IDENTIFYING POLICIES AND IMPLEMENTATION STRATEGIES
FOR IMPROVING ENERGY EFFICIENCY

CASE STUDY 1

High Fuel Efficiency Motor Vehicles

May 2010

Centre for Strategic Economic Studies
Victoria University, Australia

With the assistance of the
Energy Research Institute,
National Development and Reform Commission
Beijing, P.R. China

Report for the Australian Department of Climate Change
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1. Introduction

This case study reports 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 recent consideration is the desire to establish a globally competitive motor vehicle industry in China that shares market leadership in terms of fuel economy.

This 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. Manufacturers will increasingly therefore 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 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 highlights why the Chinese Government is giving priority to the development of electric and hybrid diesel vehicles.

There are range of policies that can be adopted to encourage low carbon transport suggested including stronger emissions standards for vehicles, fuel taxes, vehicle purchase taxes, support for infrastructure for electric vehicles and encouragement of alternative transport modes.
Part 2: Identifying Policies and Implementation Strategies for Improving Energy Efficiency

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.

Appendix A provides a review of technology options for reducing carbon emissions from transport based on the information contained in the initial report of this project. Appendix B provides a summary of the detailed review of policies for reducing carbon emissions undertaken by the UK Energy Research Centre. Appendix C 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
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-Ivecco, 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, Haerbin and Tianjin.

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.

In 2008, the top five manufacturers accounted for 40.7% of output while the top 10 made up 65.3%. Figure 2 lists the 20 top car makers in China in 2008, which hold a combined market share of 91.9%. 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 with a 56% market share, an interesting feature of Figure 2 is the presence of a number of private domestic manufacturers – namely Zhejiang Geely Automobile, Chery Automobile and BYD. These companies began producing cars quite recently in 2000 (Geely), 1998 (BYD) and 2002 (Chery) and in recent years, they have emerged to gain a significant market share without being a preferred manufacturer within the automotive industry plan. Domestic local brands make up around 44% of the market. 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.
Part 2: Identifying Policies and Implementation Strategies for Improving Energy Efficiency

Figure 2. Top 20 Car Makers in China, 2008

<table>
<thead>
<tr>
<th></th>
<th>Production</th>
<th>Sales</th>
<th>Share of production %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai Volkswagen Audi</td>
<td>481,730</td>
<td>478,059</td>
<td>9.6</td>
</tr>
<tr>
<td>FAW Volkswagen</td>
<td>480,800</td>
<td>498,908</td>
<td>9.5</td>
</tr>
<tr>
<td>Shanghai GM</td>
<td>403,939</td>
<td>408,470</td>
<td>8.0</td>
</tr>
<tr>
<td>FAW Toyota</td>
<td>366,512</td>
<td>347,663</td>
<td>7.3</td>
</tr>
<tr>
<td>Dongfeng Nissan</td>
<td>319,455</td>
<td>318,785</td>
<td>6.3</td>
</tr>
<tr>
<td>Chery</td>
<td>281,412</td>
<td>286,569</td>
<td>6.6</td>
</tr>
<tr>
<td>Guangzhou Honda</td>
<td>279,298</td>
<td>277,358</td>
<td>5.5</td>
</tr>
<tr>
<td>Beijing Hyundai</td>
<td>258,356</td>
<td>253,298</td>
<td>5.1</td>
</tr>
<tr>
<td>Zhejiang Geely</td>
<td>220,955</td>
<td>221,823</td>
<td>4.4</td>
</tr>
<tr>
<td>Chang'an Ford</td>
<td>197,366</td>
<td>200,756</td>
<td>3.9</td>
</tr>
<tr>
<td>BYD</td>
<td>192,971</td>
<td>170,882</td>
<td>3.8</td>
</tr>
<tr>
<td>Guangzhou Toyota</td>
<td>175,870</td>
<td>172,004</td>
<td>3.5</td>
</tr>
<tr>
<td>Shenlong PSA</td>
<td>172,720</td>
<td>178,060</td>
<td>3.4</td>
</tr>
<tr>
<td>Tianjin FAW</td>
<td>172,369</td>
<td>176,638</td>
<td>3.4</td>
</tr>
<tr>
<td>Chang'an Suzuki</td>
<td>123,389</td>
<td>124,123</td>
<td>2.4</td>
</tr>
<tr>
<td>Brilliance BMW</td>
<td>115,802</td>
<td>127,024</td>
<td>2.3</td>
</tr>
<tr>
<td>FAW Mazda</td>
<td>113,220</td>
<td>117,544</td>
<td>2.2</td>
</tr>
<tr>
<td>Dongfeng Kia</td>
<td>106,439</td>
<td>108,353</td>
<td>2.1</td>
</tr>
<tr>
<td>Dongfeng Honda</td>
<td>83,085</td>
<td>83,413</td>
<td>1.6</td>
</tr>
<tr>
<td>FAW Hainan</td>
<td>82,771</td>
<td>92,757</td>
<td>1.6</td>
</tr>
<tr>
<td>Top 20</td>
<td>4,628,459</td>
<td>4,642,487</td>
<td>91.9</td>
</tr>
<tr>
<td>All manufacturers</td>
<td>5,037,334</td>
<td>5,046,934</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: China Automotive Industry Yearbook, 2009

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 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
Case Study 1: High Fuel Efficiency Motor Vehicles

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 3 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 3. Monthly Production of China’s Top Five Automobile Makers, number of vehicles


One of China’s motor vehicle stand-outs is the sudden rise and success of the Shenzhen-based BYD. Figure 4 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 late in 2010.

**Figure 4. 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 realised a shift away from the traditional dependence upon foreign branded 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.

**Figure 5. Automotive Output in China, 1978-2009, thousands**

<table>
<thead>
<tr>
<th>Year</th>
<th>Motor vehicles</th>
<th>Passenger cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>149</td>
<td>100</td>
</tr>
<tr>
<td>1980</td>
<td>222</td>
<td>135</td>
</tr>
<tr>
<td>1985</td>
<td>443</td>
<td>237</td>
</tr>
<tr>
<td>1990</td>
<td>509</td>
<td>269</td>
</tr>
<tr>
<td>1995</td>
<td>1,453</td>
<td>572</td>
</tr>
<tr>
<td>2000</td>
<td>2,077</td>
<td>618</td>
</tr>
<tr>
<td>2001</td>
<td>2,342</td>
<td>704</td>
</tr>
<tr>
<td>2002</td>
<td>3,251</td>
<td>1,092</td>
</tr>
<tr>
<td>2003</td>
<td>4,444</td>
<td>2,071</td>
</tr>
</tbody>
</table>
Case Study 1: High Efficiency Motor Vehicles

<table>
<thead>
<tr>
<th>Year</th>
<th>Trucks million units</th>
<th>Trucks US$ billion</th>
<th>Cars million units</th>
<th>Cars US$ billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>1.5</td>
<td>42.7</td>
<td>2.5</td>
<td>39.8</td>
</tr>
<tr>
<td>2005</td>
<td>1.5</td>
<td>39.5</td>
<td>4.0</td>
<td>59.9</td>
</tr>
<tr>
<td>2006</td>
<td>1.8</td>
<td>47.1</td>
<td>5.2</td>
<td>73.8</td>
</tr>
<tr>
<td>2007</td>
<td>2.1</td>
<td>60.5</td>
<td>6.3</td>
<td>85.8</td>
</tr>
<tr>
<td>2008</td>
<td>2.4</td>
<td>74.6</td>
<td>7.4</td>
<td>98.0</td>
</tr>
</tbody>
</table>

Source: Datamonitor 2008

The reduction in tariffs and duties 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. 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 (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. Private vehicles totalled 52.2 million, half of which are private cars (NBSC, 2010). During the first quarter of 2010, passenger car sales continued to rapidly expand by 72% (YoY) to 3.52 million units (Bloomberg, 2010).

Figure 6. Output of Trucks and Cars in China, 2004-2008

Over the period 2004 to 2008 the average annual growth rate for passenger cars was 31.1%, while for trucks it was 12.1% (Figure 6). Datamonitor (2008) predicts further growth of about 12% per annum in both categories to 2013.

Figure 7. Automotive Market in China, Share of Market by Country of Origin of Manufacturer, 2000 and 2007

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>19.8</td>
<td>30.0</td>
</tr>
<tr>
<td>Germany</td>
<td>46.5</td>
<td>18.1</td>
</tr>
<tr>
<td>Japan</td>
<td>17.1</td>
<td>27.2</td>
</tr>
<tr>
<td>Korea</td>
<td>0.0</td>
<td>7.2</td>
</tr>
<tr>
<td>USA</td>
<td>6.7</td>
<td>13.1</td>
</tr>
<tr>
<td>Others</td>
<td>9.1</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Source: Liu and Yeung, 2008

While domestic manufacturing provides most of the supply for the Chinese automobile market, China does import some vehicles – about 314,000 units in 2007 with a value of about $10 billion with Germany, Japan, the USA and South Korea being the principal suppliers.
Figure 8 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. 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.

The principal destinations for the export of motor vehicles from China have been relatively unsophisticated markets in the Middle East and elsewhere (Figure 9) 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.
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 lead to a massive increase in the number of vehicles in the Chinese passenger vehicle fleet, as measured by vehicle registrations. Figure 10 demonstrate an almost exponential growth with the fleet of passenger vehicles more than doubling between 2005 and 2009. In most advanced industrialised countries, the market for passenger vehicles is virtually saturated with medium term growth approximating that of population growth. Figure 11 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 10. Passenger Vehicle Registrations, China, 1985-2009, million**

Source: CEIC database, 2010

**Figure 11. Passenger Vehicle Registrations, Australia, 1985-2009, million**

Source: ABS, 2009
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 12). This is based on their “Low Carbon” scenario which has overall emissions in China peaking around 2040 and remaining steady thereafter (ERI, 2009).

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.

**Figure 12. Projected Passenger Vehicle Registrations, China, 2010-2050, million**

![Projected Passenger Vehicle Registrations, China, 2010-2050](image)

Source: ERI, 2009

To achieve the same goal in China will require cars in 2030 to emit 13.8% of the level of car in 2010. This cannot be done with just improvements to ICE technology but will require a 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 fuel prices coming from 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.

Presently, 16 of the 20 most polluted cities in the world are in China. 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 Olympic games in Beijing in 2008, the 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 estimated economic costs of air pollution in China vary between 2-7% of GDP.

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 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).

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 x 10^4 tons of CO2 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. By 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.

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%). The 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 is 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).

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

- 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;
- 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 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 for recent months indicates that the growth of smaller cars as well as minivans and mini-trucks have picked up considerably, while sales of larger vehicles have been sluggish (CHINAtalk 2009a).

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 the recent Plan and by other measures, the Government has also encouraged consumers and manufacturers to move towards more fuel efficient and less polluting vehicles. By the end of 2011, the government has agreed with the automotive industry to establish the capacity by 2011 to produce 500,000 ‘new energy’ vehicles (NEV), namely pure electric, hybrid and plug-in hybrid vehicles. This should be equivalent to around 5% of overall capacity within the industry.

The Government is aiming to have 10,000 such vehicles on the road by 2010 with the support of 20 large cities each promising to use government procurement policies to promote NEV in the initial development stage. The country’s largest electric power company, State Grid Corporation of China has begun to install charging stations in larger cities such as Beijing, Shenzhen, Wuhan and Shanghai (CHINAtalk 2009b).

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 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 can receive subsidies of between RMB6,000 and RMB60,000 (KPMG 2009).

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,
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 pipelines 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 already has 400 gas-fuelled buses and plans to have 40,000 alternative energy vehicles by the 2010 Expo. Similar natural-gas fuelled bus programs are underway in Dalian and Chengdu.

Solar Power

There has been very little work on solar powered vehicles although 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 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 lead 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.

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 are Fuyuan Century Fuel Cell Power Corporation, Shanghai Shen-Li High Tech Corporation, Dalian Institute of Chemical Physics, Hong Kong University of Science and Technology, Tongji University and Tsinghua University (Gordon 2004).

*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.
4. Policy Priorities and Options for Reducing Emissions in the Future

This section presents five major policy options which could be considered by ERI in its development of the Chinese Government’s actions to reduce carbon emissions from road transport, recognising the importance given to the introduction of electric and hybrid diesel vehicles.

It draws upon CSES and other analysis of actual and proposed policy responses in China and other jurisdictions. The most comprehensive review of policy options identified to date is that undertaken by the UK Energy Research Centre (ERC) in the development of the United Kingdom’s carbon reduction strategy for transport as outlined in its “Low Carbon Transport: A Greener Future” released in July 2009. A summary of this review is given in Appendix B.

The strategy, which sets out to largely decarbonise transport in the UK by 2050, contains a brief review of alternative technologies for air, road and sea transport and sets out policies and programs that could be implemented to achieve this goal.

Specific policies

The policies identified by CSES and other sources such as the ERC review identified the following major areas for action:

1. Carbon emission and fuel efficiency standards for vehicles
2. Fuel taxes and subsidies
3. Vehicle purchase taxes and registration fees
4. Development of alternative fuel infrastructure
5. Promotion of alternative transport modes

The Chinese Government has already developed policies and implemented programs in each of these five areas. It is suggested that the reduction of carbon emissions be given the highest priority in the future development of these policies.

Supporting context

These policies will have their greatest effect if complemented by more general macroeconomic, climate change, and planning policies, including:

- policies to reduce carbon emissions in the generation and distribution of electricity;
- policies to support public research organisations and industrial research and development addressing climate change goals; and,
• land use planning and associated infrastructure development designed to make low emission transport more attractive.

4.1 Carbon Emission and Fuel Efficiency Standards for Vehicles

(i) Proposed policy

Progressively tighten and redefine the carbon emission standards for road transport vehicles in China.

(ii) Rationale

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

The current and proposed Chinese standards are relatively strict in comparison to other countries, including Japan and the European Union.

The Chinese Fuel Economy Standards (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.

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.

The Chinese Government is currently in the process of planning further improvements in fuel efficiency of the order of 18% by 2015. China currently achieves a fuel efficiency standard of about 150 g/km (6.3 l/100 km) and aims to achieve a standard of about 130 g/km (5.5 l/100 km) by 2015.

(iii) Policy details and implementation

It is proposed that future emission standards:

• cover all forms of road transport including passenger vehicles, vans, trucks and buses;
• use the current system of weight categories;
• be mandatory within each category;
• adopt the Japanese “Top Runner” approach to continual improvement;
• apply to locally manufactured and imported vehicles;
• be measured on a well-to-wheel (life cycle) basis including both production and usage;
• cover all technologies, including vehicles powered by alternative fuels and hybrid and fully electric vehicles;
• reflect the Government’s agreed carbon emission goals in the period to 2050; and
• are implemented in the context of future five-year plans.

If the goal is to reduce emissions from say 150 g/km to 30 g/km by 2050 this could be achieved by a reduction profile as shown in Figure 13. From a current value of 150 g/km, the five year target would seek to achieve 135 g/km by 2015 and 120 g/km by 2020 and so on.

*(iv) Advantages and limitations*

The main advantage of controlling carbon emissions from transport using emissions standards is that it leaves the choice of technology to achieve the standard up to the manufacturer. 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.

*(v) Consequences*

Consumers will be affected if: (i) some models are no longer available because they do not meet the standards, or (ii) vehicle prices rise if the costs of producing cars to meet the standards increase.
Increasingly stringent emission 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.

The difficulty of meeting standards may force further rationalisation on the Chinese automotive industry and transition arrangements may be required from Government. Government support for automotive R&D and technology acquisition is likely to be necessary.

Experience with meeting emission standards in a large domestic market will be advantageous for Chinese manufacturers when they face similar standards in global markets such as Japan, the USA and Europe.

4.2 Fuel Taxes and Subsidies

(i) Proposed policy

Redesign fuel taxes with the main objective being to reduce carbon emissions.

(ii) Rationale

Taxes that increase the price of fuel will reduce its use and encourage greater use of alternative fuels or non-motorised forms of transport.

Governments around the world have imposed taxes on road transport fuels mainly to raise revenue either for general purposes or for the construction of road transport infrastructure. Many recent taxes on petrol and diesel together with incentives for the domestic biofuels industry have been used to reduce the reliance on foreign oil and to encourage greater use of alternative fuels.

Governments are beginning to change the basis for fuel taxes with a view to reducing carbon emissions. France has announced taxes of 4.5 and 4 Euro cents per litre for petrol and diesel respectively (equivalent to 17 Euros per tonne of CO₂) to be introduced in 2010. Denmark, Finland, Italy, the Netherlands, Norway and Sweden all have a carbon tax of some kind on petrol and diesel as do British Columbia and Quebec in Canada. The current Swedish tax is equivalent to 108 Euros per tonne.

Governments can differentially tax vehicle fuels according to their life cycle carbon emission characteristics. Increasing the price of petrol and diesel more than for fuels which create less carbon emissions will induce consumers to: (i) reduce the amount of travel undertaken and fuel consumed, (ii) move to public transport or non-motorised transport modes such as cycling and walking, and (iii) over the longer term to switch to more fuel efficient vehicles and to alternative fuel vehicles.
In the short term however the demand for fuel is relatively price inelastic so that large increases are necessary to reduce demand significantly. This is usually very unpopular with motor vehicle owners. An alternative approach in the short to medium term is to make available to each motorist an annual quota of petrol or diesel at the current or even reduced price and impose a much larger price for fuel once the quota is exceeded. Consumers could avoid any financial penalty by adopting a range of strategies to limit vehicle use to that dictated by the quota. If quotas were transferable, this would create a market in quotas rewarding consumers that use less than their annual allowance. The policy could be designed to be revenue neutral.

(iii) Policy details and implementation

Taxes on petrol and diesel should be set at levels to achieve targets for their consumption derived from targets for carbon emissions from road transport. Economic analysis is necessary to identify how high prices should be to meet the targets, taking into account the increasing fuel efficiency of vehicles as emission standards are tightened. Any taxes on alternative fuels should be set at levels that do not discourage switching from petrol or diesel.

If taxes on petrol and diesel result in prices for these fuels below that of alternative fuels it may be necessary to subsidise their price to achieve their required uptake.

The alternative policy suggestion is set out in the attachment.

Targets for fuel consumption could be set within the context of China’s five year plans as was suggested for the emission standards policy. This means that fuel taxes and subsidies would be set within the same planning cycle.

(iv) Advantages and limitations

While the impact of increasing fuel prices is offset to some extent over time as more fuel efficient vehicles are introduced, in the short term large increases in prices are necessary to achieve significant reductions in demand for petrol and diesel. These increases in prices will be unpopular and Governments are reluctant to impose them.

The alternative policy may be more popular and achieve carbon emission targets more easily.

(v) Consequences

Increasing taxes on petrol and diesel will encourage the use of alternative transport fuels and more efficient transport modes, such as public transport, cycling and walking.
This ability of consumers to switch from petrol and diesel will depend on the availability of alternative transport technologies, alternative fuels and the capacity of the public transport network.

4.3 Vehicle Purchase Taxes and Registration Fees

(i) Proposed policy

Redesign vehicle purchase taxes and registration fees with the main objective being to reduce carbon emissions.

(ii) Rationale

At least 15 member countries of the European Union, including France, Germany and the United Kingdom have introduced passenger car taxes that are totally or partially based on a vehicle’s carbon emissions or fuel efficiency. These taxes are levied either at the time of purchase or as an annual registration or circulation tax.

Differential taxes on the purchase of vehicles and differential annual registration fees (circulation taxes) for vehicles can both reduce the demand for high carbon emitting vehicles and shift the demand towards more efficient transport modes. If vehicles are inspected for fuel efficiency each year as part of the registration process, this reinforces the effect of these policies. Subsidies for the purchase of low carbon vehicles act in the same way by reducing the price of these vehicles compared to conventional vehicles.

At least 13 countries, including Canada, France, Germany the United Kingdom and the United States have introduced programs aimed at replacing older, less efficient vehicles with newer models. The main reason for this has been the economic downturn but environmental concerns have also been important in the design of these programs in some countries. Programs typically consist of rebates to be used for the purchase of the new vehicle.

The Automotive Industry Restructuring and Revitalisation Plan released by the Chinese Government in January 2009 contained major initiatives to address concerns about pollution and climate change. In particular the Plan aims to 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:

- include 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;
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; and

increased subsidies to encourage people to scrap old cars and made it easier to buy new cars.

In January 2009 the Government announced a policy to provide subsidies for the purchase of hybrid, electric and alternative fuel vehicles in 13 pilot cities including Beijing and Shanghai. This 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 can receive subsidies of between RMB 60,000 and RMB 600,000.

(iii) Policy details and implementation

It is proposed that:

• Vehicle purchase taxes in China be based on the vehicle’s carbon emission level as measured in g/km.

• A zero tax rate or subsidies on the purchase price be implemented for vehicles that achieve emission levels that fall below a certain percentage (say 75%) of the emission standard for that weight class.

• Annual registration fees be set on the same basis.

• Vehicles be checked annually to determine their fuel efficiency prior to registration renewal.

(iv) Advantages and limitations

For some consumers increasing purchase taxes will deter them from buying vehicles and encourage greater use of more carbon efficient modes of transport. For most consumers the effect will be to shift from higher to lower emission models.

As the Chinese vehicle fleet has been growing so fast, its average age is quite low. This means that programs that change buyer behaviour through changes to new vehicle purchase prices can have a larger effect more quickly than in other countries.

(v) Consequences

The ability of consumers to switch higher to lower carbon emission vehicles will depend on the availability of these vehicles and their fuels and the capacity of the public transport network.
4.4 Development of Alternative Fuel Infrastructure

(i) Proposed policy

Provide support for the development of electric vehicle recharging stations and other infrastructure requirements for alternative fuel vehicles.

(ii) Rationale

The uptake of electric and hybrid electric vehicles will be maximised if there is adequate infrastructure to support the provisions of alternative fuels required by these vehicles. Electricity charging stations and/or battery replacement should be designed so that their use is as convenient as current petrol and diesel filling stations. In the early stages of introducing this infrastructure, the upfront cost may need to be subsidised until there is sufficient volume of use to justify a commercial service.

While the Government could mandate the use of alternative fuel vehicles by Government agencies and provide appropriate infrastructure within Government facilities, it could also subsidise the development of this infrastructure by private fleet owners as well as provide charging stations in locations such as car parks, shopping precincts and within conventional filling stations.

Large scale government procurement policies of alternative fuel vehicles would: (i) encourage the development of these vehicles by manufacturers by providing sufficiently large sales to recoup development costs, and (ii) provide an economic justification for the development of alternative fuel infrastructure by electricity suppliers and other organisations.

(iii) Policy details and implementation

In the early stages, government support should be concentrated on providing charging stations in situations where a car is parked for a significant period of time, such as parking areas provided by large employers, Government agencies, shopping malls, airports, railway stations, and large apartment blocks. Organisations which have fleets where a significant proportion can be converted to fully electric or hybrid vehicles, such as delivery vans or taxis, should be given preference. Inner city areas where congestion is high could also be targeted for early introduction of infrastructure.

Close coordination with electricity grid and supply organisations and local government will be required.

(iv) Advantages and limitations

Government commitments to buying a certain number of alternative fuel vehicles would provide certainty for vehicle manufacturers and infrastructure providers. Risks remain for
the government in allocating preferences to specific technologies, which may reflect biases towards local production rather than leading edge innovation or best practice.

(v) Consequences

The carbon emission benefits arising from the greater use of electric vehicles depends on how the electricity is produced and distributed. The effectiveness of this policy therefore depends on emission policies adopted for the electricity power industry.

4.5 Promotion of Alternative Transport Modes

(i) Proposed policy

Provide support for more fuel efficient modes of transport by increasing the capacity of public transport and through the systematic introduction of congestion charges in large cities.

(ii) Rationale

In general, private passenger vehicles such as cars are the most carbon intensive mode of transport, in terms of passenger kilometres travelled. Buses and trains have lower emissions, as do non-motorised modes of transport such as cycling and walking.

As policies are introduced to limit demand for private passenger transport, other modes must be made more available and attractive to meet the demand for transport.

For freight transport, rail and water transport have less carbon emissions per tonne kilometre than road transport.

(iii) Policy details and implementation

Lower carbon intensive modes of transport such as buses and trains can be made more attractive by subsidising their prices, and making them easier to use by providing more extensive networks and faster and more frequent services.

Dedicated lanes on roads can be provided to more fuel efficient modes of transport such as cycling and multi-passenger vehicles. Public transport, cycling and walking can be encouraged within inner city areas by preventing access from carbon intensive vehicles through licensing restrictions and congestion charges.

Use of public transport can be enhanced by the provision of more parking space at train and bus stations, and coordinated inter-modal services.
(iv) Advantages and limitations

In the longer term greater use of rail for passenger and freight transport will require a significant investment in providing infrastructure, such as new rail routes above and below ground, better control systems and logistics planning.

The ability to provide dedicated lanes is likely to be hampered within some cities because of legacy infrastructure and opposition from motorists.

(v) Consequences

The capacity to achieve greater use of alternative modes of transport is heavily influenced by land planning so policies in this area also need to be considered.
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 not produced a comprehensive roadmap of how the industry should develop or the how the technology required to meet its objectives should be developed or acquired.

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 CO₂ 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. Performances and costs at present 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 U.S.-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 (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 (eg 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 14.
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 so 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 and 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 14. UK Transport Technology Roadmap**

The Consensus Product Roadmap, mutually agreed by OEMs, defines future direction to develop products that will benefit UK plc

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 on 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.
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Part 2: Identifying Policies and Implementation Strategies for Improving Energy Efficiency


Appendix A

Technology Options for Reducing Carbon Emissions from Transport

This section reviews those key technologies with respect to cars, trucks, buses that will form the basis of the technology roadmap to be developed in the remainder of this project.

A.1 Introduction

Substantial near-term improvements in the fuel economy of new light-duty vehicles can be achieved using available, cost-effective technologies. By 2015, new car fuel consumption can be reduced by up to 25% at low cost by fully exploiting available technologies. In some cases these have negative costs to consumers because the time–discounted value of fuel savings is greater than the cost of the technologies. Technologies include direct injection systems, other engine and drive-train improvements, lightweight materials, and better aerodynamics. Although stock-turnover considerations mean that the full effect of these improvements would not be realised until 2020-2025, they could still reduce the average fuel use per kilometre for the entire stock of cars by 10-15% over the next ten years.

The means for accelerated technological change in the automotive industry in the longer run will be advances in the application of information technologies, new materials technology, engineering breakthroughs in relation to advanced engine technologies, and the comprehensive utilisation of small scale technologies throughout the industry.

The scope of the changes ranges over every aspect of the car’s design, ranging from engines, motor parts, transmission, ignition systems, exhaust controls, vehicle bodies, suspensions, brakes, wheels, vibration dampeners, tyres, filters, coolants, external coatings, windscreens and windows, seats, dashboard and instrumentation, on-board diagnostics, enhanced electronics for driver comfort and entertainment, and automated vehicle control systems. At the same time, the design and manufacture of automobiles will be revolutionised by the application of advanced virtual reality design technologies.

A.2 Alternative Fuels

One area of technological development of significance to sustainable transportation is that of alternative fuels. Transportation fuels that are alternative to refined petroleum products are: (i) natural gas-based fuels, and (ii) biofuels.

Alternative fuels do not necessarily emit less greenhouse gases than gasoline when used to power a vehicle. Most alternative fuels do contain less carbon per unit of energy than gasoline, but do not necessarily emit less total emissions well to wheel – including emissions from the extraction of the alternative fuel or feedstock, energy used in its production, distribution and storage, and its use in vehicles – in a life cycle analysis of fuel.
A few alternative fuels promise substantial reductions of greenhouse gases on a full fuel-cycle basis everywhere. These include ethanol and methanol under certain circumstances, namely when these alcohols are derived from cellulosic (woody) feedstock using advanced, low-energy production processes. However, current commercial alcohol production for transport does not use advanced processes and does not provide greenhouse gas reductions compared to gasoline.\(^1\) Other low greenhouse gas fuels include highly efficient fuel-cell vehicles if produced from renewable or other low GHG feedstocks.

Short-term savings in well-to-wheel emissions can be gained through:
- the use of turbo-injection diesel engines running on low sulphur fuel (25%);
- the use of natural gas (LPG, CNG or LNG) as a fuel (around 20% for CNG);
- cellulosic alcohols (ethanol and methanol) and biodiesel promise larger reductions (50% or more); and
- hydrogen, although the net reduction of emissions depends on how the hydrogen is obtained – on current technologies it has substantially higher emissions, but it could be considerably lower with new, advanced technologies.

In the longer term, improvements in vehicular efficiency of 50% to 55% can be achieved for all fuels used in three-litre combustion engines. Some fuels, such as cellulosic ethanol, promise even greater long-run reductions relative to gasoline, due to expected advances in upstream processes.

**Methanol and DME from Natural Gas and Coal**

Alternative fuels currently subject of much interest are methanol and DiMethylEther (DME).\(^2\) Both fuels could be produced from a wide range of feedstocks, including coal, natural gas and biomass. Methanol production from natural gas is an established technology. However, the bulk of this methanol is used for chemicals.

DME can be used as a fuel for power generation turbines, diesel engines, or as an LPG replacement in households. Current global DME production amounts to 0.15 Mt/yr. Its main use is as aerosol propellant for hair spray. Two coal-based DME plants are in operation in China, with a total capacity of 40 kt/yr. A rapid expansion of Chinese DME production is planned, to more than 1 Mt/yr.

**Biofuels**

In the future, ethanol and biogas have increased prospects for use in cars and trucks designed and built to be operable on different types of fuel. Piston engines in conventional motor vehicles can be adjusted to run on alternative fuels (such as ethanol and methanol) which reduce nitrogen-oxide emissions. A new technology known as the flexible-fuel vehicle has been developed which will detect which type of fuel its tank has been filled with and

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\(^1\) Ethanol produced from grains using conventional harvest and distillation techniques has relatively high emissions (median estimates above gasoline).

\(^2\) DME is non-toxic, contrary to methanol.
automatically adjust the engine; this would increase the flexibility of the vehicle for operational purposes.

Ethanol and biodiesel, as typically produced today in IEA countries, can reduce CO₂ emissions per litre of fuel by 20% to 50% compared with gasoline or diesel fuel, respectively, on a ‘well-to-wheels’ basis, but they are not near-zero-emissions fuels. Apart from fuel production facilities, the infrastructure investment required to support the use of advanced liquid biofuels may be relatively small, since these fuels can be blended with conventional fuels and transported using today’s fuel systems in the future. In the future, synthetic diesel fuel should be blendable in any proportions with petroleum diesel and used in conventional diesel vehicles.

World fuel ethanol production is equal to about 0.5% of global oil consumption. The production is mainly concentrated in Brazil and the United States. It is based on sugar cane (in the case of Brazil) and corn (in the case of the USA). The resource base is gradually widening to cellulosic crops and even wood.

Various countries and regions are planning a rapid expansion of ethanol production. Some scenarios suggest that a tenfold increase by 2020 (to 280 billion litres and 3.3% of the market for transportation fuels) would be feasible, based on sugar can ethanol alone.

The production of ethanol and methanol from advanced processes using cellulosic biomass (wood, grasses and wastes) is also being examined. These alcohol fuels offer potential for use in pure form, in mixtures with other fuels, in hybrid vehicles, or as a chemical fuel in fuel cell vehicles. The advantage of these fuels is that production of their feedstock is not as carbon-or land-intensive as grain crops. Because wood and grass resources are renewable and store vast amounts of carbon, most of the CO₂ emitted during the use of cellulosic biofuel could be offset by the additional CO₂ removed from the atmosphere by the renewable wood and grass used as feedstock. An important consideration in the development of biofuels is the environmental and agricultural effect of feedstock production. Such feedstocks offer far greater potential for emissions savings than existing feedstocks such as sugar and grains. Their advantage comes from a broader range of potential feedstock, such as trees, grasses and forestry waste materials, and a more efficient chain of fuel production and use.

The IEA has studied the question of global potential for biofuels production. Their studies yield a wide range of estimates, but all indicate that it may eventually be possible for biofuels to provide a high share of transport fuel, with 50% to 100% well within the range of several studies. Such estimates depend on assumptions covering many factors, including population growth, food demand, demand for alternative uses of biomass, and demand for transport fuel.

The higher the future fuel demand, the harder it will be for biofuels (or any energy source) to fully meet this demand. The IEA projects that the range of biofuels production potentials could meet at least 20% of future transport fuel demand by 2050. Whether this can be done
cost effectively is another matter. Other concerns include the effects of intensive biofuels production on ecosystems and the possible effects of developing genetically modified organisms. The latter might be important for improving productivity and lowering costs, but is controversial.

As liquid biofuels become a more important component of the transportation fuel supply, research collaboration has identified four key areas to address:
• bio-based ethanol processes such as pre-treatment and enzymatic hydrolysis of lignocellulosic feedstocks and end uses for lignin;
• potential volume and availability of liquid biofuels from the biomass industry;
• improved process economics (once feedstock availability and price are known); and,
• standards and policies for improved deployment.

A.3 Engine Technologies

The most exciting area, so far as potential for the increased energy efficiency of vehicles is concerned, is engine technology. An increase of 25% or more in the fuel efficiency of the internal combustion engine is readily attainable through the gasoline direct injection petrol engine, the use of engines in a low-load mode, and advanced diesel engines.

Among the new types of internal combustion engines likely to appear in the next decade or so is an advanced two-stroke engine accompanied by new electronically controlled fuel-injection techniques designed to both raise the efficiency of the combustion process and reduce emissions of unburnt fuel. Many of the two-wheeled vehicles which are prevalent in many developing countries are powered by two stroke engines. Two stroke motorcycles are a major source of white smoke and emissions of aromatic hydrocarbons and suspended particulate matter. Technological solutions to the smoke and unburned aromatic hydrocarbons associated with two stroke engines have now become available or are under development. They include catalytic exhaust conversion, direct cylinder electronic fuel injection and electronic computer control.

Hybrid Engines

Hybrid electric vehicles combine two power sources with at least one powering an electric motor. The range of alternative power sources includes batteries, flywheels, ultracapacitors, and heat engines. Hybrid systems come in a variety of configurations. One would use a small, constant speed internal combustion engine as a generator to power high-efficiency electric motors at the wheels, with a high-power-density battery or ultracapacitor used to provide a current boost to the motors for acceleration or hill climbing. The internal combustion engine in this case could be small, efficient and clean because it runs at one design speed. Alternative systems could rely exclusively on batteries for most trips, with the engine-generator for extended range only, or they could use both electric motors and a small internal combustion engine to drive the wheels, perhaps with the electric motors providing high power only when necessary.
Hybrid electric vehicles have three significant advantages over conventional vehicles: regeneration of energy during deceleration, automatic engine shutdown when the vehicle stops, and optimisation of engine drive to allow the electric motor to be used wherever possible. Their disadvantage is that they are heavier than conventional models because of the need to accommodate a relatively large battery pack, an electric motor and an inverter in addition to a conventional engine. This increases their manufacturing costs and reduces their potential efficiency in terms of emissions reduction. Nevertheless, fuel-economy ratings suggest fuel economy for hybrids as being 25% or better than for conventional vehicles.

Some efficiency-improving technologies, such as hybrid-electric propulsion systems, are still fairly expensive. Hybrid cars on the market today cost several thousand US dollars more than their conventional-engine counterparts, although costs are falling and there is some indication that companies such as Toyota are now at least breaking even on cost. In North America and Japan, consumers have shown enthusiasm for hybrids, although sales are low due to small production volumes and the availability of only a few models. In Europe, interest appears to be lower, perhaps because there are many diesel vehicles on the market that already fulfil the demand for high-efficiency vehicles to some extent.

The current high prices for petrol have triggered increased interest in hybrid vehicles. Toyota, the market leader has increased hybrid production and this could enable it to halve the price premium over conventional vehicles. Toyota aims to sell one million hybrid vehicles worldwide by 2010.

Honda has just launched a new hybrid version of its popular Civic in America and will put a hybrid engine into its luxury Acura. Producers in America, Europe and Korea have lagged behind Japan so far as hybrid technology is concerned. Ford has just announced it could increase its output of hybrid cars tenfold by 2010. Competitors, ranging from General Motors to BMW and DaimlerChrysler, are scrambling to roll out hybrids of their own.

**Fuel Cells**

A fuel-cell-powered vehicle is essentially an electric car with the fuel cell and storage tank (for a hydrogen-carrying substance) substituting for the battery. If the fuel is a hydrogen carrier (methanol or natural gas), an on-board reformer is required to release the hydrogen from the carrier fuel. Fuel cells work by taking hydrogen and oxygen and putting them through a chemical reaction to produce electricity and water. Excess electricity from the fuel cell can be shunted to battery storage. The vehicle can then use a high-power-density battery (or other storage devices such as an ultracapacitor or flywheel) to provide the necessary power boost for acceleration, so that the fuel cell does not have to be sized for the vehicle’s maximum power needs.

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3 This cost differential varies in different markets. An important additional cost of around $US7000 arises with the need to replace the battery pack (usually after ten years). This, in turn, is tending to depress resale values for these cars.
Fuel cells are particularly efficient energy converters, they generate no harmful emissions and they can be refuelled quickly, so that range constraints are less of a problem than with battery electric vehicles once sufficient refuelling infrastructure is put into place. Three types of fuel cells may be suitable for light-duty vehicles: proton-exchange membrane (PEM) fuel cells, alkaline fuel cells, and solid-oxide fuel cells. Of the three, the PEM fuel cells are closest to commercialisation. Substantial reductions in the manufacturing cost of the fuel-cell engine are required for them to become commercially viable.

A fuel cell system using hydrogen produces no carbon dioxide emissions during vehicle use. However, the use of hydrogen fuel means the hydrogen has to be either stored on-board or produced from other fuels such as natural gas or methanol by means of a reformer. In this case, the gains in emissions savings are reduced by the impact of reforming the fossil fuel source.

With hydrogen fuel, the engine technology is simple and emissions and energy efficiency are optimised. However, current on-board hydrogen storage options are either expensive or carry significant weight and space penalties. Hydrogen has a low energy content density so that it requires a comparatively large storage area compared with other fuels. For this reason, hydrogen is often stored as a compressed gas in pressure vessels or as a liquid in cryogenic tanks. Present on-board gaseous storage is sufficient for buses, but the pressure is too low for passenger vehicles. On-board storage tanks are still too expensive and have short lifetimes, while the high energy needs for compression and liquefaction add considerably to the final cost of hydrogen. In the very long run solid storage has the potential to store hydrogen at a low volume of storage and low pressure and require fewer energy inputs. However, it is in the very early stages of development with more scientific research and a number of applied research problems needing to be solved.

In addition, the costs of developing a suitable fuel distribution network would be very large and there are difficulties associated with the potential for losses and leaks in the production process and during the filling of vehicle tanks. The ultimate cost is uncertain because only limited operational experience is available. Hydrogen refuelling stations have been built and deliver either gaseous hydrogen (90% of the stations built in 2004 and 2005) or liquid hydrogen. They either produce the hydrogen on-site from electrolysis or steam reforming, or receive it from centralised plants. There are significant potential economies of scale operating in hydrogen distribution.

The high cost of refuelling stations and the high initial cost of hydrogen for end-users due to the low level of demand and the low density of hydrogen infrastructure creates a problem. Little hydrogen supply infrastructure will be developed without significant hydrogen demand, but hydrogen demand depends on the existence of a large-scale hydrogen supply infrastructure that can deliver hydrogen at an attractive price. In order to achieve significant momentum in the transition phase, either a dedicated fleet of vehicles that operate in a small area (such as buses) or multi-fuel vehicles that can use hydrogen or gasoline will be required in order to encourage infrastructure growth.
Case Study 1: High Fuel Efficiency Motor Vehicles

Ballard Power Systems, the biggest maker of automotive fuel cells has formed a consortium with Daimler-Benz and Ford. A combined investment of US$1 billion is planned, and the new consortium hopes to produce an initial 10,000-50,000 cars a year powered by fuel cells. Ballard is seeking investment from China as it tries to increase sales in the world’s third-largest vehicle market. Ballard has supplied the fuel cells for three DaimlerChrysler buses to for a pilot project in Beijing.

Ballard does not have the field to itself – about 30 companies are actively developing fuel cells for automotive applications, including Allied Signal and International Fuel Cells (part of the United Technologies Group) in the United States, De Nora in Italy, and Siemens in Germany. Among the vehicle manufacturers, General Motors, Honda and Toyota are also developing fuel cells.

Most fuel cell use today is limited to vehicles owned by government agencies and universities. Hydrogen-powered fuel cell buses using methanol as a primary fuel are being trialled in Europe and Australia and General Motors, Ford Toyota, Honda and DaimlerChrysler are within a few years of selling fuel cell family cars. Mercedes has developed its latest fuel cell-powered A Class, the result of a six-year research program, that uses the space between its double floor to house its fuel cell. However, the broad range of approaches being taken by vehicle producers suggests that there is no clear optimal strategy to get hydrogen and fuel cells to the market.

At present the cost of fuel cell vehicles is prohibitive with the IEA estimating it at US$167,000 currently, This breaks down into the cost of a conventional vehicle without engine (US$17,050), the cost of gaseous hydrogen storage (US$4,000), the fuel cell stack (US$144,000), and an electric engine (US$1,900). By 2010, the IEA expects the cost of the fuel cell stack could come down to US$40,000 and the overall vehicle to US$60,750. By 2030 the cost of such a vehicle might reduce to between US$22,000 (an optimistic projection) and US$27,000. The reduction in fuel stack costs to US$7,000 are achievable through mass-production and technology learning. To be competitive, the fuels stack costs need to be reduced below US$3,500, and that will require fundamental advances in materials, higher fuel cell power densities. Research is focusing on high-temperature membranes that are less prone to poisoning and enable on-board reforming. In addition to fuel cell stack cost reductions, hydrogen vehicles need improvements in their durability and reliability. Other components, such as the cost of the balance of plant, electric drive and hydrogen storage systems, need more attention.

A.4 Other Fuel-Saving Technologies

Major improvements in the energy efficiency of motor vehicles can be achieved through a radical shift in technology and design. The basic features of an advanced automobile incorporating radical new technologies are outlined below.
Materials Technology
The materials used in an average vehicle – glass, steel, aluminium and plastics – are highly energy-intensive. Moreover, traditional materials technology in vehicles is well short of optimal for recurrent vehicle energy consumption. Reconciling safety with environmental sustainability offers a considerable challenge to materials technology. Light composite structures can be even stronger than steel, although the assessment of the robustness of composites to accidental impacts is more difficult than for traditional metals. The manufacturing technology for strong, lightweight composite materials is still accomplished largely by hand and costs are prohibitive.

Much research needs to be done on the feasibility of automated manufacturing processes for new materials. Nevertheless, materials technology and its application to transportation in terms of motor body construction and for components is a key area for research in both the United States and Japan. The utilisation of new vehicle body materials, such as carbon-fibre or other composite materials, and also lighter metal alloys should increase energy efficiency by reducing mass, and at the same time have a lower energy-content in their production. The extensive use of aluminium and other light-weight materials (including high strength steels, magnesium, metal and polymer composites, titanium, and inter-metallic alloys) in suspension and other components (such as brake fittings, sway bars, and wheels) can also improve energy efficiency.

The IEA is sponsoring research on the development of revolutionary materials (structural ceramics and ceramic matrix composites) for operation at higher temperatures and pressure. Hard, wear-resistant, durable and insulating ceramic coatings are an expanding technology for improving the durability, reliability, and efficiency of diesel and turbine engines for automotive and industrial power. A key feature of the research is to assess methods of quantifying thin ceramic coating adherence in order to establish test standards for evaluating new technologies.

Research is also being conducted in the area of surface engineering in order to improve the resistance to wear and contact damage. Friction loss is inherent in most mechanical systems. This research explores the possibility that surface texture designs could reduce friction using thin films and coatings under a broad range of contact conditions.

Electronics
Integrated starter/alternator electrical systems allow engine shut down during idling or deceleration and instant restarting when needed. Regenerative braking is another energy saving technology. Improved engine efficiency operating under low-load conditions (e.g. shutting down cylinders) could increase engine energy efficiency by up to 25%. Improved drive-train efficiency and the introduction of more electric-drive-train components, such as ‘drive-by-wire’ (fully electric) steering can also improve energy efficiency.

Vehicle Maintenance
New technologies have an important role to play in enabling improvements in the maintenance of road vehicles. Better maintained vehicles will be able to operate close to their rated energy efficiency. On-board diagnostic systems monitor all the emission controls
on a vehicle and warn the driver, through instrument panel displays, of any faults that may occur. These systems have become mandatory for new passenger motor vehicles in the United States. Even greater opportunities for detecting malfunctioning vehicles is provided by the use of transponders to allow roadside units to monitor the condition of vehicles as they drive by. Within 20 years, these systems could be installed in sufficient numbers to render inspection and maintenance programs unnecessary. The aerospace industry has been a leader in developing preventive maintenance strategies, and it continues to be an area of significant technological development. There are implications in all of this for the maintenance of rail and marine transport equipment.

**Fuel Saving Technologies**

Some examples of fuel-saving technologies are summarised below:

1. *Advanced transmissions* offer an improvement of several per cent in energy efficiency.

2. *Advanced aerodynamic styling*. Enhanced streamlining, using sophisticated body design and reduced frontal areas, aimed at reduce the vehicle's drag coefficient, can offer improvements in energy efficiency of about 2%.

3. The introduction of high-pressure, low-rolling resistance tyres can reduce fuel consumption by 1.5%.

4. More efficient *accessory equipment* (such as air conditioners) can increase energy efficiency.

**In-use Vehicle Fuel Consumption**

Light-duty vehicles (LDVs) on the roads in IEA countries typically use 20-25% more fuel per kilometre than indicated by their tested, rated fuel economy. Much of this gap is inevitable owing to traffic congestion. Integrated urban/transport planning and road traffic management therefore become important influences on fuel consumption (discussed in more detail in a later sub-section of this paper).

Other measures may help to reduce in-use vehicle fuel consumption. The IEA, in cooperation with the European Conference of Ministers of Transport (ECMT), recently completed a study of technologies and measures to improve ‘in-use’ or ‘on-the-road’ fuel economy of light-duty vehicles.

The IEA estimates that a 10% reduction in average fuel consumption per kilometre could be achieved for LDVs across IEA countries through a combination of the following measures:

- stronger inspection and maintenance programs that target fuel economy;
- on-board technologies that improve in-use fuel economy as well as driver awareness of efficiency, such as adaptive cruise control systems and fuel economy computers;
- better and more widespread driver training programs; and
- better enforcement and control of vehicle speeds.

Cost estimates for the CO₂ emissions reductions offered by in-use technologies and measures vary, but many technologies show low or negative cost per tonne of avoided emissions in some situations. The effects of technologies and measures on fuel consumption
also vary, but a package can be developed that provides a 5-10% improvement in vehicle fuel economy on-the-road for a given tested fuel economy.

The self-driving car is undergoing developmental work. It can be the means of reducing in-fuel consumption through more efficient use of road space in urban areas. General Motors is trialling a car that uses updated technology combined with several existing innovations and could be in production soon. The GM car is based on the Opel Vectra, a mid-sized family vehicle and is undergoing evaluation at General Motors’ subsidiary in Germany.

The advanced technologies incorporated in the self-driving car are:
- Automatic cruise control (already available in many expensive cars) incorporating a new laser technology for use at shorter distances and lower speeds.
- A system that corrects the car when it drifts out of its lane. Lane-departure warning systems have been introduced for a very few cars already, but the new technology uses cameras and laser beams linked to an electronic control unit attached to an electric power-steering unit.

The system is unlikely to have a smooth progression into production, however, despite achieving what General Motors says is a very high level of reliability during the development stage, and despite a modest estimated cost of US$1800 a vehicle. Several obstacles stand in the way. Self-steering cars are currently illegal in most European countries, and carmakers are concerned about issues of legal responsibility. In addition, most people would prefer to be active drivers solely in control of the vehicle. Moreover, the system is basically designed for heavy urban traffic or motorway conditions, and not the open road.

A.5 Trucks and Buses

**Trucks**

Heavy-duty vehicle efficiency can be improved by about 25% (in long-distance transport) to 50% (in short distance stop-and-go transport). Heavy duty vehicles operate in both long-distance and local transport, with the total fuel use being roughly equally split. After driver compensation, fuel costs are typically the second largest expenditure item for heavy-duty vehicle operators. As a result, virtually every large new truck and bus in the United States is already equipped with a turbo-charged, direct-injection diesel engine, the most energy efficient internal combustion engine available. State-of-the-art turbo-charged diesel engines achieve 46% to 47% peak thermal efficiency, versus only 25% for spark-ignited gasoline engines. Thus, there is less potential for improving fuel efficiency in heavy-duty than light-duty vehicles.

A variety of new diesel engines are becoming available to freight trucks. **Turbocompound** engines are technically ready but have not been commercialised although high fuel prices may provide an incentive for commercial developments. **Low-heat-rejection diesels** are compression-ignition engines that run at very high temperature and do not use energy-draining cooling systems. **Gas turbines** harness fuel energy by using the burning fuel’s kinetic energy to spin a turbine rather than drive a piston. Both engines types require the
development of mass-producible materials with higher heat resistance than currently available (structural ceramics or heat-insulating composites). Estimated fuel savings for low-heat-rejection diesels are as high as one-third over modern diesels.

Electronic engine control systems can monitor and adjust fuel consumption, engine speed, idle time, road speed, and other factors. They can also provide extensive feedback data to drivers on energy use. They were developed largely to meet new emissions requirements, but they have energy-efficiency benefits as well. They are currently available on some long-haul heavy trucks. Because they can recover braking energy and shut off the engine during idling, hybrid drive trains are a promising technology to heavy-duty vehicles that operate locally, in stop-go mode.

Electronic transmission controls measure vehicle and engine speed and other operating conditions, allowing the transmission to optimise gear selection and timing, thus keeping the engine closer to optimal conditions for either fuel economy or power than is possible with hydraulic controls. This technology offers about 4% improvement in fuel economy.

Better power/load rations can be obtained through the increased use of B-double and B-triple combinations. However, there are ultimate mass limits to the extent these designs can be taken, as well as impacts on road wear and tear to be taken into account. In addition, allowable truck size is controlled by regulations in both the United States and Europe, which are not fully uniform in either region. The use of lighter materials in truck and trailer bodies, engines and components can also improve power/load ratios, but there is sometimes a trade-off with safety to be considered in implementing such technologies.

It should be noted that currently available technology does not allow automakers to improve light-truck fuel economy through advanced aerodynamics to the same extent that they improve passenger vehicles. Load carrying requirements impose structural and power needs that are more of a function of the payload weight than the body weight of the truck, yielding fewer flow-through benefits from weight reductions. Open cargo beds for pickups and large ground clearance limit potential for aerodynamic improvements. Additional safety and emission requirements would create penalties for fuel economy.

Nevertheless, modifying the shape of the truck and trailer can yield significant reductions in energy use by reducing air resistance. The primary aerodynamic improvement used on heavy trucks today is the cab-mounted air deflector, which began to be installed in the 1970s. Since then, a number of improved aerodynamic devices have been used, including various devices to seal the space between the truck and the trailer, front air dams, and improved rooftop fairings. The simpler devices can often be retrofitted to existing trucks and, according to one analysis, offer rapid paybacks. Aerodynamic improvements to trailers include side skirts to minimise turbulence underneath the trailer and rear ‘boat-tails’ to smooth airflow behind the trailer. The energy savings of these devices are difficult to measure. Aerodynamic improvements to tractor-trailers are also limited by the need to connect quickly and simply to trailers of different designs and sizes, to tolerate road surface uncertainties, and to meet size regulations.
Radial tyres have largely replaced bias-ply tyres, except for special applications such as off-road use. This has resulted in reduced fuel use. A more recent tyre innovation is ‘low-profile’ radial tyres, which weigh less than standard radials and thereby save energy. Also now commercially available are ‘low rolling resistance’ tyres, which use new compounds and designs to reduce rolling resistance. Finally, fuel savings can be achieved by tailoring tyres to specific types of service, powertrains, and roads, including the use of smaller-diameter tyres for low-density cargo, and of very wide single tyres to replace dual tyres. However, truck tyres, unlike automobile tyres, are often recapped when worn: low-profile and low rolling resistance technologies, which cannot be incorporated into recapped tyres, will largely be limited to sales of new tyres.

**Buses**

The use of *dimethyl ether* (DME) provides a way to put natural gas into a convenient liquid form as a motor fuel. A commercially viable process for DME production has recently been developed. Interest in DME is generated, in part, because it can be produced from a wide range of feedstocks, including natural gas, biomass, agricultural and urban waste and coal. Like natural gas and methanol, DME is also a potential fuel for future fuel-cell technologies. It can utilise LPG infrastructure to a large degree. It is some way towards commercial application.

*Biodiesel* is an ester-based oxygenated diesel fuel made from vegetable oil or animal fats. It can be produced from oilseed plants such as soybeans and rapeseed, or from used vegetable oil. It has similar properties to petroleum-based diesel fuel and can be blended into petroleum-based diesel fuel at any ratio for use with conventional diesel engines. It significantly reduces greenhouse gas emissions. However, it is currently very expensive (an option is to produce it more cheaply for waste cooking oils, but supplies are limited) and there are concerns about its impact on NOx emissions.

Several demonstrations for transit authorities of *hybrid-electric* vehicles have taken place. The total worldwide fleet could reach the thousands within a few years. Fuel economy has been tested in the range 55-60 litres per 100km, compared with 70-73 litres per 100km for standard diesels. The efficiency advantage for the hybrid buses occurred despite the fact that they were heavier than conventional diesel buses. Much, although not all, of the additional energy used for accelerating this weight can be recovered via regenerative braking in the hybrid-electric vehicle. Vehicle weight is a concern for hybrids from the standpoint of passenger-carrying capacity.

A life-cycle cost analysis of hybrid-electric vehicle technology is complicated by the fact that the technology is quite young and therefore a large body of real-world operating data does not yet exist. It is thought likely that capital acquisition costs, despite reducing sharply, will always be higher than for conventional buses since they include several additional components. Battery replacement costs are a second factor, while maintenance costs are as yet unknown. Against these higher costs, fuel costs and emission costs are substantially
lower. It is likely that these buses will require at least several more years of development, testing and cost reduction before they enjoy widespread commercial application.

While the understanding of the technology underlying fuel-cell stacks is approaching maturity, many surrounding vehicle and infrastructure issues remain in early development. In particular, costs, parallel development of electric-drive systems, on-board fuel storage and refuelling infrastructure challenges are likely to impede hydrogen fuel cells from becoming a competitive propulsion system in the near term and perhaps for another decade or more. Moreover, industry has no clear development path and seems to be moving in several different directions. Urban transit buses are serving as an important testing ground for fuel-cell buses.

When pure hydrogen is stored on board the vehicle and used directly, fuel-cell vehicles produce virtually no emissions except water. However, if emissions produced upstream, such as from the production of hydrogen, are included, the environmental impacts of fuel cells may be substantial, depending on the source of hydrogen and the method of reformulating hydrogen-rich fuels into hydrogen; production of hydrogen from natural gas produces a 30% savings, depending on the source of electricity. The long-term vision is to produce hydrogen by electrolysis using renewable energy sources, which would yield zero GHG emissions. On-board reforming of fuels shows that GHG emissions are only marginally lower than diesel buses.

One advantage to developing fuel cells for the transit bus sector is the central fuelling infrastructure. Since transit buses are typically centrally refuelled, new refuelling infrastructure would only be needed at bus depots. In addition, buses have more space than smaller vehicles to accommodate the fuel cell and the compressed-hydrogen tanks. However, scale economies for fuel cells will be largely driven by stationary applications, and the truck market will be of critical importance in developing transport-specific components of fuel-cell systems.

The IEA estimates that the cost of hydrogen fuel cell bus engine systems is around US$1,000,000, compared with US$500,000 for conventional diesel engines. The IEA calculates that fuel cell buses will become competitive if their additional cost is around US$100,000. Buses are potentially the easiest market in which to introduce fuel cells in the transport sector because refuelling is concentrated at fleet depots. However, other potentially leading markets for fuel cell vehicles are delivery vans (which have been operating in Germany since 2001), electric wheelchairs and carts, and forklifts.

**A.6 Timelines for Changes in Technology**

Changes in transport technologies that facilitate reductions in greenhouse gas (GHG) emissions can be considered with respect to three different time frames: near-term, medium-term, and long-term.
Technologies for the Near Term
Transport technologies for emissions-savings in the near-term are those that are currently commercially available, but whose diffusion is limited. The principal examples are:

• advanced internal combustion engines;
• hybrid electric road vehicles;
• the use of light-weight materials in road vehicles;
• improved aerodynamic styling in road vehicles;
• advanced fuel-saving transmissions;
• the use of high-pressure, low-rolling resistance tyres;
• more efficient accessory equipment in road vehicles;
• the use of ethanol derived from sugar as a fuel for road vehicles;
• on-board diagnostics to monitor vehicle emissions;
• the wider use of adaptive cruise control systems and fuel economy computers;
• advanced truck and bus designs for fuel economy;
• the increased use of electronic road pricing as a means of reducing traffic congestion;
• improvements in freight transport relating to trucking operation and system efficiency, reducing freight travel requirements, mode switching and advanced logistics and supply chain management; and
• the wider use of advanced information technologies to reduce transport requirements and facilitate virtual technologies.

The above list demonstrates that there are a huge range of newly available technologies that should provide individual incremental improvements in energy efficiency and, collectively, very substantial aggregate improvements. This would flow through to reduced GHG emissions on what would otherwise occur, given the constant emissions-intensity of energy consumed in transportation. In addition, the wider use of biofuels would reduce the emissions-intensity of transport energy. The key issue for the immediate future is accelerating the diffusion of such technologies. This implies overcoming the barriers to the wider diffusion of these technologies.

Technologies for the Medium Term
Transport technologies for the medium-term are technologies that may not be commercially available for some years but are likely to be in general use by 2030 and 2050 at the latest. Examples include:

• advanced two-stroke engines for two-wheeled vehicles;
• fuel-cell-powered road vehicles;
• ultra light-weight road vehicles;
• integrated starter/alternator electrical systems for road vehicles;
• the use of ethanol derived from cellulosic biomass as a fuel for road vehicles;
• advanced vehicle maintenance systems focussing on fuel economy;
• the introduction of self-driving cars; and
• further advances in truck and bus design.

This list contains many examples of technologies that would further increase the energy efficiency of transport. It also contains examples of technologies that would facilitate the
move towards zero-emission transport (ZET) systems. These include advances in the efficiency of transit systems based on zero-emissions electricity and the commercialisation of fuel cell road vehicles based on ZET hydrogen. The latter would be accompanied by the initial development of a hydrogen fuel infrastructure to service road transport. The diffusion of ZET transport would most likely take a considerable amount of time.

Technologies for the Long Term
Transport technologies for the long term would not be commercially available before 2050.

Zero Emission Technologies for Transportation
The vision for the long term is to achieve a zero emissions technology (ZET) energy system. This ambitious goal is necessary if the world is to reduce anthropogenic GHG emissions to acceptable levels, given the difficulties in containing such emissions from the non-energy parts of the global economy. Two possible routes are available to achieving ZET transportation: electrification and hydrogen-fuelled transport.

Electrification provides a possible framework for a ZET transportation system. The essential requirement is that the electricity used in transportation is produced by zero emissions technology. In electrified transport systems, urban transport needs would be supplied by electrified rail, other electrified people-mover systems, and, possibly, novel urban freight systems. In order to provide the maximum scope for such urban transport systems, cities would need to evolve towards high density forms in which transport and urban planning were integrated. Advances in energy storage technologies could facilitate a major role for electrified cars, buses and delivery vehicles to cover the residual needs of urban transport. Inter-urban transport between heavily populated areas would be serviced by electrified rail. The transport gaps in an electrified system would be long-distance transportation in moderate to low population density areas, marine transport and air transport.

An alternative framework for a ZET transportation system would be based on hydrogen-fuelled vehicles. The key aspects of such a system would be hydrogen fuel derived by ZET and fuel cell-powered engines. Cars, trucks and buses would use fuel cell/hydrogen technology as would long-distance rail and marine engines. As such, the hydrogen-based transport would be capable of dealing with the transport problems of long-distance travel and freight needs as well as transport in low-density urban areas.
Appendix B

Review by Energy Research Centre of Policies for Reducing Carbon Emissions from Road Transport

In July 2009, the United Kingdom’s Department for Transport released its “Low Carbon Transport: A Greener Future” setting out its carbon reduction strategy for transport to largely decarbonise transport in the UK by 2050. The strategy contains a brief review of alternative technologies for air, road and sea transport and sets out policies and programs that could be implemented to achieve this goal.

A number of detailed analyses and reviews of technologies and policies had been undertaken prior to the release of the strategy, concentrating on road transport and passenger vehicles in particular. The UK Energy Research Centre (ERC) has written a thorough review of over 500 reports and papers on policies for reducing carbon emissions from road transport. In their report (ERC 2009), they review the evidence for reducing carbon emissions and the cost-effectiveness of policies divided into two categories – (i) those that target car technology and consumer choice of cars and (ii) those that target wider travel choices. They found that the evidence for the first category of policies was better than for the second category. The review concentrates on transport policies but recognises that land use planning pays a significant role in effecting the demand for travel, choice of travel mode and the viability of public transport. As the review is based on evaluations of existing programs and policies it necessarily does not cover future programs, such as the provision of infrastructure in support of alternative fuels such as electricity and hydrogen. In addition it does not discuss programs supporting R&D or other innovation policies.

In presenting their findings, ERC divides the discussion of policies into three categories: (a) those that effect travel choices such as how and how far to travel, (b) vehicle purchase choices, and (c) fuel taxes and prices.

A. Travel choices

(i) Reducing the demand for travel

ERC found that fuel price increases reduce travel demand and encourage mode shifts and more efficient driving. Policies promoting tele-activity or working from home will also reduce demand.

(ii) Support for non-motorised modes

Policies to make cycling safer and more convenient through actions such as segregation and prioritisation encourage greater cycling activity and reduce other modes of transport. Congestion charges and other penalties for car use also lead to greater use of cycling.
(iii) Support for public transport

Although public transport creates less carbon per passenger km, the ability to switch from private to public transport is limited in the short to medium term by the need to add capacity to transport networks. This can be offset to some extent by improving utilisation at underutilised times and/or routes. Fare reductions and giving priority to public transport on roads can increase the demand for public transport. Land use planning is an important determinant of the attractiveness of public transport.

(iv) Car pooling

Car pooling reduces total car kilometres and leads to a greater uptake of non-motorised modes and public transport.

(v) Using vehicles more efficiently

This includes public awareness programs to promote more efficient driving skills, as well as measures to reduce and enforce speed limits.

(vi) Travel planning

Increased parking and other charges can encourage people to plan their travel more carefully by shifting to non-motorised modes and public transport car pooling.

(vii) Road pricing

Congestion charges for particular areas can reduce vehicle use and make vehicle use more efficient as congestion is reduced or eliminated.

(viii) Road space reallocation

Programs that reallocate road space from vehicles to pedestrians, cycling, and public transport must be carefully designed to avoid congestion for more carbon intensive transport.

B. Vehicle choice

(ix) Regulations and standards

Policies that set emission standards or fuel efficiency for vehicles need to be mandatory, ambitious, progressive and not amenable to circumvention.

(x) Vehicle taxes and subsidies
Vehicle purchase taxes can be used to make vehicles more expensive and hence reduce demand and can also designed to favour fuel efficient or low emission vehicles. Annual registration charges can be used in a similar way. Subsidies can be introduced to reduce both the purchase price and registration charges for low emission vehicles. Subsidies can also be used to encourage the greater uptake of new vehicles and accelerated scrappage of older vehicles improving average fleet efficiency.

(xi) Information labelling

Mandatory carbon vehicle labelling is rapidly becoming mandatory but can be improved by greater use in advertising.

C. Fuel prices and taxes

In the short term the demand for fuel is relatively inelastic with respect to fuel prices although more elastic in the long term as consumers buy more efficient cars and reduce the demand for travel. Large reductions in carbon emissions can only be achieved in the short term by relatively large increases in fuel prices and Governments are reluctant to impose taxes or charges to achieve these increases. If fuel taxes are continually raised to meet carbon targets that become increasingly stringent this only compounds the political problem.
Appendix C

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.

1. European Union

As part of its policy to reduce CO₂ emissions in the European Union by 20% by 2020, the European Commission has issued a regulation (No 443/2009) setting 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 CO₂ target will pay the following excess emissions premiums:

- 5 euro for the first gram of CO₂ 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 CO₂ emission targets for light commercial vehicles such as vans and minibuses. In a Communication from the European Commission in 2007 a target was
predicted of improving fuel efficiency to reach 175 g/km CO₂ by 2012 and 160 g/km CO₂ 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 $5.50 USD 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 receive are treated favourably in the calculation of a manufacturer's average to encourage their use.

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.

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.

According to an article in the New York Times in May 2009, the Chinese Government is currently in the process of planning further improvements in fuel efficiency of the order of 18% by 2015. China currently achieves a fuel efficiency standard of about 150 g/km (36.8 mpg) and aims to achieve a standard of about 130 g/km (42.2 mpg) by 2015.

4. Australia

Through the Federal Chamber of Automotive Industries (FCAI), the Australian motor vehicle industry has adopted a voluntary target of reducing average CO₂ emissions from new light vehicles to an average 222 grams of CO₂ 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 CO₂ 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”.

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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 CO₂ 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.

Advantages

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.

Disadvantages

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.