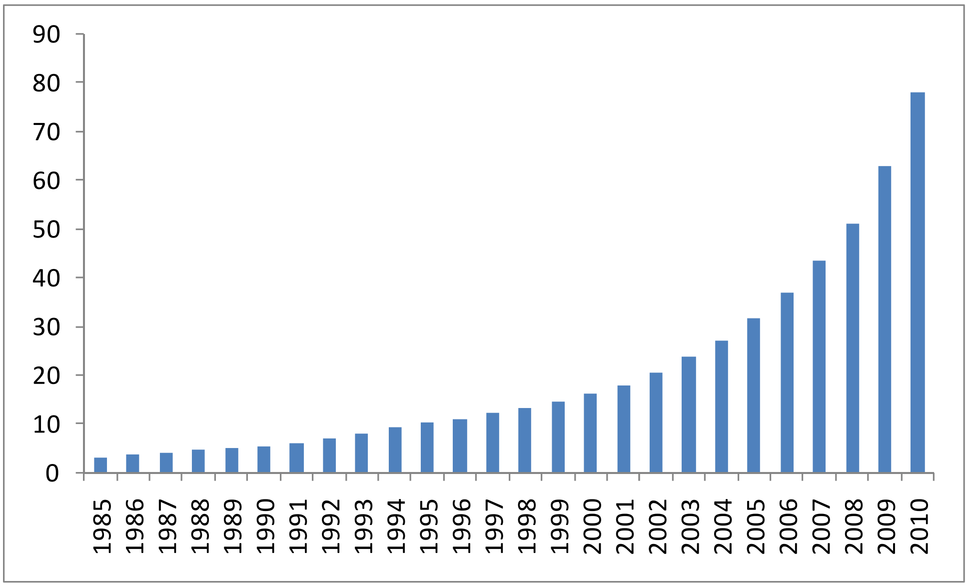
Auto parts		Motor vehicles	
Destination	US$m	Destination	US$m
US	7,873.2	Russia	1,294.5
Japan	4,595.4	Iran	599.6
Korea	1,766.7	Algeria	595.2
Germany	1,094.5	Vietnam	559.6
Canada	854.7	Ukraine	477.0
Holland	832.2	Angola	420.8
Russia	757.0	UAE	288.7
UAE	723.7	Saudi Arabia	282.6
Australia	654.8	Syria	250.6
UK	636.9	South Africa	246.1

Source: China Automotive Industry Yearbook, 2009.

2.3 Projected Demand for Vehicles and Policy Challenges

The strong growth in sales of motor vehicles, particularly for private passenger vehicles, in recent years has led to a massive increase in the number of vehicles in the Chinese passenger vehicle fleet, as measured by vehicle registrations. Figure 12 demonstrates an almost exponential growth with the fleet of passenger vehicles doubling between 2006 and 2010. In 2010, 13.8 million passenger cars were sold.

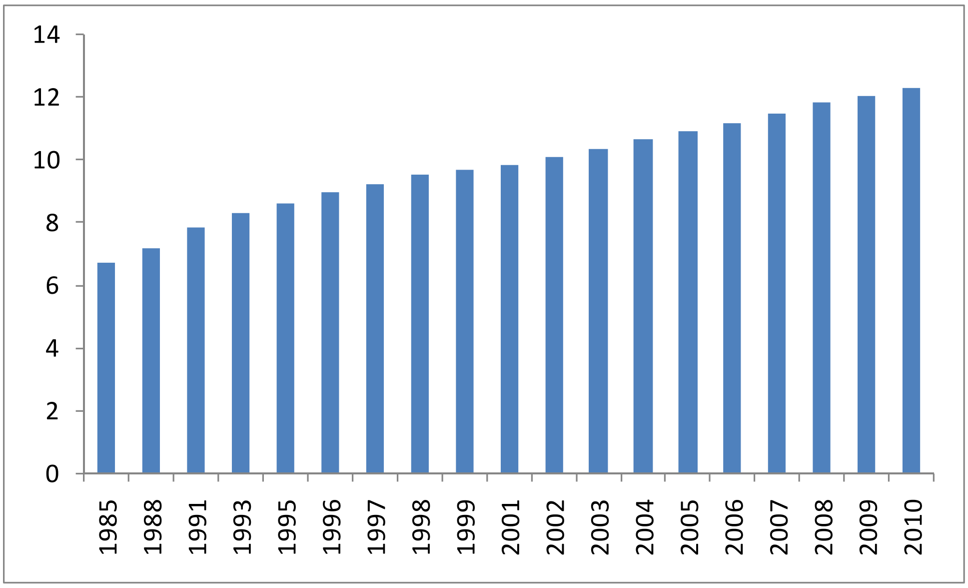
Figure 12. Passenger Vehicle Registrations, China, 1985-2010, million



Source: CEIC database, 2011.

In most advanced industrialised countries, the market for passenger vehicles is virtually saturated with medium-term growth approximating that of population growth. For example, Figure 13 shows passenger vehicle registrations in Australia as an example of such a market, with an average rate of growth in the fleet of about 2.5% over the past five years.

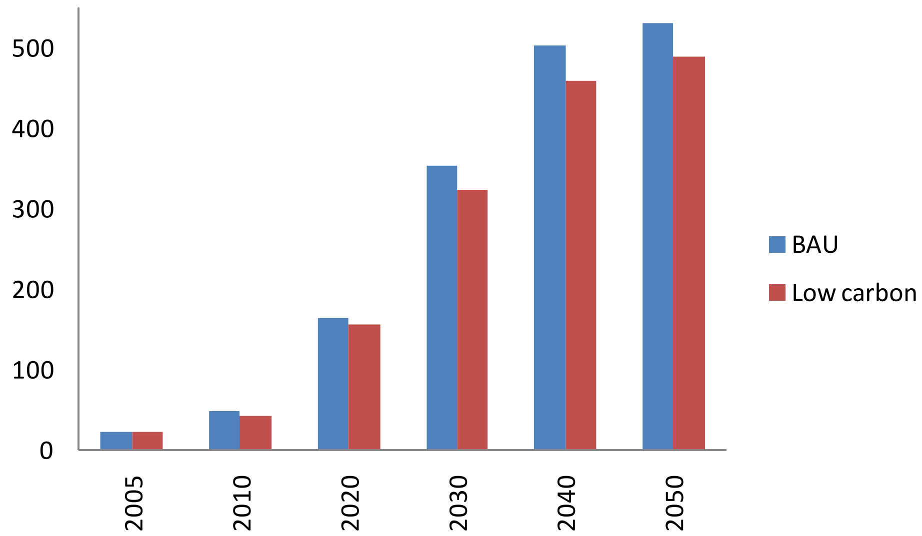
Figure 13. Passenger Vehicle Registrations, Australia, 1985-2010, million



Source: ABS 2011.

If the Australian fleet continues to grow at its current rate, then the number of cars in 2030 will be about 18.2 million or a rise of about 48%. On the other hand, the Energy Research Institute (ERI) predicts that the Chinese passenger vehicle fleet will increase from 48.7 million in 2010 to 353.8 million in 2030, a rise of 626.7%, and reach 531.1 million by 2050 (Figure 14). This is based on their "Low Carbon" scenario which has overall emissions in China peaking around 2040 and remaining steady thereafter (ERI, 2009).

Figure 14. Projected Passenger Vehicle Registrations, China, 2010-2050, million



Source: ERI, 2009.

In contrast, to maintain carbon emissions from Australian passenger vehicles at their levels in 2010 will require cars in 2030 to emit only about 67.6% of the carbon that is emitted by a car in 2010. This goal could be reached using currently available or predictable improvements to current ICE (internal combustion engine) motor vehicle technology.

To achieve the same goal in China will require cars in 2030 to emit 13.8% of the level of emissions in 2010. This cannot be done with just improvements to ICE technology, but requires the rapid adoption of alternative technologies such as hybrid and fully electric vehicles and associated infrastructure.

3. Current Policies to Reduce Emissions from Transport in China

The rapid growth of the automotive fleet in China was accompanied by increasing concern for the impact of air pollutants, both locally in terms of their influence on population health and globally in terms of the contribution of car emissions to atmospheric carbons levels and climate change. A further concern of the Government was to reduce the level of fuel imports particularly against a background of rising import dependency and increasing fuel prices due to strong international demand for oil. Prior to 1993, China was a net oil exporter. However, since then it has become the second largest global importer with the dependency on imports growing steadily.

Carbon emissions from China's road transport represent about 5% of its total emissions. However, they are growing strongly. According to the IEA (2011) China's road transport emissions have increased by more than 400% between 1990 and 2008. According to the Ministry of Science and Technology (Xinhua, 2010) emissions from motor vehicles account for 70% of air pollution in large cities. Presently, 16 of the 20 most polluted cities in the world are in China. The estimated economic costs of air pollution in China vary between 2-7% of GDP. About 79% of the nitric oxide and particulate matter pollution in Chinese cities arises from automobile use (Kearney 2009). As a result, a number of cities have implemented controls on emissions from cars. For example, in the run-up to the 2008 Olympic Games, Beijing city banned the sale of new cars that failed to meet the China IV Emission Standard, which is equivalent to the Euro IV standard to help reduce air pollution. The cities of Beijing and Shanghai also began to limit vehicle usage by excluding cars from the city's roads based upon the final digit on their number plates.

National and local governments have introduced a broad range of policy measures aimed at promoting energy efficiency in the automobile sector, including industrial strategies and supporting initiatives. More recently, the government has introduced economic incentives with lower taxes for the production and consumption of compact vehicles, and raised taxes for larger vehicles.

One of the most effective policy measures for controlling oil demand and GHG emissions has been the introduction of vehicle fuel efficiency standards. China's first fuel efficiency standards were introduced in 2000 with the aim of encouraging foreign vehicle firms from introducing more fuel-efficient technologies into the Chinese market. In 2004 the National Development and Reform Commission announced it would introduce mandatory fuel efficiency standards for passenger cars in two phases. Phase 1 standards took effect from July 2005 for new models and from July 2006 for continued models. Phase 2 standards took effect from January 2008 for new models and January 2009 for continued models. Phase 3 is set to be introduced in 2015 with a target of 42.2 mpg (around 50% higher than current US fuel economy standards and slightly below US targets for 2025).

The standard set up maximum fuel consumption limits according to 16 categories of vehicle weight and by automatic or manual transmission. A study by the China Automotive Technology and

Research Center (CATARC, 2008) found that Phase 1 increased overall passenger vehicle fuel efficiency by 9% from 9.11 litres/100 km in 2002 to 8.06 litres/100 km in 2006, despite an increase in average vehicle weight and engine size. CATARC estimates that since the implementation of the standard, 1.61 billion litres of fuel had been saved and 3.84×10^4 tons of CO_2 had been avoided. However, CATARC noted that local fuel consumption by passenger cars was only equivalent to European and Japanese levels of 10 years ago. And yet, China remains ahead of other advanced economies, such as the US and Australia, which have neglected many opportunities to improve energy efficiency over the past two decades. According to the Australian Bureau of Statistics (ABS, 2011), the rate of fuel consumption across all passenger vehicles using petrol was 11.1 litres per 100 kilometres; a figure which is only exceeded by the USA and Canada amongst OECD countries. In comparison fuel consumption for equivalent cars in China is about 50% higher than in Japan and 14% higher than the EU. Initially the government aimed to align itself with EU and Japanese vehicle fuel economy standards by 2011, but will more likely reach parity between 2015 and 2020. However, cities such as Beijing and Shanghai are accelerating the introduction of stricter fuel economy standards, which will act as a driver for local vehicle manufacturers to comply and tap into local as well as lucrative export sales. It will remain a challenge for China to align average fuel economy with Japan, which is planning new fuel economy benchmarks for petrol engines (Reuters, 2011).[1] The proposed standards will increase average fuel economy from 6.13 litres per 100 kilometres in 2009/2010 to 4.9 litres per 100 kilometres by 2020.

The highest reduction in fuel use was recorded for vehicles based on Japanese technology (18%), followed by independent domestic producers (14%), South Korean and US technology (9%), and European technology (5%). CATARC further reports that other benefits arising from the new standards are the elimination of 444 non-conforming vehicle types and a restraint in the growth of SUVs.

The overall aim of the standard's policy was for vehicles in China to meet Euro-III emissions standards in 2007 and Euro-IV standards by 2010. A survey of passenger vehicle fuel economy and emission standards by the Pew Center in December 2004 concluded that 'The new Chinese standards are more stringent than those in Australia, Canada, California and the United States, but they are less stringent than those in the European Union and Japan' (Feng An and Sauer 2004). Beijing Municipality is leading the introduction of stricter emission standards in China and has announced that it will introduce Euro V-based standards in 2012.

The *Automotive Industry Restructuring and Revitalisation Plan* released by the Chinese Government in January 2009 has been mentioned earlier in the context of moves to further rationalise the industry, but it also contained major initiatives to stimulate the market for cars in China following disappointing growth of 6.7% in 2008, to build a larger market share for domestic suppliers and to

[1] Plug-in hybrids and electric vehicles would be excluded from the requirements and yet fuel hybrids, such as Toyota's Prius, would be included.

address concerns about energy security, competitive advantage, air pollution and climate change. In particular the Plan aimed to:

- increase sales and production in 2009 to 10 million units and to keep growth at 10% per annum for the following 3 years;
- increase the market share of domestic brands from 34% to 40%; and
- increase the market share of cars with a capacity of 1.5 litres or less to 40% and for those with a capacity of 1.0 litres or less to 15%.

The measures to achieve this included:

- a lowering of the vehicle purchasing tax from 10% to 5% on cars under 1.6 litres capacity and an increase of the tax on larger cars, minivans and SUVs;
- an increase in the price of petrol and diesel following the introduction of China's first fuel tax in 2009;
- a RMB3,000 subsidy for vehicles using less than 6.3 litres of fuel or less per 100 kilometres.
- the establishment of a fund of RMB5 billion to help rural citizens upgrade 3-wheelers and low speed vehicles to small vehicles of 1.3 litre capacity or less;
- increased subsidies to encourage people to scrap old cars and purchase new fuel efficient cars; and
- efforts to remove 'any unreasonable rules' hampering car sales and to improve the process for obtaining finance for new car purchases.

Sales data following the stimulus package resulted in the rapid growth of smaller cars, minivans and mini-trucks picked up considerably as well, while sales of larger vehicles were sluggish. Overall sales of motor vehicles grew by 32% in 2010 with 13.8 million new passenger vehicles purchased. However, following the withdrawal of reduced tax rates for smaller cars, increasing levels of traffic congestion and restrictions on new registrations in Shanghai and Beijing, sales for the first three quarters of 2011 were flat with 3.2% growth and sales are expected to grow by around 5% for 2011. There has also been a noticeable rebound towards luxury and SUV vehicles.

While the emphasis on smaller cars will help control emissions of pollution and greenhouse gases, the stimulus to the whole industry and the strong growth targets will work against achieving better environmental outcomes. Through a recent *New Energy Vehicle Plan* and by other measures, the Government has encouraged consumers and manufacturers to move towards more fuel efficient and less polluting vehicles. The government has agreed with the automotive industry to establish the capacity to produce 500,000 'new energy' vehicles (NEV) by 2015 and five million NEVs by 2020. NEVs refer to pure electric, hybrid, fuel cell and plug-in hybrid vehicles. This ambitious target was initially set for 2011 and would have been equivalent to around 5% of overall capacity within the industry. However, initial teething problems in the sector have resulted in more conservative revisions to the growth of the new energy vehicle segment.

In 2009, the Government released the *Ten Cities with 1,000 New Energy Vehicles Program* so that there would be at least 10,000 new energy vehicles on the road by 2010. Due to the enthusiastic support of local governments, the program has been expanded to 20 large cities, each promising to use government procurement policies to promote NEVs in the initial development stage. The country's largest electric power company, the State Grid Corporation of China has begun to install charging stations in larger cities such as Beijing, Shenzhen, Hangzhou, Wuhan and Shanghai (CHINAtalk 2009b). Beijing Municipality has committed itself to ensure that funding and infrastructure meets the growing demand for electric vehicles (EVs). By 2016, it will establish a network of 182 battery replacement stations, 68 recharging stations, 6 battery charging points and 210 battery distribution centers. Shenzhen plans to have 24,000 electric vehicles on the road and 12,750 charging stations by 2012. Hangzhou is to install 56 battery charging and replacement stations using 590 AC charging in 2011.

China's 12th Five Year Plan (2011-2015) for EVs was developed by the Ministry of Science and Technology (MoST). Even though the plan was yet to be formally released, by late 2011, the first phase of the plan had been implemented covering 77 projects with RMB780 million in government funding allocated. The strategic direction of the plan is to advance electric vehicle technologies including batteries, electric motors and electric control systems. The key aims during the plan period are to:

- develop a domestically manufactured light PEV;
- have one million EVs nationwide;
- expand the pilot EV cities program from the original 10 cities to over 70;
- introduce standards for EVs and supporting infrastructure;
- build over 2,000 charging stations and 400,000 charging bays in the pilot cities;
- decrease battery production costs by 50%; and
- expand the annual production capacity of batteries to 10 GW.

The draft EV Plan provides broadly defined technology pathways for: battery production; integrated EV systems; performance; standards for technologies covering battery recharging and replacement; pricing ratio of EV, hybrid and PEVs; and market share.

Supporting the move to electric cars, the Government also announced that it would create capacity to produce 1 billion Amp/hr of high performance battery modules, or the equivalent of about 750,000 Chevrolet Volt battery packs; and create a fund of RMB10 billion to support domestic manufacturers to upgrade technology and develop new alternative energy engines.

This emphasis on alternative fuel vehicles technology was first flagged in the Science and Technology Middle- and Long-Term Development Plan (2006-2020) which highlighted hybrid, alternative fuel and fuel cell vehicles as priorities for research. It also announced the establishment of a State Key Laboratory of Automotive Safety and Energy within the Ministry of Science and

Technology (MOST). This was followed more recently by the establishment by MOST of a Beijing New Energy Auto Design and Manufacture Base in December 2008.

In January 2009, the Government announced a program to provide subsidies for the purchase of hybrid, electric and alternative fuel vehicles in 13 pilot cities including Beijing, Shenzhen and Shanghai. The program is largely aimed at buses and taxis and vehicles used by the government in areas such as the postal services. "Zero emission" and alternative fuel cars, such as fuel-battery hybrids, plug-in hybrids and pure electric vehicles can receive subsidies of between RMB6,000 and RMB60,000 from the national government, with similar amounts on offer from municipal governments up to a total subsidy of RMB120,000.

While the current average carbon intensity of China's electricity grid remains high due to the dependence upon coal, there are few carbon emission reduction benefits arising from promoting EVs. However, there remains significant regional variation in carbon intensity across the national grid. According to Michalowe (2011) and Huo et al. (2010), the national average operating margin for six of the grids is 1.003 kg CO2-e/kWh. In contrast, Cao, Guo, Gu and Zhang (2011) provide a 2007 figure of 0.982 kg CO2-e/kWh. Given that two thirds of new coal thermal capacity has been either supercritical or ultra-supercritical, these average figures are likely to have already fallen significantly. In addition, there are clear signs that significant future reductions in the carbon intensity of the grid shall take place in the coming two decades.

Given the current situation of high carbon intensity for the national average across the grid and the significant variation with lower intensities in southern and eastern grids, there is a need for well-designed pilot and demonstration programs to ensure they do not exacerbate carbon intensity of the grid. Therefore, pilot EV programs should be implemented in areas where the grid's carbon intensity is lowest or where pairing with distributed renewables and/or storage capacity is efficient and effective. The Shenzhen and Beijing pilots provide a useful contrast on this point. While both cities are part of the pilot '10 Cities, 1000 Vehicles' electric vehicle program, they provide an opportunity to highlight the divergent designs of government support.

The control of the development of alternative fuel vehicles in China rests with the National Development and Reform Commission (NDRC) which issued the Administrative Regulations for the Approved Commencement of the Manufacture of New Energy Automobiles in October 2007. The regulations put NDRC in charge of approving companies wishing to manufacture alternative fuel vehicles. The regulations distinguish between: (a) 'initial' stage technologies, which may only be manufactured in small batches, (b) 'developing' stage technologies, which can be produced in larger batches, and (c) 'mature' technologies, which can be mass produced. Manufacturers wishing to make these vehicles must possess at least one key technology involving energy storage, mechanical operation or system control.

The technologies covered by the regulations include hybrid vehicles, battery electric vehicles (including solar powered), fuel cell vehicles, hydrogen-powered vehicles and other technologies such as high-efficiency accumulators (Zhang 2008).

Several projects and initiatives are being undertaken to increase the use of alternative fuels and technologies. These include the following.

Natural Gas

The number of vehicles powered by natural gas is still small at about 200,000 and widespread uptake is likely to be constrained by the lack of infrastructure to supply this fuel. However for locations near natural gas supplies, the potential for greater use is considerable. The Dongguan local government in Guangdong province has announced it will invest RMB72 million in the construction of 60 natural gas fuelling stations by 2015 and will convert 90% of the local bus and taxi fleet to run on natural gas. Shanghai had 400 gas-fuelled buses and 40,000 alternative energy vehicles for the 2010 Expo. Similar natural-gas fuelled bus programs are underway in Dalian and Chengdu. In promoting these programs, the government should highlight natural gas' lower end-of-pipe emissions but address the supply source and the full life cycle emissions in designing and implementing policies which promote the use of natural gas.

Solar Power

There has been very little work on solar powered vehicles, although the Zhejiang 001 Group has produced 10 concept cars based on their electric bike technology. These vehicles have a limited range of 150 kilometres and require 30 hours for recharging. However additional work on solar power is being undertaken in universities and research laboratories.

Biofuels

The Government has set a goal of producing 10 million tonnes of ethanol and 2 million tonnes of bio-diesel by 2020 to replace oil consumption in rural areas. After a rapid expansion in the production of ethanol from biomass, the Government restricted further development in 2006 because of concerns about the use of food crops for fuel production. This has led to a switch to non-food crops and several plants using feedstock plants have been set up in Guangxi, Jiangsu, Hebei and Hubei provinces. An R&D partnership between Royal Dutch Shell and the Qingdao Institute of Bioenergy and Bioprocess Technology has been established to investigate biofuels. There is a need for a high level of caution in embracing biofuels. However, it is likely that biofuels will play an increasing role globally as a fuel substitute. Therefore, policies aimed at promoting cleaner biofuels and reducing lifecycle emissions are critical whilst avoiding the potential negative implications for food production and land management.

Fuel Cells and Hydrogen

While the economics of fuel cells in cars is still not favourable in any country, China has undertaken both research and demonstration projects with this technology. In 2002, the Government announced it would invest about USD$18 million in a three-year fuel cell development program, the majority of the funding going to the Dalian Institute of Chemical Physics. Both Beijing and Shanghai have had demonstration trials for fuel-cell powered buses. As part of its plan to develop advanced hybrid-electric and fuel cell vehicles, MOST provided funding for the development of 150kW fuel cell bus prototypes.

Some of the institutions involved in developing fuel cell technology include the Chinese Academy of Science and Technology, Zhejiang University, Shanghai Shen-Li High Tech Corporation, Shanghai Automotive Industry Corporation, Dalian Institute of Chemical Physics, Hong Kong University of Science and Technology, Tongji University and Tsinghua University.

Electric and Hybrid Vehicles

While hybrid electric-petrol vehicles such as the Toyota Prius, the Honda Civic Hybrid and the Buick LaCrosse have been available in China for a few years, their sales have been small mainly because of their cost. Following the Government's emphasis on 'new energy' vehicles, however, several domestic manufacturers have begun to produce hybrid vehicles.

In 2008 BYD Auto released its F3DM plug-in hybrid electric vehicle sedan, the world's first production vehicle of this type, with a range of about 100 kilometres between charges. BYD Auto was set up in 2003 and is part of BYD Company Limited, which was established in 1995 and produces about 65% of the world's nickel-cadmium batteries and 30% of the world's lithium-ion mobile phone batteries. BYD has attracted a lot of publicity because of the decision by Berkshire Hathaway to invest in the company. In April 2009, BYD announced a joint venture with Volkswagen to explore using BYD designed batteries in their future hybrid/electric vehicles.

In February 2009, Chery produced its first electric vehicle, the S8, with a range of 93 miles and 4-6 hours recharge time. Other companies such as Beiqi Foton and Chang'an have also produced prototype hybrid vehicles. FAW has set up a hybrid electric bus manufacturing plant in Dalian and in April 2009 the Renault-Nissan alliance in cooperation with the Ministry of Industry and Information Technology and the Wuhan municipal government agreed to build a pilot electric-car program in the city. The China Automotive Engineering Research Institute set up an electric car R&D facility in Chongqing in February 2009.

Figure 15 presents examples of electric vehicle models announced by Chinese automotive manufacturers over the past few years.

Figure 15. Recent Examples of Electric Vehicle Announcements in China

Manufacturer	Model
BYD	E6
Chery	M1 EV, QQ3 EV
Chana	Benni EV-Chana
Zotye	5008 EV
Gonow	GA6380 EV
Haima	Freema EV
Lifan	620 EV, 320 EV
Great Wall Motors	ULLA

Source: Earley et al. 2011; author's own.

4. Policies for Emission Standards and Vehicle Prices

In previous papers for this project, a number of policy options for reducing emissions from road transport have been described, including the introduction of stricter standards for fuel efficiency or carbon emissions, fuel taxes and subsidies, vehicle purchase taxes and registration fees, the development of alternative fuel infrastructure, and the promotion of alternative transport modes.

Developments in emission standards for a range of countries have been described and these are summarised in the appendix to this report.

As a result of the discussion at a joint ERI-CSES conference in September 2010, further work has been done on a policy option that has been gaining increasing attention internationally. This is the combination of vehicle purchase fees and rebates known as a "feebate". It complements and extends the setting of emission standards.

Feebates

Governments are becoming increasingly interested in reinforcing the impact of emission standards by other measures such as applying penalties to high emission vehicles and/or subsidies to low emission vehicles.

This is captured in the concept of a feebate as defined by Bunch et al. (2011):

> *A market-based policy for encouraging greenhouse gas emission reductions from new passenger vehicles by levying fees on relatively high-emitting vehicles and providing rebates to lower-emitting vehicles.*

Currently Denmark, France, the Netherlands and Norway have implemented programs that impose fees and rebates on motor vehicles according to the level of carbon emissions of the vehicle. A range of other countries either just impose fees or just give rebates.

Feebate programs vary in their design among countries, but the simplest design is described in a study for the International Council on Clean Transportation by German and Meszler (2010) and is shown in Figure 16.

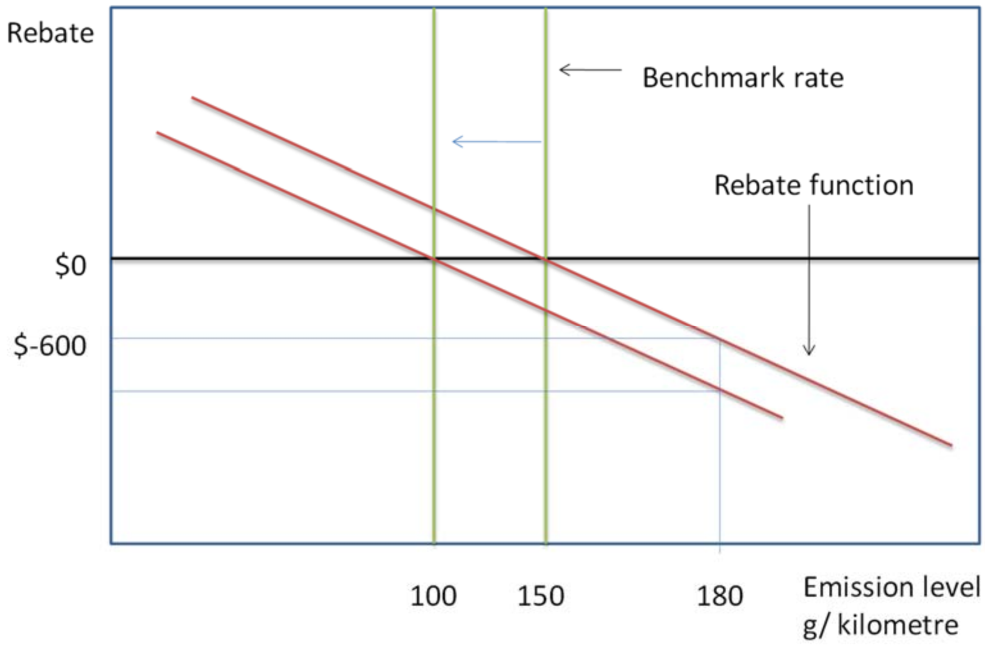
An emissions standard is set in terms of grams of carbon emitted per kilometre, and this is shown as the vertical line "Benchmark CO_2". Vehicles with a lower emission level receive a rebate which is determined by the slope of the rebate function, while those with a higher emission level pay a fee (or negative rebate).

The feebate is calculated using the following formula:

Feebate = rate(benchmark rate - emission rate of vehicle)*

where rate is in currency units per gram per kilometre.

Figure 16. An Idealised Feebate Program (German and Meszler 2010)



If for instance the benchmark rate is 150 grams of carbon emitted per kilometre and the rate is $20 per gram per kilometre, then a car with an emission level of 125 grams would receive a rebate of $20*(150-125)= $500, while a car emitting 180 grams would be levied a fee of $20*(150-180)= $600.

Over time the benchmark rate can be lowered, in which case the size of the rebate will be lowered and the size of the fee increased. In Figure 16, if the benchmark rate is reduced from 150 to 100, then the fee levied on a car emitting 180 grams would rise from $600 to $1600.

In most designs of a feebate program, the fee is paid by the manufacturer rather than the dealer or consumer, although it is expected that most of the fee will be passed onto the consumer as a higher purchase price.

In the absence of a feebate program, manufacturers will tend to design cars to meet the emissions standard and no better. The feebate encourages manufacturers to design their cars so that fewer will exceed the limit and be charged fees, and more will exceed the limit and earn a rebate.

Once an emission standard has been set, consumers are likely to pay more for cars if manufacturers have to design to the emissions limit, because manufacturers will pass on the extra cost. Under a feebate program, consumers will have to pay an additional amount if they purchase a car which exceeds the benchmark.

The cost of the standard and the feebate may however be offset if consumers travel the same distance as before but consume less fuel because of the increased fuel efficiency. The savings in fuel cost will offset to some extent the increased cost of the vehicle.

Bunch et al. (2011) in their examination of the potential introduction of a feebate program in California concluded that under plausible assumptions, about three different versions of a future feebate scheme are possible:

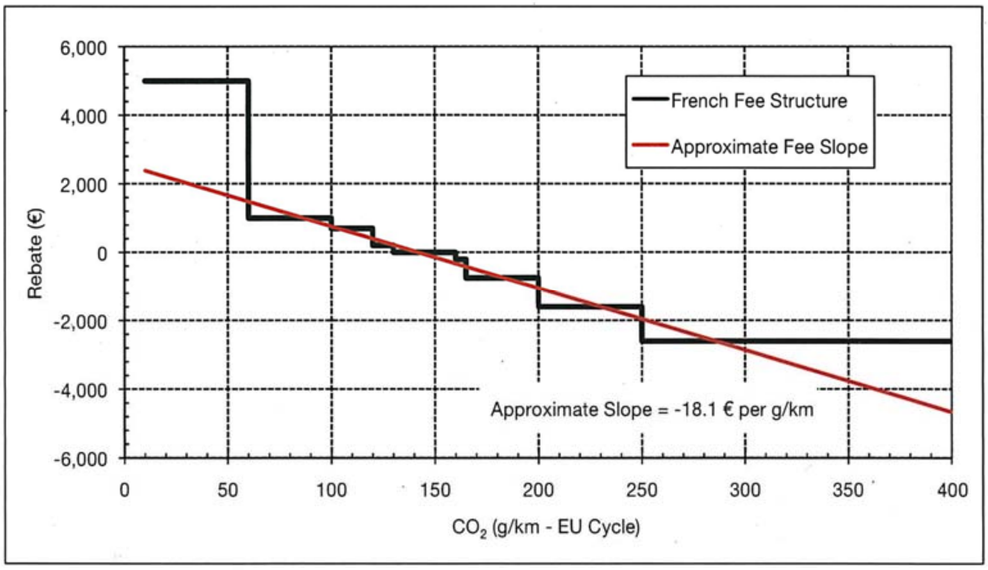
> *…when all costs and benefits are taken into account, the monetary value of fuel savings outweighs other costs (including loss of consumer surplus, administrative costs, etc.) so that all three feebate systems generate a net negative social cost. In other words, in addition to reducing greenhouse gas emissions, feebates also generate net positive social benefits.*

A feebate program can be designed so that it is revenue neutral to the government. If this is the case, then consumers purchasing less efficient cars are effectively subsidising those that buy more efficient cars. However as the feebate program encourages consumers to shift to more efficient vehicles, in the absence of a shift of the benchmark rate, there would be more rebates and fewer fees so the program would no longer be revenue neutral. Periodically lowering the benchmark therefore, would restore revenue neutrality. The revenue neutral feebate program has thus an in-built tendency to continuous improvement in emissions reduction.

In its assessment of the environmental and economic impacts of feebates for the European Union, the Institute for Prospective Technological Studies concluded that:

> *In general, a feebate system is almost neutral in terms of total new car sales but there is a clear shift to smaller cars and, given the incentive to shift the purchase decisions to lower CO2 emitting cars, the policy instrument results in reductions of GHG car emissions. This holds true both in the short term (by 2015) and in the long term (by 2020).*

Figure 17. The French Feebate Program (German and Meszler 2010)



The French feebate program is the one that is closest to the idealised version discussed above and is illustrated in Figure 17 reproduced from German and Meszler (2010). Instead of a continuous rebate function, the French program has been designed around emission intervals, with a zero rebate of 130-160 grams per kilometre. The fitted line in Figure 17 indicates that the program is equivalent to imposing a fee of around 18.1 Euros per gram per kilometre. The program over compensates vehicles with very low emissions levels and undercharges vehicles with very high emission levels.

5. Automotive Technology Roadmaps

While the Chinese Government has given strong indications of its on-going support for the domestic automotive industry and provided assistance in the development of alternative fuel vehicles, it has only recently finalised a comprehensive roadmap of how the industry should develop or how the technology required to meet its objectives should be developed or acquired. This roadmap is described in the following section.

Roadmaps are common in industries that are reliant on the development of new technology to maintain their competitive positions. Thus roadmaps have been developed in the USA and elsewhere for the semiconductor, software, nanotechnology, aerospace, light metals and building industries. In Australia, the Department of Resources, Energy and Tourism published a Hydrogen Technology Roadmap 'to assess Australia's hydrogen research capabilities and strengths and to identify what actions Australia could take to prepare for the possible emergence of a hydrogen economy' (Wyld Group 2008). This roadmap however concentrated on stationary energy applications with little discussion of potential use in road transport.

The NRMA set up The Jamison Group to produce "A Roadmap for Alternative Fuels in Australia" (Jamison Group 2008), which sets out a series of recommendations to reduce dependence on fossil fuels in transport. However there is only limited discussion of how to develop alternative technologies for application in Australia. The CRC for Advanced Automotive Technologies has reviewed Technologies for Sustainable Vehicles (Albrecht et al. 2009) as the first report of its project to determine the impact that electric vehicles could have on CO_2 emissions in Australia, and to determine the requirements for charging infrastructure, the impact on the electricity demand, and the need for additional renewable energy generation. Again however, the report does not specify a technology roadmap for the introduction of electric vehicles in Australia.

For a number of years, Japan has had strategies and associated technology development programs to develop more fuel efficient vehicles and to reduce carbon emissions within the transport sector. In 2009, the New Energy and Industrial Technology Development Organization (NEDO) released the final draft of the "2008 Roadmap for the Development of Next Generation Automotive Battery Technology." This roadmap covers the development of batteries used in plug-in hybrid cars and electric cars, which are expected to play main roles as next generation vehicles. Present performances and costs, as well as those to be attained by 2010, 2015, 2020, and after 2030, are shown as target values. The overall aim is to develop innovative batteries that will have 7 times the performance of current batteries at 1/40 of current prices. The roadmap fits within the larger Next-Generation Vehicle and Fuel Initiative announced in May 2007 by the Ministry of Economy, Trade and Industry (Noda 2008).

In the USA, the Department of Energy released its National Battery Collaborative (NBC) Roadmap in December 2008 (USDOE 2008). The NBC is a 6- to 8-year program with funding up to $4.5 billion.

The aim of the NBC is to help ensure that the United States leads the world in current and next generation battery technology and establishes a robust and dominant US-based battery manufacturing industry.

The United States Council for Automotive Research (USCAR) was founded in 1992 as an umbrella organization for collaborative research among Chrysler Group LLC, Ford Motor Company and General Motors Company. Its goal is to further strengthen the technology base of the U.S. auto industry through cooperative research and development. The United States Advanced Battery Consortium is part of USCAR and aims to develop electrochemical energy storage technologies which support commercialization of fuel cell, hybrid, and electric vehicles. The consortium has set long-term goals for the cost and performance of advanced batteries for electric vehicles (USABC 2010).

The US state of California introduced its Zero Emission Vehicles (ZEV) Program in 1990 to promote the use of zero emission vehicles. The program goal is to reduce the pervasive air pollution affecting the main metropolitan areas in the state, particularly in Los Angeles, where prolonged pollution episodes are frequent. Although concentrating on pollutants such as NOX and SOX and particulates, the program has also incorporated California's greenhouse gas targets, namely to reduce these to 1990 levels by 2020 and by 80% by 2050. The program was subject to a review by staff of the California Air Resources Board and this involved a comprehensive review of electric and fuel cell vehicle technologies which set out development paths for these technologies (CARB 2009).

In recent months the International Energy Agency (IEA, 2009) and the Canadian Government (Electric Mobility Canada 2009) have also released technology roadmaps for electric vehicles.

As noted earlier, the most comprehensive strategy for reducing carbon emissions from transport is that announced by the United Kingdom in 2009. The programs and policies making up this strategy have been supported by a range of technology and policy reviews such as the King Review of Low Carbon Cars (King 2007, 2008), the report of the New Automotive Innovation and Growth Team (NAIGT 2009) and other reports (e.g. Ricardo 2009). This latter report on the future of the automotive industry in the UK incorporates a comprehensive technology roadmap and research agenda for achieving low carbon transport. These recent reports build on an earlier major foresight exercise by the UK motor vehicle industry (SMTT 2004) which has recently been updated (KTN 2009).

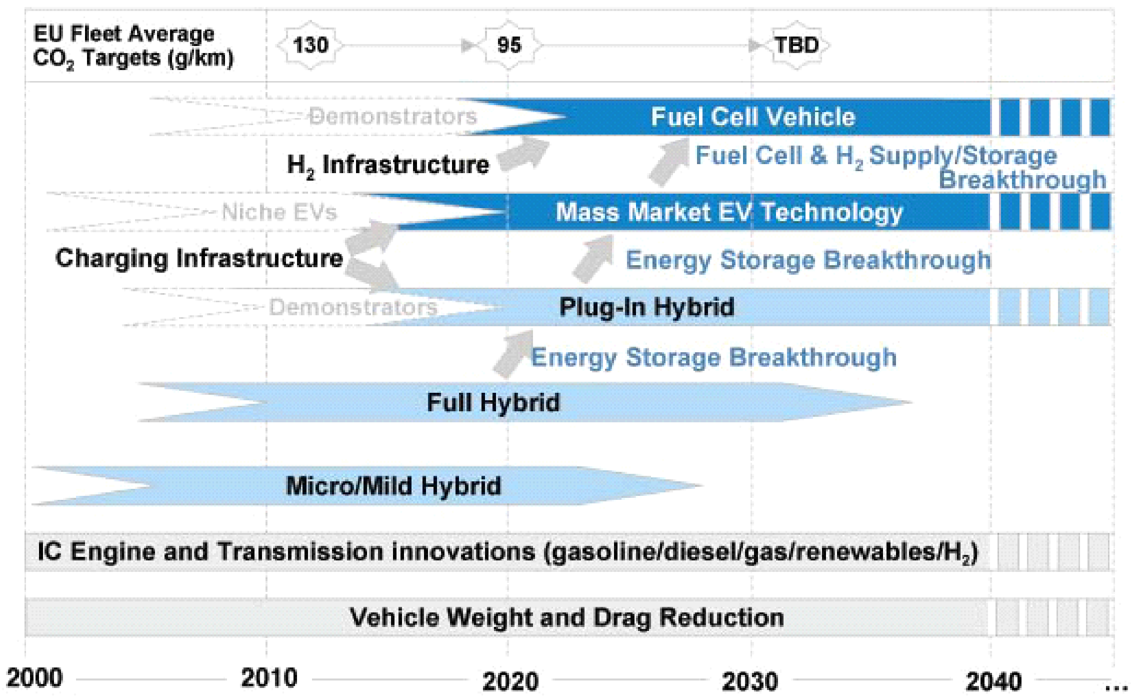
The UK Energy Research Centre provides a review of energy technology roadmaps relevant to the UK, including those for road transport and hydrogen and fuel cells (UKERC 2009).

Most of the roadmaps referred to above set out goals and expected technology development paths for improvements to conventional transport technologies, emerging technologies and anticipated technologies. The UK Consensus Roadmap developed by NAIGT is a good example, and an overview of this is reproduced as Figure 18.

The roadmap notionally covers the period from 2010 to 2040 and begins at the bottom of the figure with those efficiency improvements that are possible for any type of road transport vehicle such as reducing weight through the use of light metals and composite materials and improving aerodynamic design by designing vehicles so that drag is minimised. Improved tyre technology is also important in reducing rolling resistance.

The second level of the roadmap covers improvements that can be made with conventional fuel internal combustion engines, either using existing fuels such as petrol or diesel or alternative fuels such as natural gas, biogas, biofuels derived from crops, cellulose or algae, and possibly hydrogen. The efficiency of engines can be improved with advanced turbocharging, better injection control, lowering engine friction, electrification of engine accessories and other known or near term technologies.

Figure 18. UK Transport Technology Roadmap



Source: NAIGT, 2009.

Hybrid vehicles using both ICE engines and electric motors are the next group of technologies on the roadmap, and range from micro hybrid in which the electric motor drives accessories through to fully hybrid in which the engine creates electricity to drive the electric motor. Currently most emphasis is on plug-in hybrid electric vehicles (PHEV) which rely on recharging the batteries that provide power to the motor, while the IC engine provides power on long distance trips. As noted in the figure, the full development of both PHEVs and fully electric vehicles require significant improvements in battery technology to match the performance of current vehicles at a reasonable price.

The other main option for low carbon vehicles is those powered by fuel cells which convert a fuel directly to electricity to drive electric motors. Although there are a number of fuels that can be used in a fuel cell, hydrogen is the one which has gained most support. There are however major obstacles to producing, transporting, and distributing hydrogen, and in storing sufficient amounts on board which need to be overcome before fuel cell vehicles are competitive with conventional vehicles.

6. Technology Roadmap for China's Electric Vehicle Industry

On the basis of extensive research on the technological requirements for electric vehicles, their battery and control systems, as well as in-depth consultation with industry and research organisations in China and overseas, the Energy Research Institute has developed a comprehensive policy and technology roadmap. The roadmap draws upon previous analysis by the ERI and the Centre for Strategic Economic Studies (CSES) described in earlier papers produced in the course of this project. The roadmaps found that the widespread deployment of electric vehicles will be dependent upon three important factors: advances in battery technology; the deployment of charging facilities; and pricing parity between electric vehicles and conventional vehicles.

The reports by ERI and CSES are being prepared for publication in both Chinese and English in the latter part of 2011. The roadmap and its background analysis are summarised in this section of the report.

While further improvements can be made in electric motors and control systems for electric vehicles, the roadmap concentrates on the improvement of battery performance and cost so that electric vehicles can be competitive with mainstream internal combustion engine vehicles in terms of consumer acceptance. Aside from performance and cost, electric vehicles need to be as convenient as ICE vehicles on other aspects such as safety and refuelling.

China already has significant capabilities in lithium-ion battery technology which is seen as the standard for the near term development of electric vehicles.

6.1 Competitive Position in Electric Vehicle Battery Technology

In 2010, the Fraunhofer Institute for Systems and Innovation Research in Karlsruhe, Germany released a technology roadmap for lithium-ion batteries to the year 2030 (Fraunhofer ISI 2010). Supporting the analysis was a search of patents for lithium-ion batteries granted worldwide between 1990 and 2008. The results in 5-year intervals are given in Figure 19.

It is clear that Japan has dominated the research into lithium-ion batteries until about 5 years ago. Its position has been challenged more lately by South Korea, while the USA has maintained a share of patents of about 17%. China is now the fourth largest country with respect to patents, a position it has developed from zero over the past 10 years. Germany and France are the leading European countries, while the share of all other countries has increased over recent times indicating a much wider research effort than in the past.

Figure 19. Shares of Lithium-Ion Battery Patents, %

	1990-1994	1995-1999	2000-2004	2005-2008
Canada	5.7	3.6	2.3	2.0
China	0.0	0.0	3.8	6.2
France	6.9	3.9	2.8	2.5
Germany	2.3	5.5	4.8	4.8
Great Britain	0.6	1.7	1.5	1.1
Japan	64.0	62.6	57.5	35.4
Other	3.9	1.5	1.1	12.7
South Korea	0.0	1.7	9.7	16.6
Switzerland			0.7	1.9
USA	16.6	19.5	15.8	16.8

Source: Fraunhofer (2010).

An additional analysis by the Institute of publications on research into battery systems during the period 2005-2009 showed lithium-ion systems to be the dominant type (Figure 20).

Figure 20. Shares of Battery Publications, 2005-2009, %

Battery type	Share
Lithium-ion	73.6
Lead-acid	14.4
Nickel metal hydride	5.3
Nickel cadmium	1.3
Redox flow	1.1
Metal air	1.0
Lithium-sulfur	0.6
Sodium-sulfur	0.3
Sodium nickel chloride	0.2
Other	2.1

Source: Fraunhofer (2010).

It is clear from this and other analyses that developers of both hybrid and fully electric vehicles are standardising on lithium-ion battery technologies, although there is substantial work on other advanced battery types being undertaken in research organisations.

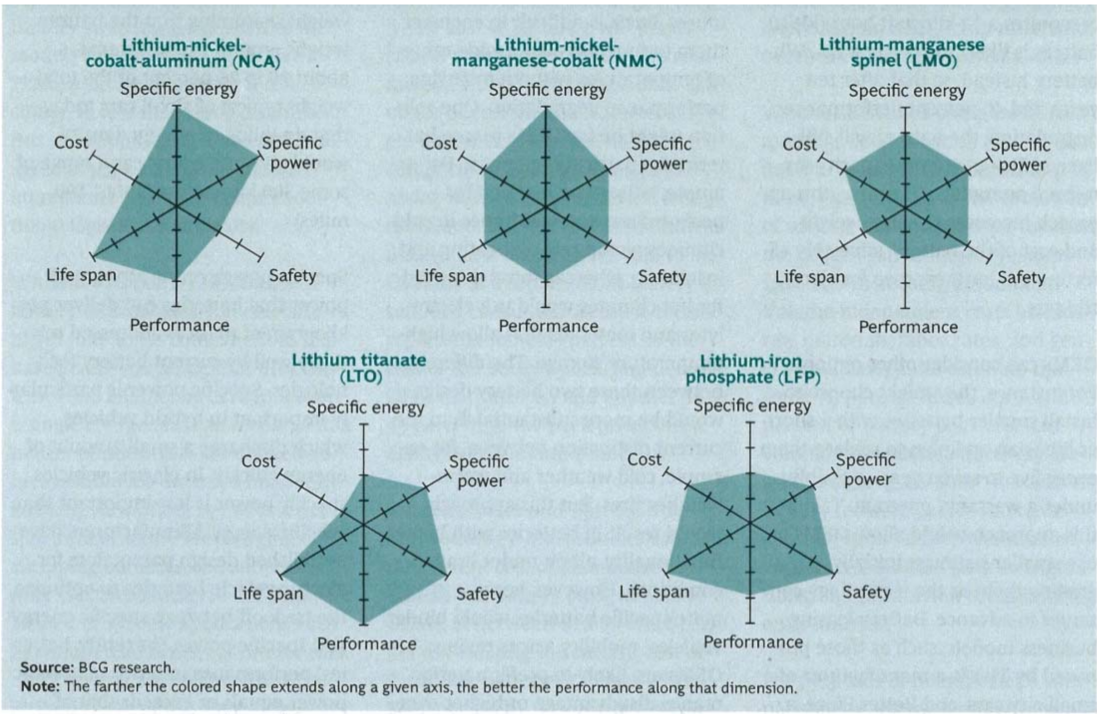
There are several types of lithium-ion battery technologies, the most important of which are:

- Lithium-nickel-cobalt-aluminium (NCA)
- Lithium-nickel-manganese-cobalt (NMC)
- Lithium-manganese spinel (LMO)
- Lithium titanate (LTO)
- Lithium-iron phosphate (LFP)

According to a report by Boston Consulting Group (2010), recent patent activity for lithium-iron phosphate technologies has been twice that of LTO and four times that of NMC, due to the better safety characteristics and higher usable capacity of LFP. Boston Consulting Group evaluated the different lithium-ion battery technologies along six dimensions (Figure 21):

- Safety
- Life span, namely charge-discharge cycle and battery age
- Performance, namely peak power at low temperatures, state-of-charge measurement and thermal management
- Specific energy measured as energy stored per kilogram of weight
- Specific power, measured as power stored per kilogram of weight
- Cost

Figure 21. Boston Consulting Group Comparison of Lithium-Ion Battery Technologies



Source: BCG (2010).

While no one battery technology is superior on all criteria, the lithium-iron phosphate battery is probably the safest, scores well on life span and is reasonable on specific power, performance and cost.

Given the intensive research effort underway on lithium-ion batteries, the limits for these batteries are likely to be reached within the next ten years and the other advanced battery technologies will need to be developed to meet performance requirements for motor vehicles.

A workshop conducted by the Advanced Research Projects Agency – Energy (ARPA-E) in November 2009 assessed the various advanced battery technologies including lithium-air, lithium-sulfur, lithium-metal, zinc-air, and molten metal such as sodium nickel chloride

They concluded that:

- Lithium-ion batteries have significant room for continued improvement to meet USABC Long-term EV Battery Targets.
- Lithium-sulfur battery technology is continually maturing in energy density and cycle life.
- Lithium-Air technology is still in its early stages, but here were large prize in terms of energy density at the end of the tunnel.
- Zn-Air/Metal-Air held strong promise and there had been good progress to date, but opportunities in metals other than Zn need more exploration.
- Sodium nickel chloride batteries had made strong recent progress and had many positive attributes; thermal management is an issue and makes fleet applications most appealing.
- For the U.S. to regain battery manufacturing leadership, novel high performance battery architectures and new manufacturing processes need to be developed and deployed domestically.

In 2009, the German consultants Roland Berger reviewed China's plans to become a market leader in electric vehicles. They concluded that Chinese suppliers already had some competitive advantages, namely:

- Lower raw material costs and ability to drive down manufacturing costs for Li-ion battery cells fast by using domestically produced equipment.
- In Li-ion battery production, they will have the economies of scale necessary for future success. China already has a significant manufacturing base for Li-ion cells and is putting vast resources in research and production ramp-up.
- Chinese suppliers have successfully developed leading quality permanent-energized synchronous machines – at significantly lower price than overseas competitors. To do so, they can leverage the fact that China possesses 80% of global neodymium resources, the critical material to produce permanent magnets.

They also found that Chinese suppliers lead by BYD had successfully developed LiFePO4 batteries offering competitive performance in EV usage for local market and giving a significant cost advantage to global competition.

In 2008, Argonne National Laboratory in the USA reviewed lithium-ion technology activity in China across industry and research institutions.

They found that "the PRC is making vast progress in manufacturing lithium-ion battery technology". There were major research centres at Tsinghua University, Tianjin Institute of Power Sources, Tongji University, General Research Institute for Nonferrous Metals, Beijing Institute of Technology, China Electrotechnical Society and associated spin-off companies and joint ventures. In addition there were several hundred manufacturers – the bigger ones being BYD, Tianjin Lishen Battery, Shenzhen BAK Battery, and Shenzhen B&K Technology. In addition China is the second largest producer of lithium based on its vast resources of lithium ore.

6.2 Technology and Policy Roadmap for China

Introduction

The technology and policy roadmap for electric vehicles developed by ERI notes that of the three major components of electric vehicles – the motor, control systems and batteries. As the battery imposes the major constraint on the performance of an electric vehicle, it is therefore the area where most improvement is required, and is the focus of technology development and policy currently and will be into the future.

Lithium-ion batteries offer the greatest scope for improvement so manufacturers have standardised on this type of battery for development over the medium term.

The other key factor to enable electric vehicles to be able to obtain significant market share will be the existence of a reliable and convenient charging infrastructure, whether this is at home or at work or through a network of public charging stations.

In seeking to develop a viable electric vehicle industry, China has started later than other countries, notably Japan and South Korea, although there have been major alliances among battery companies and automotive manufacturers in the USA and Europe. In addition, the Government has only just begun to provide large amounts of funds for R&D while this has been the case in other countries for some time. As noted above however, China's position with respect to battery technology has improved significantly over recent years.

In common with other countries, manufacturers in China have begun to release both hybrid and fully electric vehicles; although at present the numbers being sold are small, with most being used in a range of bus and passenger car demonstration projects. National standards for electric vehicles have been released and major consortia including assemblers, battery manufacturers, electric supply companies and others have been formed to further the development of battery and vehicle technology.

Some of these efforts are beginning to bear fruit. For instance:

- Shenzhen Lei Day (Shenzhen) Co., Ltd has developed lithium-ion batteries with a range of 300 km, at a maximum speed of 120 kph, for a cost of 40,000 yuan; and
- Shanghai Jing Shen Electric Motor Vehicle Development Co., Ltd has developed lithium-ion batteries with a range of more than 500 kilometres at a top speed of 120 kph.

The chief reason for the slow uptake of electric vehicles is their price. For example, despite a maximum government rebate of RMB 123,000, BYD's plug-in hybrid compact sedan, F3DM, costs RMB 88,000 compared to RMB 58,000 for BYD's F3 gas-driven model

Focus for technology development

In order to be competitive with conventional automotive technology based on the internal combustion engine using petrol or diesel, electric vehicles need to overcome a number of limitations on the performance and cost of lithium-ion batteries. Developing smaller, lighter batteries with greater energy and power density and longer life will enable electric vehicles to match conventional vehicles in terms of acceleration, speed, distance travelled and cost.

The principal limitation of all battery technologies is that the energy density is much lower than petrol or diesel. This means that to carry a comparable energy amount as a standard ICE fuel tank, the battery would weigh well over a tonne. Batteries therefore become the heaviest component of an electric vehicle, and reducing this weight while maintaining the same amount of energy is a major source of improvement in performance.

In addition, the life of a battery, whether measured in terms of elapsed time or the number of charging cycle, is a key determinant on the life-time cost of an electric vehicle.

Batteries as a power source in an electric vehicle consist of an array of battery cells and require a sophisticated control system to coordinate the demands from the motor, with the power available from each cell taking into account driving conditions, temperature and a number of other factors. Such systems require high level skills and resources to manufacture to acceptable quality standards, and China currently relies on overseas suppliers for the components of control systems. Developing these systems for electric vehicles will present a major challenge to the Chinese automotive industry.

Other major issues to address in plans for the development of the electric vehicle include the development of acceptable common standards for batteries, and devising appropriate business models for sustainable charging stations and networks plan for the roll-out of charging.

Characteristics of roadmaps for electric vehicles and charging infrastructure

In addressing the challenges presented by a shift to greater reliance on electric vehicles, ERI has developed roadmaps for both advanced battery development and for charging infrastructure.

Based on an extensive review of the literature and discussions with experts in electric vehicles and battery technologies, the possible improvements in energy density, energy capacity and lifetime of lithium-ion batteries are as shown in Figure 22.

The periods used in these tables align with those of the current Chinese 5 year development plan and the next three plans to 2030.

Figure 22. Indicative Trends for Performance of Li-Ion Batteries

	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035
Energy density by mass Wh/kg	90—125	150	225	500		700
Energy density by volume Wh/L		150	200	460	600	
Energy capacity kWh	16	24	40-48	80	112	
Life expectancy charging cycles	1000	1500			3800	
Life expectancy years		5.4			13	

Source: Zhuang Xing and Jiang Kejun, Energy Research Institute.

Energy density

The future trends in energy density according to a number of international sources are:

- An IEA study indicates that battery energy density per unit volume of 150-200Wh/L is achievable in the near term and the potential improvement rate is 1.5-2% per annum; furthermore battery specific energy (energy consumption per unit volume) is about 100 Wh/kg, with a potential improvement rate of 1.5-2% per annum (IEA, 2010).
- According to Japanese researchers, battery power density follows an increasing trend from 460Wh/L in 2020 to 600Wh/L in 2025, an average increase of 5% per annum (IEA, 2010).
- Energy density objectives set by NEDO of Japan are: 500Wh/kg by 2015, and 700Wh/kg by 2030.
- The IEA report describes the case of Japanese data: battery energy density can be increased from 150Wh/kg in 2007, to 225Wh/kg in 2015 and to 1050Wh/kg by 2030 (IEA, 2010).

Taking these and other findings, a consensus development path gives energy density levels (by mass) in 2015, 2020, 2025 and 2030, as 150Wh/kg, 225Wh/kg, 500Wh/kg, 700Wh/kg, respectively; and energy density by volume in 2015, 2020, 2025 and 2030, as 150Wh/L, 200Wh/L, 460Wh/L and 600Wh/L, respectively.

Energy capacity

Similarly, an expected profile for energy capacity can be developed based on analysis by the IEA, and sources in Japan, the USA and Europe.

These predict that the total capacity of the Lithium-ion battery in the years 2015, 2020, 2025 and 2030, will reach a level of 24kWh, 48kWh, 80kWh and 112kWh, respectively. As noted earlier, to be equivalent in performance to a conventional ICE vehicle travelling 500 kilometres, battery capacity needs to be at least 75kWh (IEA, 2010). This should be reached by 2025, making the electric vehicle competitive with ICE vehicles.

Battery lifetime

Experts in China and internationally expect that battery cycle life will continue to improve as technology advances, from about 1,000 in 2010 to about 2015 to 1500, and 3500 or even higher by 2020. If this value is achieved for 2020, this would also remove one of the impediments to the competitiveness of electric vehicles.

In summary then, based on these results it is expected that as battery energy density increases, battery capacity will increase from 16kWh in 2010 to 48 kWh in 2020 and 112 kWh in 2030, and electricity consumption per 100 km will decrease from 18 kWh/100km in 2010 to 8 kWh/100km in 2030. Batteries with greater numbers of charging cycles will enter the market, life-cycle charging times will increase from 1000 in 2010 to 3800 in 2020, and these technical advancements will bring down battery costs and hence the life cycle costs of electric vehicles.

If these improvements in performance can be achieved as expected, electric vehicles will become widespread in China in the period from 2020 to 2025.

Figure 23 summarises these and other key feasible performance parameters providing a set of guidelines for the future development of lithium-ion batteries.

Figure 23. Parameters for the Development of Lithium-Ion Batteries

	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030
Fully charged capacity (kWh)	16	24	48	80	112
Battery cost (USD/kWh)	750	375	290	107	75
Battery cost (RMB 1,000/car)	80	60	60	57	56
Energy density (mass, Wh/kg)	125	150	300	500	700
Energy density (volume, Wh/L)	207	269	460	600	600
Total power (kW)	20	45	90	90	90
Battery life cycle (No. of charges)	1,000	1,500	3,500	6,000	6,000
Safety	----	Standardised	Standardised	Standardised	Standardised

Source: Zhuang Xing and Jiang Kejun, Energy Research Institute.

Figure 24. Analysis of Expected Trends in Characteristics of Electric Vehicles

	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030
Electric vehicles					
Battery capacity (kWh)	16	24	48	80	112
Cost per power output (RMB/kWh)	0.48	0.60	0.75	0.94	1.18
Mileage capacity (kWh/km)	0.18	0.13	0.08	0.08	0.07
Mileage efficiency (RMB/km)	0.09	0.08	0.06	0.08	0.08
EV fuel cost (RMB/car)	43200	39067	30104	37694	41299
Unit battery cost (US$/kWh)	750	375	130	75	30
EV battery cost (RMB/car)	80400	60300	41803	40200	22512
Battery life expectancy (years)	3.6	5	11	22	22
No. of battery swaps (set/years)	4.1	2.8	1.4	0.7	0.7
EVs total lifetime battery costs (RMB/car)	413256	226728	99503	67938	38045
	456456	265795	129607	105632	79345
Annual costs	30430	17720	8640	7042	5290
Advanced fuel ICE vehicle					
Petrol price (RMB/litre)	6.6	8.5	10.2	11.0	11.8
Diesel price (RMB/litre)	6.4	8.3	9.9	10.6	11.4
Fuel mileage (l/km)	0.050	0.039	0.031	0.024	0.020
Diesel fuel mileage (l/km)	0.047	0.038	0.030	0.024	0.020
Total lifetime mileage (km)	500,000	500,000	500,000	500,000	500,000
Advanced fuel vehicle cost (RMB/car)	165000	167550	158356	133574	117738
Advanced diesel vehicle cost (RMB/car)	150400	155333	149317	128100	114170
Annual costs	11000	111170	10557	8905	7849
Vehicle cost comparison: EVs vs ICE	291456	98245	-28749	-27941	-38394

Source: Zhuang Xing and Jiang Kejun, Energy Research Institute.

Based on the analysis of likely trends in key performance aspects of electric vehicles, lithium-ion batteries and associated charging infrastructure, a technology roadmap has been developed. A summary of this roadmap is given as Figure 24.

A policy roadmap to achieve this technology roadmap is shown in Figure 25 and outlines programs to be developed in research and development, economic stimulus measures, emission and manufacturing standards and charging infrastructure.

The technology roadmap envisages a number of stages as follows.

(i) Research and development demonstration phase (2010-2015)

In the period up to 2015, electric vehicles will mostly be in the demonstration phase. After several years of effort in research and development, the electric vehicle will gradually meet the requirements of mass production. With improved battery performance, battery costs will be reduced significantly, the unit cost of energy the battery falling to nearly half the current cost (about 2,500 yuan / kWh), so that the cost of electric vehicles is also reduced.

Improved battery performance will enable driving range to be increased by 16%, and maximum speed by 40%, with power consumption over 100 kilometres reduced by 22%.

Charging facilities will start to be built in the main buildings of a small number of cities. By 2015, there will be over 4,000 charging stations with 25,000 charging points at a cost of 140 billion yuan. Charging stations will be located in large residential area at the main office buildings and will spread to airports, railway stations, hospitals, shopping malls, gas stations and other public places. Fast charging and battery replacement methods will be developed in the demonstration phase. National electric car numbers in 2015 will reach 250,000 and will shift focus gradually from public service vehicles to micro-electric cars.

(ii) A rapid development phase (2016-2020)

In the 2016-2020 period, China's rapid development of electric vehicles will begin. Electric vehicles and battery technology are expected to continuously improve performance and gradually approach the performance of petrol cars. With higher performance batteries, the cost of electric vehicles will substantially reduce bringing prices closer to wide spread acceptance.

There will be charging facilities in nearly 10 cities by 2020 with at least 10,000 new stations and 30,000 new charging points. By 2020 electric vehicle sales will reach 1.35 million or more, accounting for 23% of the global electric vehicle market. With national electric car and battery production and manufacturing capacity close to 1.4 million, the Chinese electric vehicle will enter the mature stage of development.

(iii) A commercial development phase (2021-2030)

In the 2021-2030 period, electric vehicles will be fully commercialised and be capable of meeting the goals of the national low-carbon development scenario. In 2025 and 2030, the number of electric vehicles will reach 50 million and 95 million, accounting for 25% and 28% of all vehicles. Annual sales will reach more than 8 million to make a significant contribution to energy saving. Advanced electric vehicle technology, battery technology and charging technology continue to be developed and applied to further improve battery technology. The electric car will have a range of 400km, and will see a rapid decline in battery costs, with the unit energy cost of the battery down to RMB200/kWh.

Charging systems will continue to improve with fast charging and will reach the same level of convenience as current petrol stations. Solar charging stations will begin to be built and will be available in 10% of all stations in 2030. Smart grid and advanced communications technologies will further improve the power grid, and make electric cars a grid-friendly electricity load.

Figure 25. Electric Vehicles Technology Roadmap

	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030
EV development targets					
Total EV (1,000)	Few	1250	8,000	50,000	94,000
EV market (1,000)	Few	250	800	5000	
EV technological progress					
Highest speed (km/h)	85	120	140		
Distance (km)	112	130	200	350	400
Mileage (kWh/100km)	16-18	13-14.3	10	8	
EV battery technology					
EV power density (Wh/kg; Wh/L)	90-125 Wh/kg	150 Wh/kg; 150 Wh/L	225 Wh/kg; 200 Wh/L	500 Wh/kg; 460 Wh/L	700 Wh/kg
Battery power capacity (kWh)	16kWh	24 kWh	40-48 kWh	80-93 kWh	112-124 kWh
Battery recharge limit	1000 times	1500 times (5.4 years)	3000 times	3800 times (13 years)	Integrated super battery capacity
Battery cost $/kWh	$750	$375	$107	$75	$30
Battery charging station technology and roll-out					
Battery charging station development plan (State Grid & Southern Grid)	325 stations with 18,700 charging points	Additional 4325 stations with 24,800 charging points	Additional 10,000 stations with 30,000 charging points		
Battery charging station system and roll-out schedule	Commence construction of standard charging using recharge points & battery swap method. Based mainly in residential districts and the car parks of vehicle fleets.	Standardised charging using recharge points & battery swap method. Located at airports, train stations, hospitals, shopping centres, petrol stations.	Standard recharging leads supported by rapid charge and battery swapping.	Complete integration of an electric charging network. Arrival of solar charging stations. Advanced vehicle-to-grid (V2G) technology improves utilisation rate. Trials of mobile charging.	Complete integration of an electric charging network. Solar charging stations hold 5-10% of market share. Mobile charging network in operation.

Source: Zhuang Xing and Jiang Kejun, Energy Research Institute.

Figure 26. Detailed Electric Vehicles Technology and Policy Roadmap

	2010 2011 2012 2013 2014 2015	2016 2017 2018 2019 2020	2021 2022 2023 2024 2025	2026 2027 2028 2029 2030
Strategic Plan	Set up initial institutions and agencies			
	Formulate & release national EV development policy and plan	Integrate the large and heavy EV and component production and industries		>>>> >>>> >>>>
	Formulate and implement supportive EV policies and measures	>>>> >>>> >>>> >>>>	>>>> >>>> >>>>	>>>>
	Systemise design and formulation plan for EV industry	Implement the EV industry development program	>>>> >>>> >>>> >>>>	>>>>
R&D Policy	Set up coordinated research approach	Gradually establish an integrated industry innovation system		
	Formulate EV innovative technologies plan	Carry out basic research into next generation battery technologies, materials and components		>>>> >>>>
	Carry out testing and evaluation for emerging and breakthrough battery materials, technologies and innovations according to the key technology procedures research program.			
Economic stimulus policies	Set up a dedicated EV development fund			
	Focus on battery technology, in particular advancing research into first generation battery technology to reduce economic costs			>>>> >>>> >>>>
	Provide assistance and remove economic costs and barriers to encourage independent innovation of battery technology components			>>>> >>>>
	Provide financial subsidy for purchase of hybrid (Y50,000) and fully EV (Y60,000)	Phase out EV subsidy and assistance programs		
	Provide EV owners with free parking, free vehicle registration, consumption tax exemption, free upgrade for household power charging and a preferential electricity tariff.			
Standards	Prioritise the introduction of comprehensive industry standards for all aspects of EV			
	Standardise battery and vehicle types, connections, points, chargers and stations		>>>>	>>>> >>>> >>>> >>>>
	Introduce National Grade IV emission standards; Phase in National Grade V emission standards	Commence National Grade VI emission standards		>>>> >>>> >>>>
Charging infrastructure	Research the necessary market settings, grid connectivity, policies and regulations for setting up an effective EV charging infrastructure and system			>>>> >>>>
	Establish EV battery charging and supply service system for users	>>>> >>>> >>>> >>>>	>>>> >>>> >>>>	>>>>

Source: Zhuang Xing and Jiang Kejun, Energy Research Institute.

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Appendix: Fuel Efficiency and Emission Standards in Various Countries

Fuel efficiency and/or GHG emission standards for new vehicles have been set by the European Union (EU), the USA, China, Japan, Australia and other countries. The stringency of these standards, as well as how they are defined and enforced, varies considerably from country to country.

The main advantage of controlling GHG emissions from transport using emissions standards is that it leaves the choice of technology to achieve the standard up to the manufacturer and/or the consumer. If emission standards are known in advance and a path for reducing emissions over the longer term is made clear, then manufacturers and other participants can plan model development and research and development programs to meet the standard. While setting an emission standard controls the amount of carbon per kilometre, it does not directly control the number of vehicles sold or the distance travelled in those vehicles. Increasingly stringent standards might be expected to increase the price of vehicles, deterring some consumers from buying cars and substituting public transport for private transport, especially in situations where this is convenient and affordable.

1. European Union

As part of its policy to reduce CO_2 emissions in the European Union by 20% by 2020, the European Commission has issued Regulation No. 443/2009, which sets emission performance standards for new passenger cars registered in the EU. This was approved in April 2009 and sets the fleet average to be achieved by all cars as 130 grams per kilometre (g/km) compared to current levels of 160 g/km. The requirement will be phased in so that in 2012, 65% of each manufacturer's new cars must comply, rising to 75% in 2013, 80% in 2014 and 100% from 2015 onwards.

A longer term target of 95 g/km has been specified for 2020 and measures to achieve this will be defined in a review in 2013.

For cars using petrol, fuel efficiency in litres per 100 kilometres (L/100 km) is equivalent to dividing emissions in g/km by 23.8. The new standard of 130 g/km is therefore equivalent to 5.5 L/100 km, while 95 g/km is equivalent to 4.0 L/100 km.

From 2012 to 2018, manufacturers exceeding the CO_2 target will pay the following excess emissions premiums:

- 5 euro for the first gram of CO_2 exceeding the target;
- 15 euro for the second gram;
- 25 euro for the third gram; and
- 95 euro for each subsequent gram.

From 2019 manufacturers will pay 95 euro for each gram exceeding the target.

Manufacturers will be able to group together to form a pool to act jointly in meeting the target. Independent manufacturers selling less than 10,000 vehicles per year can apply for an individual target, and special purpose vehicles such as those with wheelchair access are exempt.

The EU is currently assessing CO_2 emission targets for light commercial vehicles such as vans and minibuses. In a Communication from the European Commission in 2007 a target was proposed of improving fuel efficiency to reach 175 g/km CO_2 by 2012 and 160 g/km CO_2 by 2015 with a further goal of 120 g/km by 2020.

2. United States

The United States has regulated fuel efficiency through its Corporate Average Fuel Economy (CAFE) regulations since 1975. The standard applies to cars and light trucks defined as those with a gross vehicle weight rating of 8,500 pounds (3,900 kilograms) or less manufactured for sale in the United States. CAFE standards are administered and set by the National Highway Traffic Safety Administration (NHTSA) within the Department of Transport.

The CAFE standard for 2009 is 27.5 miles per gallon (mpg) for cars and 23.1 mpg for light trucks.

In 2007, the Bush administration announced a goal of 35 mpg by 2020.

In May 2009, the Obama administration increased the CAFE to 35.5 mpg and brought the introduction forward to 2016. This new standard was set to be equivalent to 250 gram/mile (172 g/km using the European test cycle or 156 g/km using the US test cycle). The Department of Transport will have responsibility for fuel efficiency, while the Environmental Protection Agency will regulate GHG emissions.

If the average fuel economy of a manufacturer's annual fleet of car and/or truck production falls below the defined standard, the manufacturer must pay a penalty, currently US$5.50 per 0.1 mpg under the standard, multiplied by the manufacturer's total production for the U.S. domestic market. However manufacturers can earn CAFE "credits" in any year they exceed CAFE requirements, which they may use to offset deficiencies in other years. CAFE credits can be applied to the three years before or after the year in which they are earned. Cars that can be run on alternative fuels such as ethanol blends are treated favourably in the calculation of a manufacturer’s average to encourage their use.

In July 2011, the US Government announced a further target of 54.5 mpg (or 4.3 litres per 100 kilometres) to be achieved by 2025. This represents a 5% annual improvement in fuel efficiency between 2017 and 2025.

3. China

In September 2004, the Chinese Government through the Standardization Administration of China (SAC) issued Fuel Economy Standards (FES) for light-duty passenger vehicles (LDPV). The first phase took effect on 1 July 2005, with a second phase beginning on 1 January 2008. The China Automotive Technology and Research Center (CATARC) undertakes automobile testing, certification and automotive research, and was responsible for drafting the standards.

The FES limits fuel consumption by weight category and does not differentiate between petrol and diesel vehicles. The standards do not apply to alternative fuel vehicles or imported vehicles.

The standard differentiates “normal structure” vehicles with manual transmission and less than 3 rows of seats from “special structure” vehicles with automatic transmission of more than three rows of seats and for which the standard is 6% less stringent.

According to CATARC, the national average fuel consumption of passenger cars in China was 8.1 L/100 km in 2006 down from 9.1 L/100 km in 2002.

In Phase 1, standards for LDPVs under 3,500 kg and with no more than 9 seats were introduced in 16 weight steps for new models on 1 July 2005 and for continued models in 1 July 2006. Phase 2 tightened the standard by 10% and took effect for new models on 1 January 2008 and for continued models from 1 January 2009.

At the time of writing, China is expected to release shortly its Phase 3 standards which will be fully effective by 2015. A further target for 2020 is also being considered. According to a recent overview of vehicle emission standards (Feng, Earley and Green-Weiskel 2011), average motor vehicle fuel consumption in China will have gone from 9.11 L/100 km in 2002 to 8.06 in 2008, to 7.77 in 2009 and is estimated to fall to 6.67 by 2015 and 5.0 by 2020. The latter figure corresponds to about 116 gram of CO_2 per km.

Unlike the standards in Europe or the USA, every model produced by a manufacturer must meet the Chinese FES standard for that weight category; otherwise the model cannot be produced.

4. Australia

Through the Federal Chamber of Automotive Industries (FCAI), the Australian motor vehicle industry has adopted a voluntary target of reducing average CO_2 emissions from new light vehicles to an average 222 grams of CO_2 per km by 2010 (or 176 g/km on the European Drive Cycle). FCAI estimates average emissions as 222.4 g/km in 2008.

In July 2009 the Council of Australian Governments (COAG) decided to "undertake a detailed assessment of possible vehicle efficiency measures, such as CO_2 emission standards, which international studies have indicated have the capacity to reduce fuel consumption by 30 per cent over the medium term, and significantly contribute to emissions reductions".

In July 2011, the Commonwealth Government announced a broad range of initiatives for reducing carbon emissions in the economy. While road transport was exempt from the imposition of a price for carbon, the Government announced that mandatory emission targets would be introduced in consultation with industry and stakeholders. The average CO_2 emissions for light vehicles sold in Australian were 213 g/km in 2010. The Government has proposed average mandatory CO_2 emissions standards of 190 g/km by 2015 and 155 g/km by 2024, as a starting point for discussion. This is equivalent to 8.0 and 6.5 litres per 100 kilometres, respectively, and is well behind the EU and Japan.

5. Japan

Japan has regulated fuel efficiency for light-duty passenger and commercial vehicles since 1999. Initially targets were set for vehicles using petrol for 2010 and for diesel in 2005. The result was to be an average fleet fuel economy of 35.5 mpg in 2010.

The standards cover passenger vehicles with a capacity of 10 passengers or less and freight vehicles with a gross vehicle weight of 2.5 tons or less. They were followed by a series of fuel efficiency standards: standards for LPG vehicles were introduced in 2003, and in 2006 standards were introduced for heavy freight vehicles with a gross vehicle weight over 3.5 tons and passenger vehicles with a capacity of 11 or more passengers (with a gross vehicle weight over 3.5 tons).

The most recent revision of the standard was in December 2006. Fuel economy targets are set for each of 16 weight classes with a view to achieving fleet average fuel economy of new passenger vehicles of 16.8 km/L or 6.0 L/100 km by 2015. This is equivalent to 125 g/km of CO_2 emissions using the NEDC test.

Manufacturers are allowed to accumulate credits in one weight class to offset those in other classes subject to some limitations. Although they had realised the earlier target before 2010, there are only weak penalties if manufacturers do not comply with the standard.

The strongest aspect of the Japanese scheme is the so-called "Top Runner" method for continually improving standards. This method determines standard values based on vehicles presently on the market that have the highest fuel efficiency, while taking into consideration future prospects for technological development. This provides a built-in mechanism for regularly revising the standard.