



Global Fuel Economy Initiative

Toward 50by50:
An Assessment of Prospects and Progress

Draft synthesis report on research under the
Global Fuel Economy Initiative

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Summary

The Global Fuel Economy Initiative was launched in early 2009. It set a target of improving the average fuel economy (in litre/100km terms) for the global vehicle light-duty vehicle fleet by at least 50% by 2050 (50by50). In terms of miles per gallon this would be a doubling of performance. This level of improvement is envisaged to be feasible using “existing, cost-effective incremental fuel economy technologies.” The purpose of this report is to assess the progress being made in reaching this goal and the prospects for reaching the goal in the light of on-going research and other developments that have occurred the past year or so.

Although the 50by50 target is a global target, the situation differs significantly between regions. For example, in Asia there is a large share of relatively small and efficient cars and thus the average fuel economy is currently better than in some of the OECD countries. Recent GFEI-sponsored research on fuel economy potential for India and China suggests that, except for very small and inexpensive cars in those countries, the levels of engine and drivetrain technologies used today do not vary substantially compared to the level employed in the US and EU markets. Although growth in GDP per capita and consequent shifts in consumer demand towards cars at the higher cost end of the product range is likely to increase the average size, weight and power of vehicles in markets such as China and India, technology improvements should be able to compensate and help improve fleet average fuel economy over time - given appropriate regulatory incentives. Whilst a 50% improvement in fuel economy may not be feasible in countries starting from such relatively economic fleets as India today, some regions such as the EU are on a path for greater than 50% improvement.

Overall, since currently about two-thirds of new cars are sold in the OECD, the 50% GFEI target still appears appropriate and achievable on a world-wide basis. More specifically, the 2005 average global new vehicle fuel economy level of about 8 L/100km can probably be reduced to close to 4 L/100km. This is equivalent to increasing fuel economy from about 30 to about 60 MPG, from 12.5 km/L to 25 km/L or reducing CO₂ emissions from gasoline vehicles from 180 gCO₂/km to 90 gCO₂/km. A new vehicle fleet average fuel economy level of 4 L/100km by 2030, or something close to it, may be a useful target for most countries to aim at.

In some countries it may be necessary to augment the incremental technology improvements described elsewhere in this paper with widespread use of electric vehicles to reach these targets. The need for this will depend on whether additional incremental fuel economy technologies not accounted for in current studies become available and achieve widespread commercialization over the next 20 years. More generally, the regulation of fuel economy will tend to limit increases in vehicle size and performance and in some countries regulation meeting the targets may require changes to the current size mix and/or performance of vehicles.

Report overview

In Section 2 we summarize recent trends in new LDV fuel consumption across a range of countries and describe a study conducted under GFEI sponsorship to improve understanding of the factors explaining the wide cross-country differences in fuel consumption performance that are presently observed. The study suggests that most - though not all - of this difference can be explained by “observable differences” -- diesel penetration, curb weight, performance (horsepower/curb weight) and automatic transmission penetration - rather than differences in the level of the sophistication of the basic technology being incorporated into vehicles.

In Section 3 we summarize recent studies of the technical potential to improve new LDV fuel economy in the US, Europe, China and India. These studies suggest that the GFEI is correct in its belief that the technical potential exists to improve fuel economy by enough to meet the 50by50 goals.

However, technical potential does not automatically translate into improved fuel economy performance. In Section 4 we observe that in both the US and Europe (but especially in the former) this has not been the case over the past couple of decades. Indeed, between the mid-1980s and about 2005, the fuel economy of new US LDVs became worse, even though technologies with the potential to improve fuel economy were constantly being introduced into the fleet. Instead, this technical potential was used to enable increased vehicle size and weight and improved vehicle performance, such as acceleration. In Europe, the translation of technical potential into improved fuel economy performance was better - between 22% and 83% of the technical potential to improve fuel economy actually resulted in improved fuel economy, with the percentage depending on the country and whether the vehicle was powered by gasoline or diesel. The prospects for meeting GFEI targets in the future will depend heavily on maximizing the use of technology potential for fuel economy improvement.

In Section 5 we describe major policy initiatives by the EU and the US federal government that have been finalized to improve car fuel economy as well as initiatives being taken by governments of selected other countries. In early 2009, the EU issued a rule permitting the average new car registered in the EU emit no more than 130 g CO₂/km by 2015 and no more than 95 g CO₂/km by 2020, although the 2020 target is only indicative and will be subject to negotiation before it becomes binding.¹ The rule also established a system of penalties that would charge manufacturers between €5 and €95 per car for each gram that their fleet average exceeded these standards. In the US, the Obama Administration accelerated the goal of reaching a fleet average of 35 mpg by 2020 established in the Energy Independence and Security Act of 2007 to require that it be met by 2016. It also moved to establish the first CO₂ emissions standards for US LDVs, with these standards being linked to the fuel economy standards. According to the USEPA, by 2016, the new US LDV fleet will be limited to emitting 155 g CO₂/km.²

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1. The average new car in the EU emitted approximately 163 g CO₂/km in 2004.
 2. Average new LDV in the US emitted approximately 230g CO₂/km in 2004. (EPA, 2009).

In Section 6 we discuss one of the challenges to achieving rapid improvement in stock-average fuel economy - given the relatively slow turnover of the world car fleet. On average, cars remain in service for at least 15 years, and some remain in service much longer. This limits the speed with which technologies introduced in new cars can be diffused throughout the entire car fleet. During the recent severe recession, many governments have undertaken efforts to stimulate new car sales. Some of these efforts were ostensibly designed to speed fleet turnover. We describe these efforts and review what their results might suggest about the feasibility of using financial and other incentives to accomplish this goal. We conclude that the ability of these or similar programs to accelerate fleet turnover has yet to be demonstrated.

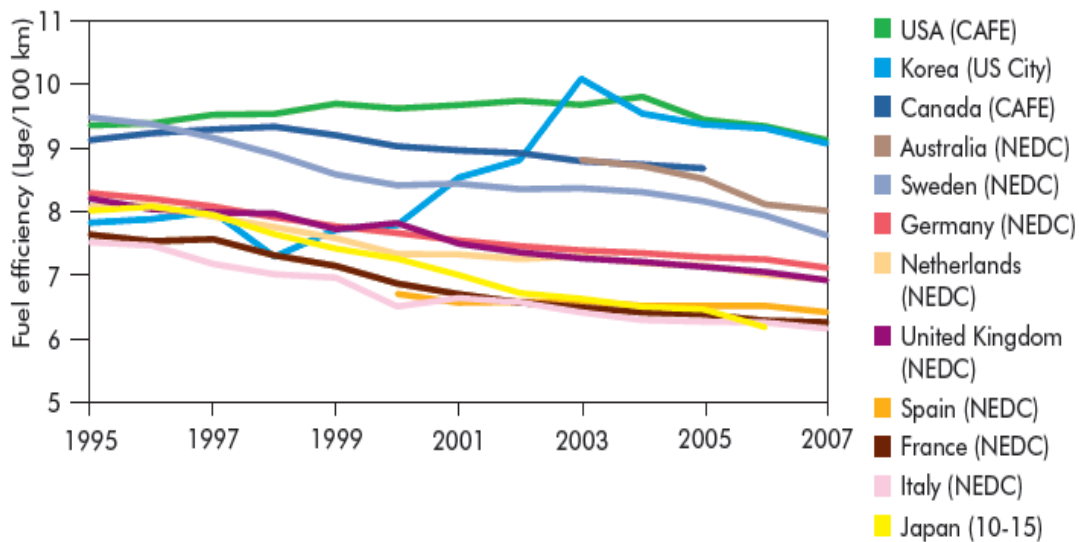
After many cars finish their period of service in one country they are moved to another country where they are used for additional years. In Section 7 we examine this large but little-studied trade in used cars. A recent paper by Fuse, Kosaka and Kashima estimates that in 2005, world trade in used automobiles totaled 5.7 million vehicles - 13% of total worldwide production of new vehicles during that year. We know surprisingly little about these cross-border flows, especially the fuel consumption and emissions characteristics of the cars being moved from one country to another. In this section we also describe an effort being sponsored by the GFEI which takes Mexico as a case study in order to understand better the characteristics of these cross-border flows and to provide policymakers with tools to limit the importation of high-polluting used vehicles.

One of the objectives of the GFEI is to build capacity in less-developed countries to understand trends in fuel economy and CO₂ emissions and to establish policies, such as standards, regarding them. In Section 8 we describe a study sponsored by the GFEI and undertaken by the Clean Air Initiative for Asian Cities (CAI-Asia) to provide a basis for ASEAN and its member countries to adopt a pro-active approach to promote fuel economy by establishing a common framework for adopting fuel economy policies and measures in support of the goals of the Global Fuel Economy Initiative (GFEI). We also discuss the GFEI activities to support the development of fuel economy policies at the national level. With support from the EU, US Government, and the Global Environment Facility (GEF), among others, the GFEI has started to help countries improve data on existing fleet fuel economy and emissions while also developing a practical approach to developing policy and technology plans for doubling fleet fuel economy in the next few decades. The project targets regional and national-level policy development, and is initiating 50by50 pilots in 4 countries in Latin America, Africa and Asia. GFEI has also supported a range of awareness-raising and networking activities, such as regional fuel economy workshops in the ASEAN, CEE and Latin American regions.

Recent trends in average fuel consumption for new cars

Throughout much of the 1980s and 1990s, new car fuel economy remained relatively constant across most OECD countries. It began to show steady improvements in Europe and Japan in the mid-to-late 1990s in response to new national and regional policies. But it wasn't until about 2005 that new car fuel economy began to improve again in the US. Figure 1, taken from the IEA's recent publication, *Transport Energy and CO₂: Moving Toward Sustainability* (2009), shows reported fuel economy figures (in liters per 100 kilometer) for a selected group of OECD countries.

Figure 1. New LDV tested fuel economy in various OECD Countries: 1995-2007



Notes: US City, CAFE, NEDC and 10-15 are acronyms referring to different test cycles that are not directly comparable.

Source: IEA Mobility Model database.

While trend data such as this is interesting, it doesn't enable us to understand what factors are responsible for the more than 50% variation in the average fuel consumption rates across OECD member countries. The figure for each country's fleet average new car fuel economy represents the combined influence of several different factors. As the results in Figure 1 for Korea show, sometimes a change in just one of these factors - in the case of Korea, a sharp increase in the share of new SUV's in the new light duty vehicle mix - can overwhelm other trends moving in the opposite direction.

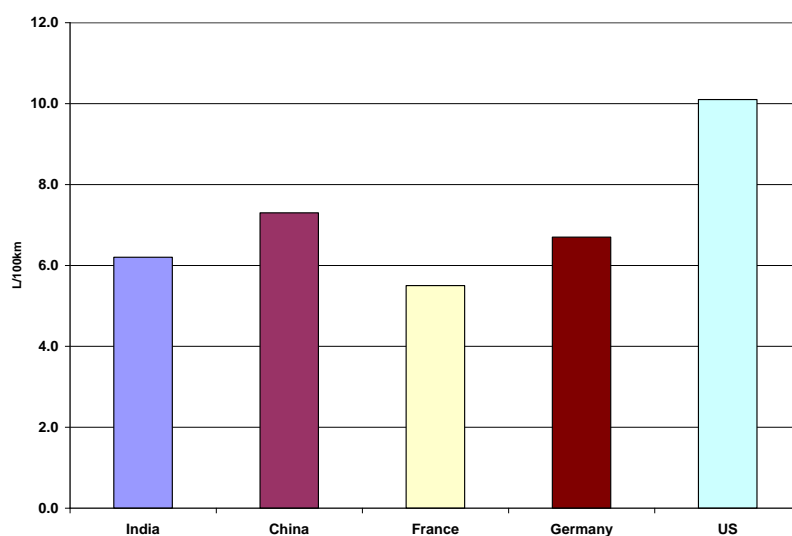
In order to assess the progress being made by different countries and regions in achieving the GFEI's 50by50 goal, it is necessary to have much more detailed cross-country measures of fuel consumption performance as well as information on the various factors that explain this performance. This is particularly important for non-OECD countries, since nearly all the future growth in vehicle sales will take place in these countries. Surprisingly, outside of the US, official data sets are not easily available that provide detailed vehicle sales data by vehicle nameplate, engine and transmission along with data on the official fuel economy test value. To help overcome this lack of data, the GFEI has been compiling a database comparing the fuel economy and related characteristics of light-duty vehicles for a number of more developed and less developed countries, based on work undertaken by the IEA. Over the past year it commissioned the consultancy ICF International (ICFI) to produce a consistent set of measures of fuel consumption performance and the factors influencing this performance for France, Germany, the United States, China and India.³ Taken together, these 5 countries accounted for 24 million new car registrations in calendar year 2008, absorbing about half of all new car production.

3. "Analysis of Vehicle Technology and Fuel Efficiency in India and China: Final Report," prepared for the International Energy Agency by ICF International, Arlington, VA, November 2009.

Figure 2 shows the estimated average fuel consumption of new cars (in l/100km) in 2008 by country as calculated by ICFI. In this case, the fuel economy results reported by governments have been adjusted to account for differences in the test methods used in the different countries.⁴ Specifically, the figure for the US has been multiplied by 1.13. This means that the data shown in Figure 1 above actually *understates* average US new car fuel consumption by 13%. The figure for India has been adjusted upwards by 8%.

Drawing upon a range of sources, ICFI classifies light duty vehicles into size or market classes using a European notation system that is approximately consistent with the US system for larger vehicles. Passenger cars are divided into five classes and light trucks are divided into four classes, based on a combination of interior volume and engine size, to reflect market intent (See Annex 1).

Figure 2. Average New Car Fuel Consumption by Country (l/100km): 2008

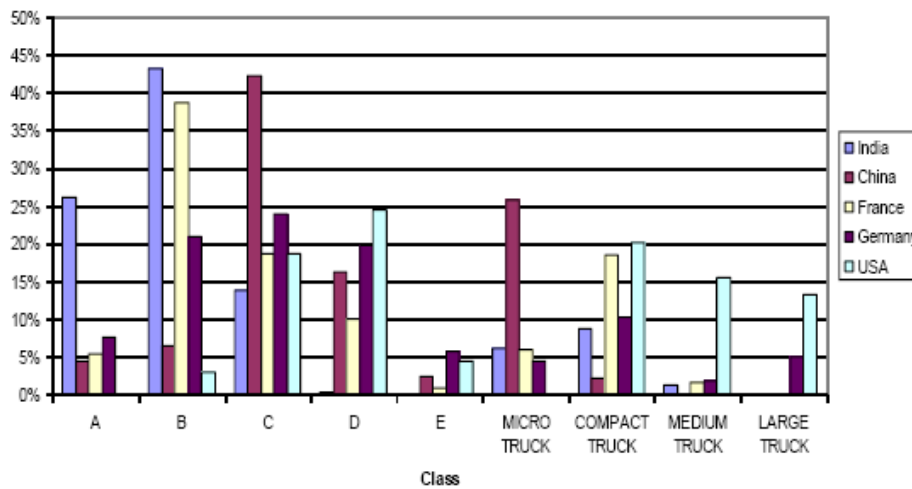


Source: Compiled from data in ICFI report.

The relative importance of each vehicle size class as a share of total new car registrations varies significantly across the five countries (Figure 3). Indeed, certain classes not sold at all in some countries are among the leading sellers in others. For example, A-class vehicles, which make up over 25% of sales in India, aren't even sold in the US. Conversely, D-class vehicles, which make up over 25% of US sales, sell in negligible numbers in India.

4. These different test procedures are intended to reflect the different patterns of driving that are typical of each country or region. The US uses the "Federal Test Procedure." Europe and China use the "New European Driving Cycle" or NEDC. India uses a "modified" version of the NEDC to account for local conditions. To permit a greater degree of comparability of fuel consumption data across countries, ICFI adjusted the reported test fuel consumption data for each country to what it would be using the European NEDC test procedure. This was accomplished by multiplying reported test fuel consumption for US vehicles by 1.13 and reported test fuel consumption for Indian vehicles by 1.08.

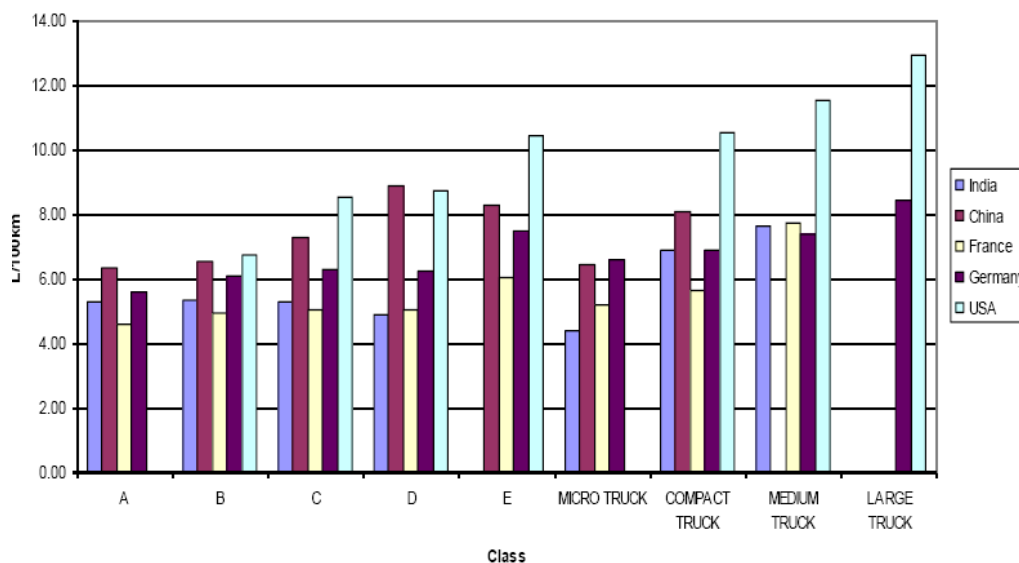
Figure 3. Market share of calendar year 2008 new car registrations by country and vehicle class



Source: ICFI report.

Within-class differences in average fuel consumption, while still significant, are somewhat narrower than fleet differences. (Figure 4) This underscores the importance of fleet mix in determining a nation's or region's new car fuel economy performance.

Figure 4. Within-class Average fuel consumption (in liters/100km) by class



Source: ICFI report.

What explains *within-class* differences in fuel consumption across countries? In particular, are there significant differences in the technological sophistication of vehicles - i.e., a "technology gap?" To investigate this, ICFI performed a detailed multivariate statistical analysis that enabled it to decompose the differences vehicle characteristics at the size class level across the five countries. These were divided into "observable differences" -- diesel penetration, curb weight, performance (horsepower/curb weight) and automatic transmission penetration - and differences in the level of the sophistication of the basic technology being incorporated into the vehicles.

As a result of this analysis, ICFI downplays the idea that there is a significant “technology gap” across the new vehicle fleets of more developed countries. Indeed, comparing the differences between France (the country with the most efficient fleet) and the US (the country with the least efficient fleet) ICFI concludes:

Outside of the different percentages of diesel use, there are no significant differences in the use of fuel efficiency technology between France⁵ and the US. The differences in diesel penetration, vehicle performance, weight, and the use of automatic transmissions almost completely explain the difference in class-specific fuel consumption. All of the differences allocated to other technology fall between $\pm 2.5\%$, i.e., they are not significant.

ICFI finds that there is more of a “technology gap” - though still not a large one -- between the vehicles being sold in more developed and less developed countries.

There is a technology opportunity of about 10% in most high sales volume classes in China, relative to the technology employed in France. With one exception, Class-E, Chinese vehicles have about 10% higher fuel consumption after adjusting for all other factors except technology. In class A, the differential rises to 33.8%, but this is largely explained by the fact that the Chinese Class-A market is very small and dominated by a few older models produced by small local manufacturers under license. Class E is dominated by imports with the Audi A6 being the best seller, and it features advanced turbo-charged direct injection gasoline engine, explaining the positive fuel consumption offset of 10% relative to France.

There also is a significant technology opportunity in the high sales volume segments in India, but this must be tempered by the fact that the opportunities are in very cost sensitive segments. Classes A, B, and compact trucks account for about 78% of total sales. There appears to be a significant technology opportunity in these classes. In classes C and D, the products are almost completely from international suppliers building the same product that they offer across the world, with the only compromise being some reduction in compression ratio or engine calibration to account for the local fuel quality, so that differences with France are small (<5%).

So, while some have argued that developing countries might achieve rapid improvements in fuel economy by “catching up” with the automotive technology of the developed countries, this work suggests that this potential is more limited, and that some technologies may not be cost-effective in the current dominant car types (small and very inexpensive) in countries such as India.

That said, and as will be described in more detail in the following section, there is the potential for new technology to yield significant increases in fuel economy across *all* light-duty vehicle types, and the technical potential will increase in developing countries if the share of larger and higher priced cars grows.

5. France was used as the benchmark since it had the lowest fuel consumption of the five countries. ICFI did not present a detailed analysis of the difference in technology between France and Germany since the same models are sold in both countries and the technology differences reflect the higher level of technology employed by the German luxury car manufacturers, including the widespread use of downsized, turbocharged direct injection gasoline engines by BMW and Audi.

How great is the technical potential to reduce new car fuel consumption by 2020 and by 2030?

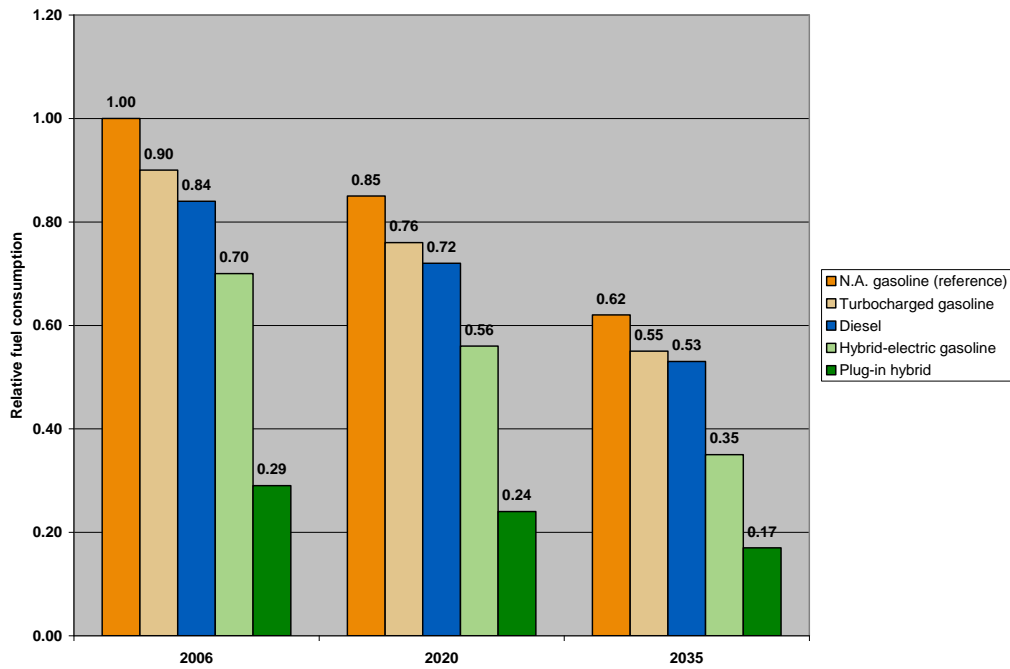
The past year or so has seen the publication of several studies that assess the potential of various technology improvements to reduce new car fuel consumption. These studies generally support the discussion in GFEI's brochure (GFEI, 2009) that "...the technologies required to improve the efficiency of new cars 30% by 2020 and 50% by 2030...mainly involve incremental change to conventional internal combustion engines and drive systems, along with weight reduction and better aerodynamics... [and that] to achieve a 50% improvement by 2030, the main additional measures [required] would be full hybridization of a much wider range of vehicles (possibly including, but not requiring, plug-in hybrid vehicle technologies.)"

a. The United States

One recent study that provides an especially comprehensive survey of this topic as it relates to the United States was issued in late 2009 as part of the US National Academy of Sciences and the National Academy of Engineering's America's Energy Future (AEF) Project. The AEF project produced a series of five reports designed to inform key decisions as the US began a comprehensive examination of energy policy issues. Of greatest relevance to the GFEI is the report by the AEF's Panel on Energy Efficient Technologies, especially the section on light-duty vehicles in its chapter titled "Energy Efficiency in Transportation." This drew on a wide range of recent US studies, especially those conducted over the past few years by Professor John Heywood and his colleagues at MIT (Cheah, et. al., 2007; Bodek and Heywood, 2008; Bandivadekar, et. al., 2008). Annex 2 describes the incremental technology improvements reviewed by the panel.

Figure 5 shows the NRC Panel's summary estimates of the potential reduction in petroleum consumption over the next 25 years (i.e., by 2035) for each vehicle powertrain type assuming that the *entire* potential of these technologies is used to improve fuel economy rather than performance. These results are for vehicles with performance levels and interior size essentially the same as today's new vehicles, but with a 20% vehicle weight reduction, a 25% reduction in vehicle drag coefficient, and a 33% reduction in the tire rolling friction coefficient. In other words, a C-class car in 2035 would still have the same interior room and still accelerate just as rapidly as a C-class car of today. It would be lighter, and, therefore, could use a smaller engine. The smaller engine would be more efficient. The vehicle itself would be more aerodynamic and have improved tires. It would use improved lubricants. But it would not be a "smaller" or "poorer performing" car.

Figure 5. Potential reduction in fuel consumption of new US LDVs by MY2020 and MY2035 relative to MY2006 using different powertrain types

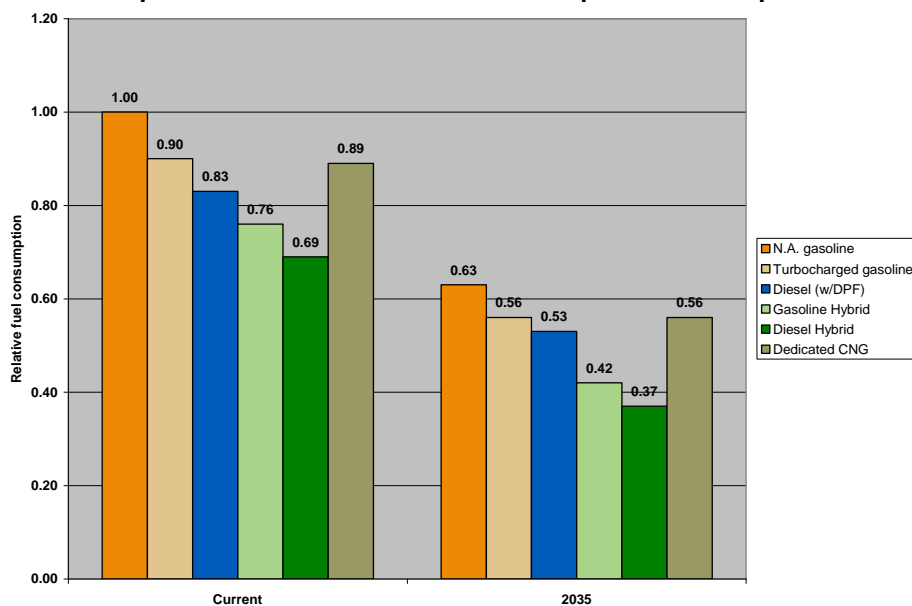


Source: Compiled from NRC, 2009

b. Europe

The technologies described above also have the potential to reduce the energy consumption of the European car fleet. The improvement that they might yield by about 2035 has been estimated by Bandivadekar, et. al. (2008). (As in the case of the US, these results assume that the *entire* potential of the technologies to improve fuel economy is actually used to do so.) Their results are summarized in Figure 6.

Figure 6. Technical potential to reduce fuel consumption in European vehicles by 2035



Source: Compiled from Bandivadekar, 2008.

These studies suggest that in both the US and Europe there is the technical potential to achieve large reductions in new LDV fuel consumption by 2035, consistent with a GFEI target of 50% reduction in fuel consumption from 2005. However, as we will see below, in the past, technical potential has not translated fully into actual reduction in fuel consumption. To reach the GFEI target, this situation will have to change radically.

c. China

The ICFI report also reviewed technology developments in China and India. In China, ICFI expects that conventional technology improvements will keep pace with developed country technology with a lag time of 4 to 5 years, with the significant exceptions of the downsized, turbo-GDI technology and full hybridisation. Between 2008 and 2020 ICFI expects a net reduction in fuel consumption for new cars of about 16 to 18%, ignoring the effects of any shift in the mix of sizes and weights of vehicles.

The majority of engines in China are relatively small 4 cylinder engines. Reducing the cylinder count further is possible but has negative consumer perceptions. Without reducing cylinder count, GDI- turbo is a relatively high cost technology. Of the 20% improvement in fuel economy likely in the US to 2016 from turbo-charging, only about 10% of the technology opportunity will be captured in China.

China is unlikely to follow in any major way with hybrid technology due to the high cost in a very cost sensitive market. The Chinese government is also trying to position China as a leader in EV technology, promoting both battery manufacturers and EVs with significant subsidies. The current subsidies are in the \$5000 range but this is much too small to overcome the high first cost of the EV in China, and EV sales are well below announced targets. ICFI does not anticipate that EV sales will have a large market share (>5%) even by 2020 in China, but major growth could occur in the post-2020 time frame. The role of hybrids and other relatively expensive fuel economy technologies may also grow in importance after 2020, as the Chinese market evolves.

d. India

India has one of the smallest vehicle size mixes of any major country, but in the 2002 to 2007 period, the size mix trended away from the entry level A class to the B and C classes. However, the introduction of the Tata Nano a sub- A class car, suggests major growth potential in the very small vehicle market. The Nano was introduced in the market in mid-2009, and sales in 2010 for this model alone will account for about 10% of the total Indian light vehicle market. Other manufacturers including market leader Maruti and Ford are planning products in this segment that could be introduced in the 2012 to 2014 time frame. ICFI forecasts that the A class market could account for 1.2 million of the 2.8 million vehicle market implied by a 10% growth rate from 2009 to 2015, or a 43% market share, up from about 26% in 2008. This is an unusual development since the typical pattern is for vehicle size to increase with increasing income, and is possibly attributable to the very low price (less than Euro 2500) that might succeed in accelerating consumer movements from motorcycles to cars.

From the perspective of fuel consumption, these new models are quite significant due to their potentially excellent fuel economy. The Tata Nano has been certified at 4.24 L/100km (4.55 L/100km in the city and 3.85 L/ 100km highway) which is a consumption rate 28% lower than the 2008 estimated average of 5.86 L/100 km. Even if fuel efficiency improvements in other classes are minimal, the fleet average fuel consumption will be reduced to about 4.9 L/100km from the current 5.86 L/100km estimated for 2008, a 16.4% reduction. Larger

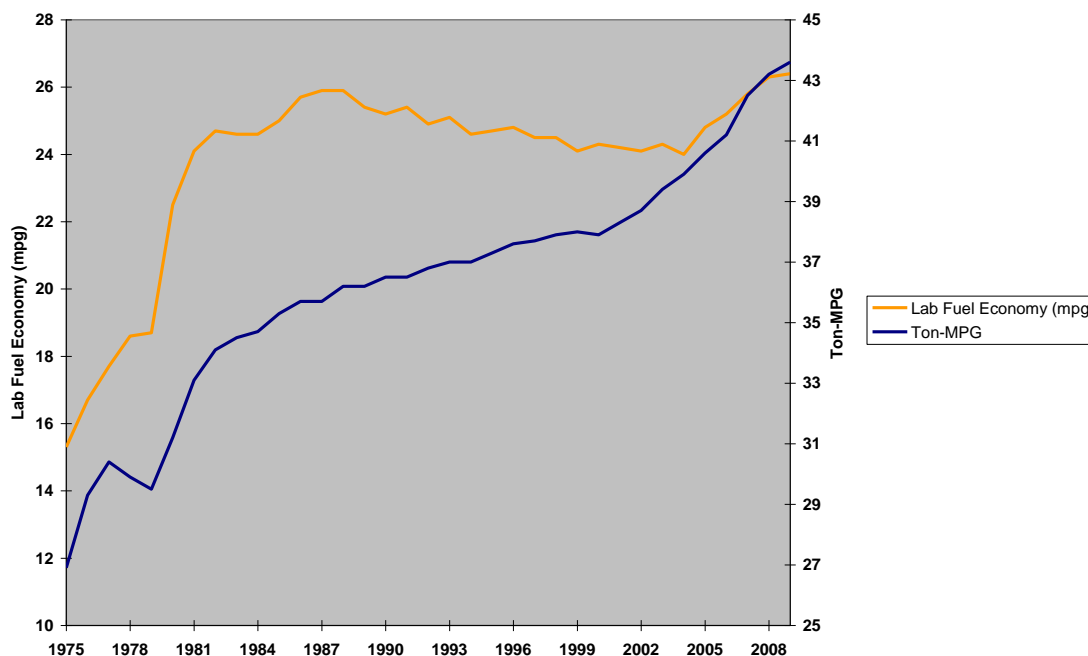
reductions could occur if the other classes also aggressively adopt technology to compete with the low priced (and low profit) sub A class cars. As in China, we do not anticipate widespread use of downsized GDI - turbo engine in India since the baseline engine size is already very small and the turbo is not well suited to India’s low speed driving conditions. Hybrid technology appears to be too expensive for this market at the current time but could be adopted in the post-2020 time frame.

Vehicle average size, short daily driving distances and the weather favor the EV, but the country has a poor electricity supply situation with frequent power cuts in many parts of the country. Hence, until the power supply situation improves, any significant move to EV technology could be counter-productive.

The critical distinction between the technical potential to improve fuel economy and how much of that technical potential is realized

To improve fuel economy, technical potential must be utilized for that purpose. This has often not been the case. Consider the experience of the United States. Since the late 1970s, the US EPA has published an annual report titled “Light-duty Automotive Technology and Fuel Economy Trends.” The data provided in this report begins in 1975; the latest edition (published in November 2009) covers data through 2008. This report provides detailed information about the size, weight, performance, and technology of vehicles in the new US light-duty vehicle fleet. Figure 7, prepared from data from the latest edition, compares the fuel economy (in mpg) as determined by EPA tests in the laboratory (“Lab fuel economy”) and a measure of technical potential, the efficiency with which vehicles move weight using a given amount of fuel (“ton-miles per gallon”, or “Ton-MPG”).

**Figure 7. Lab Fuel Economy (mpg) and Ton-Miles per Gallon:
New US Light-Duty Vehicles, 1975-2009**

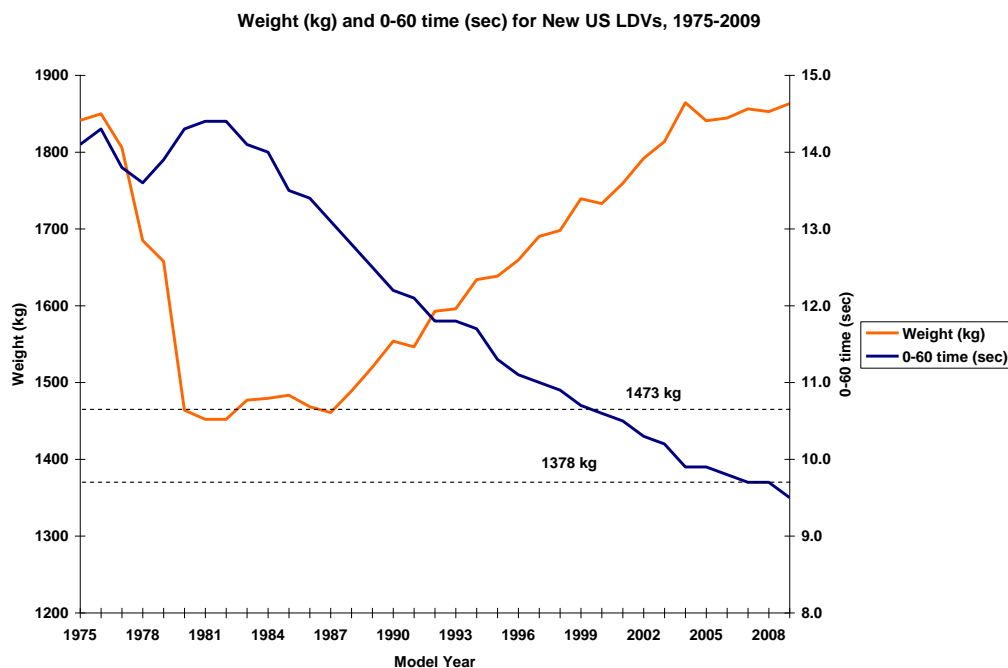


Source: Plotted by author from data in USEPA, Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2009.

From 1975 until 1982, average fuel economy of the new US light-duty fleet actually grew faster than its technical potential. This is explained by the fact that the weight of each class of car (subcompact, compact, midsize, large) declined and by shifts in buyer preferences from larger toward smaller vehicles. During this period, fuel economy improvement in the US was spurred both by the “push” of the US CAFE regulations and by the “pull” of high gasoline prices.

However, by the middle of the 1980s, gasoline prices had fallen sharply -- eroding the “pull”-- and the original CAFE targets had been largely achieved and were not increased -- eroding the “push.” From the mid-1980s, although technology having the *potential* to improve fuel economy continued to be incorporated into new US LDVs, new light-duty fleet fuel economy stagnated, declining slowly from 1988 through 2004. It began to grow again only in 2005. The USEPA summarized the cause of this performance as follows: “From 1987 through 2004, on a fleet-wide basis ... technology innovation was utilized exclusively to support market-driven attributes other than CO₂ emissions and fuel economy, such as vehicle weight (which supports vehicle content and features), performance, and utility. Beginning in MY2005, technology has been used to increase both fuel economy (which has reduced CO₂ emissions) and performance, while keeping vehicle weight relatively constant.”⁶ (See Figure 8)

Figure 8: Weight (kg) and 0-60 time (seconds) for New US Light-Duty Vehicles: MY1975 through MY2009



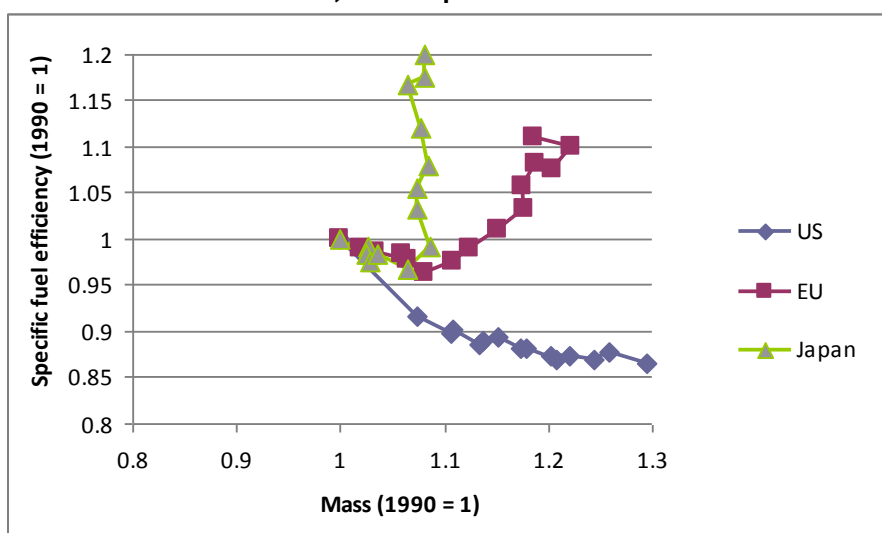
Source: Plotted by author from data in USEPA, Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2009.

⁶. US EPA, “Light-Duty Vehicle Technology and Fuel Economy Trends: 1975-2008,” November 2009, p. vi.

While the US represents the extreme case of fuel economy improvement potential not being translated into actual improvements in fuel economy, it is not the only country or region where this happened. Using data for 1995-2006 for France and Germany and for 1995-2001 for Italy and the UK, Bandivadekar, et. al. have estimated the share of fuel economy increase potential that was used to increase fuel economy at between 22% and 83%, depending on the country and whether the vehicle is powered by gasoline or diesel. The 22% figure is for German diesel-powered vehicles; the 83% figure is for Italian gasoline-powered vehicles. Most other values are between 50% and 70%.

Figure 9, adapted from IEA 2009, shows the evolution of fuel economy and weight between 1990 and 2006 for new cars in the US, the EU, and Japan. After the mid-1990s, only Japan managed to keep the weight of its new vehicles constant, thereby enabling the fuel economy of its new vehicles to improve significantly.

Figure 9. Evolution of Fuel Economy and Weight for New Passenger Vehicles in the US, the EU, and Japan: 1990-2004



Source: Adapted from IEA, 2009.

To illustrate the impact on average US new car fuel economy by 2035 of the degree to which technical potential is translated into actual improvement, the NRC Panel whose estimates of “technical potential” were shown above, developed two scenarios in which “technical potential” was the same, but in which there was variance in the share of technology potential translated into improved fuel economy (what they term “Emphasis on Reducing Fuel Consumption” or ERFC), the share of all new LDVs that are automobiles, and the relative sales mix of vehicles employing different technologies. (See Box 1 for details.)

In the “conservative” scenario, the ERFC is assumed to be 50%, automobiles are assumed to constitute 60% of vehicle sales, and the average weight of new US light-duty vehicles in 2035 is assumed to be approximately 1500 kg, approximately their average weight in the mid-1980s. (This is shown as the upper dotted line in Figure 8 above.) Under these assumptions, by 2035, fuel consumption of the average new US LDV is 38% less than at present. In the “optimistic” scenario, the ERFC is assumed to be 75%, automobile are assumed to increase their share of total vehicle sales to 70% by 2035, and the average weight of new US light-duty vehicles is assumed to be about 1400 kg (shown as the lower dotted line in figure 8.) Under these assumptions, by 2035, fuel consumption of the average new US LDV is 50% less than at present.

Although these two scenarios are considered to be purely “illustrative,” they show what is required *in addition to incorporating the incremental technologies described in the section above* in order for the US new LDV fleet to meet the 50by50 goal for new cars by 2035.

Box 1. Illustrative Future Vehicle Sales Mix Scenarios Used in the Panel’s Analysis

	% ERFC ¹	Share of Light Trucks (%)	% Average Vehicle Weight Reduction	Sales Share (%)					Fuel Consumption Reduction from Current (%)
				Gasoline NA	Gasoline Turbo	Diesel	Gasoline Hybrid	Plug-in Hybrid	
Conservative									
2025	50	40	17	55	24	7	14	0	26%
2035	50	40	20	49	21	7	16	7	38%
Optimistic									
2020	75	40	17	52	26	7	15	0	26%
2035	75	30	25	36	26	9	20	9	50%

¹ERFC = Emphasis on Reducing Fuel Consumption = Share of technology potential devoted to decreasing actual fuel consumption

The first scenario, designated “conservative” by the Panel, assumes that the new US LDV fleet achieves a corporate average fuel economy of about 35 mpg in 2025 and continues this rate of improvement through 2035. The average reduction in vehicle weight implied by the weight reduction assumptions in the “conservative” scenario is 323kg by 2025 and 380kg by 2035. By the latter year, the average US LDV would weigh 1 473 kg - approximately what it weighed in the mid-1980s (see Figure 8). The share of technology potential devoted to decreasing fuel consumption (designated ERFC in Table 3) is 50%. In this scenario, the new US LDV fleet actually realizes a fuel consumption reduction of 26% by 2025 and a fuel consumption reduction of 38% by 2035.

The Panel’s “optimistic” scenario assumes that the new US LDV fleet reaches 35 mpg in 2020 (rather than 2025) and that this higher rate of improvement continues through 2035. The assumed vehicle weight reduction is 323kg by 2020 and 475kg by 2035. By this latter year, the average US LDV would weigh 1378 kg, about 100 kg less than it weighed in the mid-1980s. The share of technology potential devoted to decreasing actual fuel consumption is assumed to be 75%. In this scenario, the new US LDV fleet achieves a fuel consumption reduction of 26% by 2020 and a reduction of 50% by 2035.

Although plug-in hybrids appear in both scenarios after 2020, they play only a minor share in the improvement in either scenario.

Source: NRC, 2009.

For this reason, the Panel concluded:

These illustrative scenarios show that substantial changes in vehicle weight and size, significant improvements in the efficiency of ICE powertrains, and the increasing production over time of hybrid systems, will *all* be needed to reduce the in-use fuel consumption of the US light-duty vehicle fleet. The market will need to respond by purchasing these improved vehicles in steadily growing volumes despite their higher price, and forego expectations of ever-increasing vehicle performance. If the trends indicated by these scenarios are to occur, the assumed vehicle changes (or their equivalents) will need to start soon. (emphasis added) (NRC, 2010.)

The ICFI report expresses concern that in China, some of the potential for higher fuel economy may be lost due to changes in fleet mix. They note that the Chinese market has been moving towards larger vehicles for the last 7 to 8 years and A class vehicles are now a very small segment of the market. (ICFI reports that one Chinese manufacturer publicly commented that it could easily produce a very cheap sub-A segment car like the Tata Nano but there was

no market in China for such a vehicle.) The average vehicle sold in China is now larger than the average French vehicle, and many observers see this trend continuing as incomes rise. Luxury vehicles, which accounted for just one percent of the market 8 years ago, accounted for 2.5% of the market in 2008. SUV models in the large/ luxury segment are also increasing. Sales in the C, D and E segments as well as the compact SUV segment have risen much faster than sales in the A and B segment. The E segment in particular is dominated by luxury European brands with the Japanese entering this segment only recently with the Lexus and Infiniti brands. The Chinese E- segment is so large in absolute sales that this is the most important market for sales volume leader, Audi, outside of Germany.

ICFI estimates that fleet upsizing may negate 3 to 5% of the potential fuel economy benefits produced by improved technology if new taxes recently enacted by the Chinese government (described below) do not act as a deterrent to the recent trend towards large and luxury vehicles. Fuel price increases can have modest effects on size mix sold, but the retail fuel market is often insulated from price shocks in China. ICFI forecasts a fuel consumption reduction of about 13 to 15% from 2008 to 2020 under stable crude prices of \$70/bbl, and about 20% under rising crude prices to \$100/bbl.

Policies to encourage the production and purchase of cars with significantly lower fuel consumption

The last few years have seen many governments adopt new and/or strengthened policies to require the production and purchase of cars having lower fuel consumption. The primary motivations have been to improve energy security and reduce CO₂ emissions from cars. The rapid run-up in oil prices that occurred in 2008 was an important factor stimulating government policy action.

a. The pros and cons of alternative policy instruments

In the spring of 2010 the ITF convened a discussion on instruments to promote innovation for low carbon cars (ITF 2010). The pros and cons of a wide range of instruments were debated, and the group reached certain conclusions about which instruments might be appropriate in which circumstances.

i. Carbon prices, land use and transport planning

There was wide agreement on the need for appropriate carbon prices. Fuel taxes or cap-and-trade mechanisms can fulfil that role. To take their full effect, carbon prices need to be embedded in a framework guided by land use and transport planning. It is also often argued that carbon prices in transport could usefully be relatively high compared to other sectors, to the extent that mobility is a less elastic and therefore less distortionary tax base than is found in other carbon-intensive sectors.

ii. Fuel economy standards and vehicle taxes

Some economists and stakeholders oppose standards on principle, arguing that manufacturers should not be made responsible for energy use in transport. At its most extreme this means no coercive policies (possibly including taxes) should be used. Alternatively it means that policies should work through demand rather than directly on supply. While few would take this line to argue against standards as such, the argument does have some bearing on what kind of standard to use. Defining standards in terms of

sales-weighted averages requires manufactures to steer sales in a particular direction, rather than just attaining some performance level conditional on the type of vehicle, and is in this sense more intrusive than a technology neutral standard, which would require differentiating sales-weighted average targets by the average weight or size (footprint) of vehicles by manufacturer. (Fuel taxes, of course, are even more neutral with respect to choices). In the ITF roundtable discussions it was also noted that if the goal is to push innovation, it may be better not to structure standards to allow shifts in the sales-mix as a compliance mechanism.

An intermediate view is that fuel economy standards are useful when appropriate carbon prices cannot be implemented. At the other extreme some policy makers believe that as it is imperative to abate strongly and quickly, standards should be used to make sure targets are reached. In this view, standards and taxes should be combined and made to be mutually reinforcing. Taxes are mostly a demand-pull measure, and standards, mostly a supply-push measure. Given the structure of the market for fuel economy and perceived inertia in the demand for driving, both elements are needed (although some argue that driving should not be discouraged rather than that it is difficult to discourage it). Consistency between demand and supply-side incentives is required to keep emission concerns squarely among manufacturers' strategic priorities.

The auto industry needs a regulatory environment that provides as much certainty as possible if it is to make the large capital investments necessary to maximise the fuel economy of new cars, and even more so for shifting to new primary energy sources. Standards can provide this certainty and the longer the planning horizon the better. Binding standards for the short term can be complemented by indicative targets for the longer term. For example the European Union's standard of 120 g CO₂/km by 2012 for the new car fleet average is accompanied by a 95 g CO₂/km target for 2020. Standards may outperform taxes in stimulating innovation because they are more closely tied to supply, where innovative effort is concentrated.

It may also be noted that harmonisation of tax structures is frequently more difficult than harmonisation of standards. This is particularly noticeable in the European Union, where fiscal policy is strictly subject to national sovereignty whereas a single CO₂ emissions standard for the whole region was developed by the European Commission. Moreover, vehicle registration and circulation taxes have an element of local government control in many countries. In relation to the remark that taxes and standards should be mutually reinforcing, Bastard (2010) highlights the lack of coordination between the structure of taxes and vehicle efficiency labels in Europe and the Union's CO₂ standards for cars. Manufacturers contend that this can raise compliance costs for manufacturers and weaken their incentive to design cars to maximise fuel efficiency because of the extreme fragmentation of the European market that results from the different break points employed in differentiation of taxes and labels.

iii. Subsidising low carbon vehicles (e.g. fee-rebate programmes)

Temporary subsidies for low carbon vehicles are often defended on the grounds that such technologies are at a cost disadvantage as long as the scale of production is small compared to that of conventional vehicles and because experience and competition keeps the cost of innovation for internal combustion drive trains relatively

low. The subsidy then is designed to ramp up production. This is a separate function to subsidies to R&D intended to stimulate innovation and justified on the basis of knowledge spillovers. Subsidies should be targeted to affect supply rather than increase profits, the latter being a risk especially in imperfectly competitive industries. For efficiency, subsidies should be designed to be as neutral as possible with respect to particular technologies. Research prizes combined with performance standards may be fairly neutral, but complete neutrality is not possible. Even a subsidy based on graduated performance standards will need to check compliance at some point in time and will rely on imperfect information on (future) costs and performance. If innovation is to be steered in a particular direction, there is a price to pay in terms of abandoning pure neutrality. And while it makes sense to see the subsidies as temporary, deciding when the phase out begins is less than straightforward. Removing subsidies that industries have become dependent on is always difficult, even when the original reason for the subsidy no longer applies. This is a strong argument in political economy for avoiding subsidies in the first place. On the other hand, manufacturers risk seeing subsidies for the purchase of electric or fuel cell vehicles cut back before they can recoup the costs of developing the vehicles. The risks of relying on political commitments are exacerbated by the time it takes to develop new cars of this sort. Governments may be able to guarantee the availability of subsidies for 3 or 4 years but just getting new products to market may take much of this time. Electric vehicle subsidies in France, Germany and especially the UK have been structured to provide some security in this respect.

In sum, the risks associated with subsidies induce rather negative attitudes towards them among economists and sometimes manufacturers. “Reluctant support” for subsidies at the ITF roundtable was based on the premise that breakthrough technologies are needed if the energy base of transport is to be transformed. Innovation in the car industry is not of the “lone creative entrepreneur” type, but the transformative efforts required for very low carbon transport should not necessarily be expected to emerge unaided from industry. Policy intervention then is needed, even given tangible risks that it turns out more costly than hoped for, provided that the risks of not attaining policy targets are deemed larger than the risks of intervention.

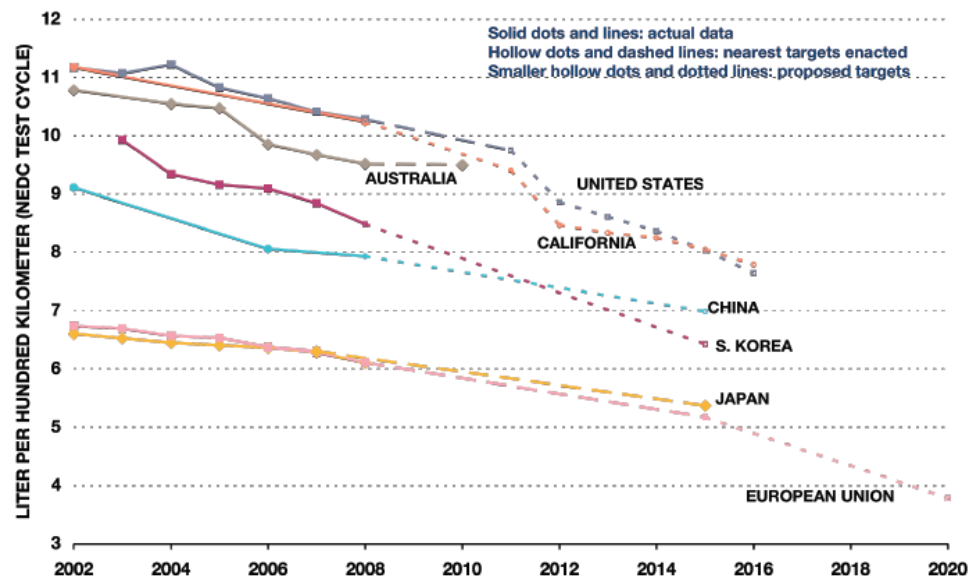
iv. Providing information

Decisions on what level of fuel economy to invest in take place under considerable uncertainty. One important source of uncertainty is the effective fuel economy that a prospective purchase would deliver. Better information in that respect would lead to better decisions, and loss aversion would become less prominent in affecting outcomes. Better information can come in several forms. Simple labels, analogous to those used to indicate household appliances’ energy efficiency in the EU, provide easy guidance for comparison among models. But customized fuel economy information can be helpful as well. Giving prospective buyers access to tools (e.g. online) to investigate how a vehicle’s average (labelled) fuel economy would change according to particular driving patterns reduces uncertainty on the quality of the average as an indicator (and invites buyers to think carefully about their usage patterns).

b. Recent developments in fuel economy and CO₂ emissions policies

In the past few years, several countries have adopted and tightened their policies improving passenger vehicle fuel economy and reducing CO₂ emissions from these vehicles. (Figure 10.) Two recent policy developments particularly worthy of note were the issuance in April 2009 of CO₂ emissions performance standards for new passenger cars by the European Union and the adoption in April 2010 by the US EPA and US NHTSA of rules tightening US fuel economy standards for light-duty passenger vehicles and linking them to CO₂ emissions targets.

Figure 10. Actual average fleet fuel efficiency data through 2008 and nearest targets enacted or proposed thereafter by region



Source: ICCT, 2009.

i. Adoption of EU CO₂ emissions performance standards⁷

Prior to April 2009, the EU relied upon voluntary commitments by European, Japanese and Korean motor vehicle manufacturers associations to reduce fuel consumption and CO₂ emissions from passenger cars. In these commitments, made in the early 1990s, the three Associations had pledged that the vehicles sold by their members in the EU would average 140 g CO₂/km by 2008 (for the European manufacturers) or by 2009 (for the Japanese and Korean manufacturers) with an interim target of 165-170 g CO₂/km by 2003.⁸ The agreements also stated that Governments would introduce incentives for consumers to buy low emission vehicles in support of the targets, though the European Commission had no power to ensure any specific measures were adopted and in the event countries were very slow to develop such incentives. By February 2007, dissatisfied with the progress being made, the Commission indicated that it intended to “...propose, if possible in 2007 and at the latest by mid 2008 an EU legislative framework to reduce CO₂ emissions from light duty vehicles with a view to reaching the EU objective of 120 g CO₂/km by 2012.” It was this “legislative framework” that eventually led to the regulation published on April 23, 2009.

7. European Union, (2009).

8. In 1995, the EU15 average level of 186 gCO₂/km.

This regulation set a target fleet average of 130 g CO₂/km, with 65% of each manufacturer's cars newly-registered in the EU having to meet the 130 g CO₂/km average in 2012, 75% having to meet it in 2013, 80% having to meet it in 2014, and 100% having to meet it from 2015 onwards.⁹ A long term target of 95 g CO₂/km was set for 2020, with the means for reaching it to be defined in a review to be completed no later than 2013. Manufacturers will be able to join together to form pools which can act jointly in meeting specific emissions targets. Independent manufacturers who sell fewer than 10,000 vehicles per year and who cannot or do not wish to join a pool can instead apply to the Commission for an individual target.

The regulation established penalties that manufacturers would have to pay for failing to meet these targets. Until 2018, these payments would begin at €5 for each car registered for the first gram exceeding the 130 g CO₂/km level, rising to €95 for the fourth and subsequent gram. From 2019, the €95 per gram penalty would apply to the first and each subsequent gram exceeding the 130 g CO₂/km level.

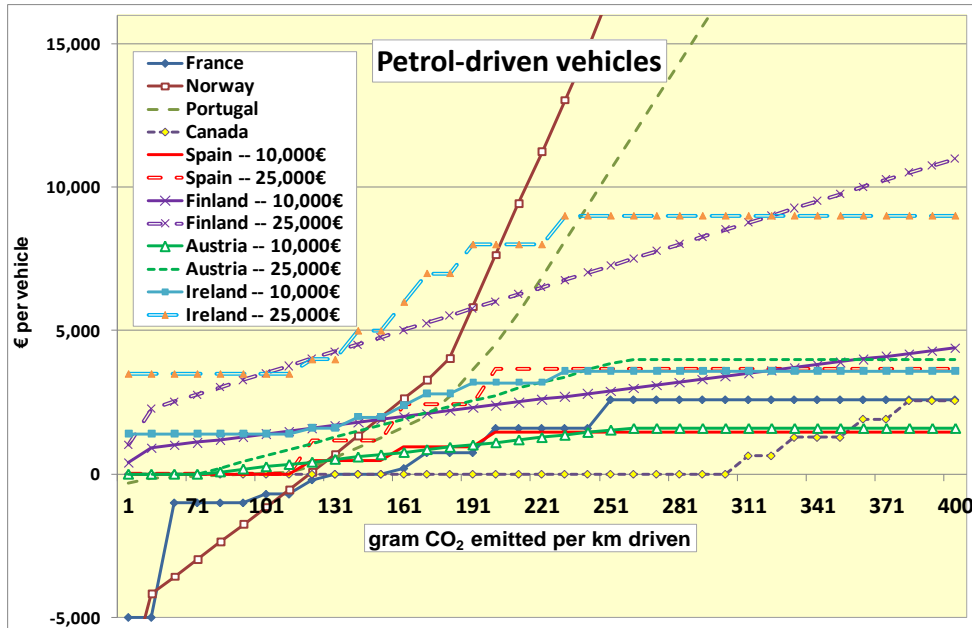
In the EU, vehicle taxation is the exclusive preserve of the Member States. As of the beginning of 2010, 16 EU Member States had put in place one or more economic measures intended to reduce CO₂ emissions from cars, most of which had been introduced within the past three years. Many of these economic measures took the form of purchase taxes. The way taxes are differentiated, with different break points separating vehicle classes (illustrated in Figure 11) atomises markets and reducing some below the threshold at which customizing vehicles to benefit from the incentives makes commercial sense, diluting the impact of tax incentives. Moreover, converted into Euros per ton of carbon emitted over the vehicle lifetime, some of the taxes are structured to penalize low emission vehicles; and the structure of tax incentives is often not aligned with the structure of information and labeling schemes for vehicle fuel efficiency.

Whilst current economic instruments do create strong environmental incentives driving a decrease in the CO₂ emissions of the new car fleet, the fragmentation of incentives has a significant cost. Other regions with reasonably integrated car markets, such as Canada-USA-Mexico should avoid fragmentation. The solution is to correlate incentives directly to CO₂ emissions with linearly differentiated rates, avoiding steps and break points.

Just how much the current economic instruments might be driving a decrease in the CO₂ emissions (and energy consumption) of the new car fleet is suggested in a paper by ADEME and IFP titled "Influence of Weight and Performance on Private Car Fuel Consumption." This paper traces CO₂ emissions performance and weight of the French new vehicle fleet from the mid-1990s through 2008. Between 2001 and 2007, average CO₂ emissions from new cars sold in France fell by 1 gm/km per year. However, as the French "bonus/malus" scheme was introduced in 2008, CO₂ emissions fell by 9 g/km. The impact is illustrated in Figure 12. The average weight of vehicles sold in France, which had been growing steadily at a rate of about 20 kg/yr, fell in 2008 by 32 kg - the first decline in 20 years. This reduction in weight was also accompanied by a reduction in average engine power. Previously it had been growing at about 2 kW per year. In 2008 it fell by 5 kW.

9. From 2012 to 2015, a "limit value curve," was established in the regulation. This curve indicates the maximum CO₂ emissions permitted for cars of different vehicle mass while preserving the fleet average. Vehicles with a mass of 500 kg can emit no more than 90.1 gCO₂/km, while cars of 2500 kg can emit no more than 185.5 gCO₂/km.

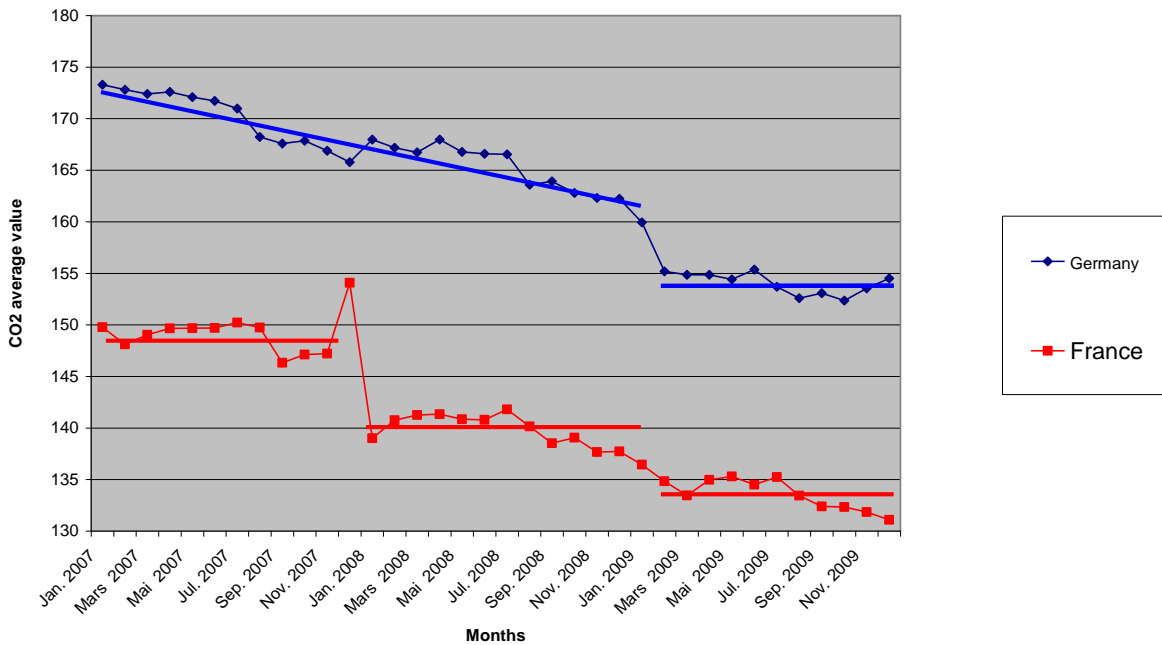
Figure 11. Differentiation of One-off Vehicle Taxes (purchase or registration taxes) in Europe



Source: OECD, 2009.

Figure 12. Monthly Evolution of Average Specific CO₂ Emissions from New Cars sold in France and Germany

Monthly evolution of CO₂ G and F 2007-2009



Source: Bastard, 2010.

ii. New US Fuel Economy and CO₂ Emissions Standards¹⁰

In the US, the principal policy tool used to impact vehicle fuel consumption has been the Corporate Average Fuel Economy (CAFE) standards. These standards were established in 1975 and, at least for automobiles, remained essentially unchanged until the Energy Independence and Security Act of 2007 raised them significantly. This legislation required that new passenger cars and light-duty trucks achieve an average of 35 mpg (6.7 L/100km) by 2020.

This legislation also changed the basis on which a manufacturer's CAFE was to be calculated. Since 1975, manufacturers had been required to meet different standards for passenger cars and light trucks (including pickups, vans, and SUVs) and to meet them both with their domestically-produced and their imported fleets. The new CAFE standards were to be based on the "footprint" of different categories of vehicles.¹¹ (See Table 1.) The percentage improvement in fuel economy required for each vehicle category will be the same. A certain amount of trading or transferring of CAFE credits among manufacturers is to be permitted. Automakers will pay a civil penalty on each vehicle they sell of \$5.50 for every 0.1 mpg that they fall short of reaching their CAFE target. According to NHTSA, since 1983 manufacturers have paid more than \$735 million in CAFE penalties.

Table 1. Model Year 2016 CO₂ and Fuel Economy Targets for Various MY 2008 Vehicle Types

Vehicle Type	Example Models	Example Model Footprint (sq. ft.)	EPA CO ₂ Emissions Target (g/mi)	NHTSA Fuel Economy Target (mpg)
Example Passenger Cars				
Compact car	Honda Fit	40	206	41.1/5.7
Midsize car	Ford Fusion	46	230	37.1/6.3
Full-size car	Chrysler 300	53	263	32.6/7.2
Example Light-duty Trucks				
Small SUV	4WD Ford Escape	44	259	32.9/7.2
Midsize crossover	Nissan Murano	49	279	30.6/7.7
Minivan	Toyota Sienna	55	303	28.2/8.3
Large pickup truck	Chevy Silverado	67	348	24.7/9.5

Source: EPA/NHTSA 2010, p. 46.

In early 2009, the Obama administration proposed accelerating the date by which the new CAFE targets must be achieved. It also proposed issuing the first CO₂ emissions standards for automobiles and integrating them with the CAFE standards. On April 1, 2010, EPA and NHTSA jointly published final rules reflecting this proposal. At the same time, the two agencies also announced that they were beginning to consider what post-2016 standards ought to be.

10. These standards have also now been adopted by Canada.

11. Footprint" is defined as the product of a vehicle's wheelbase times its average track width.

The EPA/NHTSA rules apply to new passenger cars, light-duty trucks, and medium-duty passenger vehicles and cover model years 2012 through 2016. EPA's rule requires that MY2016 vehicles meet an estimated combined average emissions standard of 250 grams of CO₂ per mile (225 g CO₂/mi for passenger cars; 298 g CO₂/mi for light trucks.)¹² But just how this translates into a standard for new fleet fuel economy is somewhat complicated.

EPA's press release announcing its standard states that the 250 gram CO₂/mile level is "...equivalent to 35.5 miles per gallon *if the automotive industry were to meet this CO₂ level all through fuel economy improvements*" (emphasis added). But EPA does not expect manufacturers to meet the 250 g CO₂/mi required "all through fuel economy improvements." Rather, manufacturers are expected to take advantage of the option provided in its regulations to generate CO₂-equivalent credits by reducing emissions of hydrofluorocarbons (HFCs)¹³ and CO₂ through improvements in their air conditioning systems. By law, NHTSA cannot reflect air conditioning improvements in its CAFE standards. So the combined fleet CAFE standard actually set by NHTSA was 34.1 mpg. But even this level is not expected to be reached. NHTSA expects that some manufacturers may continue to pay civil penalties rather than achieved the required CAFE levels. It also expects that manufacturers will manage to earn the maximum number of flexible fuel vehicle (FFV) CAFE credits that they are permitted to earn.¹⁴ This leads NHTSA to project that the final fleet-wide CAFE level that will be achieved in MY2016 is 32.7 mpg for the combined light-duty fleet. If so, this would represent a reduction in new light-duty fleet fuel consumption of about 20% (on a L/100km basis).

In the US, the CAFE standards and the civil penalties and credits that accompany it are the primary policy instrument used to promote greater energy efficiency of light-duty vehicles. While the US has taxes on car acquisition and ownership, they are not all that large compared with Europe.¹⁵ Vehicle registration fees are nominal, and fuel taxes, though they vary by state, are a fraction of European levels.¹⁶ There are few additional financial incentives offered by governmental units to encourage the purchase of more fuel-efficient vehicles.¹⁷ Rather, the CAFE program presumes that the penalties attached to not meeting the fuel economy targets will be sufficient to induce manufacturers to build vehicles having the appropriate fuel economy characteristics and price them such that customers will buy them in sufficient numbers. However, increased attention is being given to the possibility of supplementing the CAFE standards with incentives, such as "feebates" (similar to the French "bonus/malus" system) to strengthen the signal to consumers to purchase more fuel-efficient vehicles.

12. 250 g/mile is equivalent to 155 g/km.

13. HCFCs are extremely potent greenhouse gases. The global warming potential per kilogram of various HCFCs ranges from 437 times to 32,600 times the global warming potential of a kilogram of CO₂.

14. The manufacturers can earn a limited amount of CAFE credit by manufacturing vehicles capable of utilizing up to 85% ethanol (E-85) even if they don't actually use this fuel.

15. In 2008, the average cost of car ownership in the US totaled \$7095 per year. License, taxes and registration fees totaled \$554. TEDB Edition 28, pp. 10-16 and 10-17.

16. In 2007, the average price of gasoline in the US was \$2.88 per gallon, 14% of which was taxes. TEDB Edition 28, pp. 10-4 and 10.5.

17. There are incentives for the purchase of hybrid vehicles, but the number of vehicles that can benefit from these incentives is severely limited.

The projected US fuel economy level for 2016 of 250 g CO₂/mi (which translates into 155g CO₂/km) and 32.7mpg (7.2 L/100km) is somewhat less stringent than the targets embodied in the EU regulations for 2015 (130 g CO₂/km and 4.9-5.6 L/100km (42-48 mpg) depending on whether the vehicle is powered by diesel or gasoline.) For reference, the fleet average fuel consumption Japanese target for 2015 is 6.0 L/100km (40 mpg).

iii. Evolving standards in China

Chinese fuel economy standards have been imposed by weight class, and separate standards apply to automatic and manual transmission vehicles. The standards were first imposed in 2005, were tightened in 2008, and are applicable as an efficiency floor. (In other words, all vehicles must meet standards; there is no manufacturer averaging.) The 2005 standards affected few vehicles since the targets for smaller vehicles were all set above 8L/100km for automatic transmission vehicles and were set at over 11L/100km for 1 500 kg curb weight vehicles. The typical midsize US car, for example, has a curb weight of about 1500kg and has fuel economy levels of about 8L/ 100km or lower on the US cycle and 9L/100km on the Chinese test. The standards for 2008 were lowered by 1L per 100 km at the lightest end and by almost 2L/100km at the heaviest end but the standard for a 1 500 kg vehicle is still 10.5 L/100 km. Thus, it appears that standards are not a binding constraint on most Chinese vehicles at this point.

Standards will be made more stringent in 2012 and perhaps in successive four year periods. Most 2008 vehicles were well below fuel consumption requirements. It is not clear if government policy intends standards to be technology forcing, or to simply prevent the sales of the highest fuel consumption vehicles in any weight class. ICFI forecasts that Chinese standards will not be a binding constraint over the next decade.

The Chinese national government has also been concerned about the trend to larger and more powerful vehicles mentioned above and has taken two steps to control this trend in the future. First, it has imposed fuel economy standards that are more stringent for heavier vehicles than lighter vehicles. Second, it has lowered the tax rate on vehicles with engines smaller than 1.6L from 3% to 1%, while increasing taxes on vehicles with engines over 3L from 15% to 25%.

iv. Limited progress in India

Two significant unknowns for the Indian market are the state of fuel economy regulations and the future of the light duty diesel. The Indian government agreed in principle to adopt fuel economy standards in 2007 but standards have still to be proposed. Internationally, India has been resisting mandatory GHG emission cuts. The government may not design standards to be technology forcing even if standards are adopted. It is not expected that fuel economy standards will have much effect on the overall level of fuel efficiency for cars, given the very high level of efficiency without standards. Second, the large subsidy for diesel fuel to assist commercial trucking has made light duty diesels popular and the current market share already exceeds 20% and may increase more in the B-class and larger segments. Many NGOs are complaining about the diesel fuel subsidy being harnessed by relatively rich car owners, and it is possible that light duty diesel vehicles may be taxed extra to offset the fuel subsidy. This could reduce diesel penetration, but the effect on average fuel consumption would be to increase it by a maximum of 4 to 5 % relative to the 2008 baseline if diesel penetration goes to zero, which is not likely.

ICFI expects the average fuel consumption of the vehicle fleet to drop by at least 16% in 2015 relative to 2008, driven largely by the anticipated popularity of very cheap sub A class cars. By 2020, the net reduction in fuel consumption could be around 20% to 22 % or more due to both the mix shift and modest technology improvements (~5%) to all vehicles. It does not anticipate that fuel economy standards will be a major driver of actual fleet fuel consumption in India to 2020.

v. Developments in South Africa

Transport is the second largest energy-consuming sector in the country and is expected to grow considerably in the medium-term. As the country adopts reduction targets for CO₂, a vehicle labeling system has been introduced for fuel economy accompanied by legislation on a feebate system, and incentives for technology upgrades to spur turnover in the vehicle park.

As of 2008, all car dealers in South Africa have been required to display stickers on the windscreens of new cars, informing prospective buyers how fuel efficient each vehicle is and how much carbon dioxide it emits.¹⁸

The new budget for 2010 recommends that the 2009 ad valorem CO₂ emission tax on new passenger motor vehicles be converted into a flat rate CO₂ emissions tax, effective from September 1st, 2010. This tax will be implemented as a specific tax, based on new passenger car certified CO₂ emissions at R75 per g/km for each g/km above 120 g/km, in addition to the current ad valorem luxury tax on new vehicles.¹⁹

c. Chile evaluates the potential of standards

There are two main elements of the proposed energy efficiency policy for light-duty vehicles by the newly-formed Ministry of Energy: an incentive program for the purchase of hybrid electric vehicles and a planned vehicle fuel economy labeling system. Labeling regulations and their implementation schedule are currently pending.

Chile does not have direct vehicle fuel economy standards, but national agencies are evaluating their potential. Several other relevant programs are under development or in pilot stage, including the development of a fleet procurement manual, which will explicitly include life-cycle considerations, allowing for the more expensive up-front purchase price of efficient vehicles to be amortised over the lower lifetime operating costs.

d. Brazil implements fuel efficiency labeling

In November 2009, Brazil's National Institute of Metrology, Standardization and Industrial Quality ([Inmetro](http://www.inmetro.gov.br)) implemented a new labeling system for cars that informs consumers about the fuel efficiency of the new vehicles they might purchase.²⁰

18. Pretoria News, (2007).

19. Budget 2010/2011 Tax Proposals." South Africa National Treasury, 2010: 9. Accessed 16 March 2010 (www.treasury.gov.za/documents/national%20budget/2010/guides/Budget%20Tax%20Proposals.pdf).

20. www.temasactuales.com/temasblog/consumer-protection/brazilian-fuel-economy-labels-for-cars/.

e. Mexico's development of fuel economy standards

Mexico is in the process of developing fuel economy standards. Mexico's vehicle fleet averaged about 13 kilometers/liter (7.69 L/100km, 179 gCO₂/km or 30.5 mpg) in the 2008-2010 time frame (using the CAFE test cycle). Passenger cars averaged 14.8 km/L (6.8 L/100km, 157 gCO₂/km or 34.8 mpg) in 2008. National authorities are now developing standards. The objective is to achieve a level of 18 km/L (5.5 L/100km, 130gCO₂/km or 42.3 mpg) in 2015. The purpose of these standards would be to reduce greenhouse gases and to curb oil imports. The government has created a website (www.ecovehiculos.gob.mx/) that allows consumers to check the fuel economy of particular vehicles.

The GFEI is developing a series of country-specific pilot projects working with a range of key stakeholders in some of these countries in order to promote greater fuel economy in these countries.

Can fleet turnover be accelerated?

In order to achieve a 50% reduction in fuel consumption worldwide by 2050, it will be necessary for the new car fleet to have reduced its fuel consumption by this amount by roughly 2030-2035. The subsequent 15-20 years would be required for the on-road fleet to reflect the energy consumption characteristics of the newest cars. But what if this time lag could be reduced significantly?²¹

The sharp worldwide economic downturn in 2008 and 2009 prompted governments in many countries to introduce fiscal measures to encourage the purchase of new cars. In some cases, these policies had an explicit energy efficiency improvement component. As of mid-2009, 17 EU countries, representing more than 85% of the new car market, had specific schemes in place. Many of these schemes took the form of incentives for purchasing a car and scrapping an old one; others took the form of loans for car purchase. They presented a large diversity in monetary value, criteria and duration.

In the United States, the government funded a vehicle scrappage program that gave buyers a rebate when they traded in an old vehicle while purchasing a new one.²² Generally, the trade-in vehicles must have had fuel economy of 18 mpg or less and be less than 25 years old. The rebate was either \$3,500 or \$4,500, depending on the difference between the fuel economy of the new and the trade-in vehicles. Canada and Japan also initiated scrappage programs. A number of European countries introduced scrappage schemes too as part of stimulus packages. France differentiated the subsidies available according to CO₂ emissions, the UK did not stating that the purpose of the scheme was economic stimulus not environmental protection.

To determine the environmental impact of scrappage schemes the two keys are (1) the differential in fuel economy between the old and new vehicles, and (2) the number of years the retired vehicles would have been operated but for the program.

21. In fact, the trend has been in the opposite direction, at least in the United States. The median age of cars in use in that country almost doubled between 1970 and 2008, from 4.9 years to 9.4 years. Transportation Energy Data Book - Edition 28, Table 3.9.

22. The US program required that vehicles turned in be rendered inoperable. This was not always the case in the programs of other countries.

Evidence suggests that the US program did result in the purchase of more fuel-efficient vehicles while the incentives were in place. Sivak and Schoettle estimate that the program improved the average fuel economy of all vehicles purchased in July 2009 by 0.6 mpg and in August 2009 by 0.7 mpg.²³ But how much change in fuel consumption would this increase in fuel-efficiency actually produce? In a working paper published in August 2009, Knittel developed what he termed “back of the envelope” calculations of the fuel savings and the implied cost of carbon dioxide would be under a range of assumptions.²⁴

Imagine a CfC [Cash for Clunkers] program with a \$4500 rebate. Suppose the driving habits of both the clunkers and new cars are same, say an annual vehicle miles travelled of 12,000 miles. If the clunker's fuel economy is 16 mpg, while the new car's fuel economy is 25 mpg, then the scrappage program saves 270 gallons for every year the clunker would have been on the road. When burned, a gallon of gasoline creates roughly 20 pounds of carbon dioxide. Therefore, the program saves 2.7 tons of carbon dioxide each year the clunker would have survived. If the clunker would have survived another four years, the program has saved 10.8 tons of carbon dioxide for \$4,500, or an average cost of over \$400 per ton.

But Knittel argues that the annual vehicle miles traveled by the clunker and the car replacing it is not likely to be the same:

For the greenhouse gas savings [and fuel savings] what matters is the total miles driven by the new and the clunker....[T]he calculations in Lu²⁵ suggest that a 13-year-old car will be driven for 3.5 years with an expected VMT of 30,300 miles. At the average mpg of clunkers, this implies 1,859 gallons of gas consumed. In the first 3.5 years of a new car, the expected VMT is 47,726. At the average mpg of new cars, this implies a total consumption of 1,924 gallons of gasoline.

In this calculation, the cash for clunkers program actually produces an **increase** in fuel consumption and GHG emissions. But this is result is misleading. Changing from an old “gas guzzler” to a new “fuel sipper” does not automatically lead to a substantial increase in driving. For a single-vehicle household, the impact of the change would be measured by the reduction in average fuel cost per mile of the household's vehicle. The magnitude of this reduction - known as the “rebound effect” - has been extensively studied. It seems to be between 10% and 30% over the long run - not the 58% implied by the example above.²⁶

Knittel recognizes this:

A family of three may trade in their teenager's car, that was being driven only 6,000 miles, and purchase a new car that will primarily be driven by one of the parents, shifting the parent's previous car to the teenager. Under this scenario aggregate VMT may not increase. However, the reductions in fuel consumption are uncertain since, while the teenager's “new” car is more fuel efficient than her previous car, the parent's new car may not be.

23. Sivak and Schoettle, (2009).

24. Knittel, (2009) .

25. Lu, (2006).

26. UK Energy Research Center, (2007).

The basic dilemma of a “cash-for-clunkers” program is that the requirements of the program that the cars that are scrapped be quite old and fuel-inefficient almost guarantees that they are likely to be driven much less than newer cars in a multi-car family. Evaluation of the impact on fuel consumption (and GHG emissions) of a “cash-for-clunkers” program certainly must take this issue into account. The GFEI is currently working with TNO to examine these issues further, and the results of that work will be published soon.

There are other policy measures that can accelerate fleet turnover. The Japanese “Shaken” is a compulsory safety inspection which cars in Japan have to undergo every two years, except new cars, for which the first inspection is not due until three years after purchase. The Shaken typically costs between 100,000 and 200,000 yen.²⁷ This creates an incentive for Japanese vehicle owners to purchase a new car rather than go through the Shaken, presumably lowering the average age of the Japanese car fleet. But the vehicles that are traded in are not scrapped. Rather, many are exported. Therefore, the impact of this policy on worldwide fuel consumption and GHG emissions is more difficult to determine.

There have been efforts to ban the operation of older transport vehicles in certain situations. The Ports of Los Angeles and Long Beach in California are among the largest sources of industrial pollution in the Los Angeles Basin, handling approximately 15 million containers each year. Many of these containers are moved by trucks within the ports and between the ports and rail yards where the containers are loaded onto trains to be shipped elsewhere. In the past, most of the trucks used these port operations, since the distances that had to be traveled were short and there were no significant grades to be negotiated. In November 2006, the Ports of Los Angeles and Long Beach in California adopted a Clean Air Action Plan that included a “Clean Truck Program.” As part of this program, all pre-1989 trucks were to be banned from entering the Ports as of October 1, 2008. As of January 1, 2010, 1989-1993 trucks were to be banned in addition to 1994-2003 trucks that had not been retrofitted. On January 1, 2012, all trucks that do not meet the 2007 Federal Clean Truck Emissions Standards were to be banned from the Port. It was estimated that the Plan would cut diesel-related particulate matter (PM) pollution by more than 47% and smog forming nitrogen oxide (NOx) emissions by more than 45% within the first five years, resulting in emissions that would be below 2001 levels. Measures under the Plan also were projected to result in reductions of sulfur oxides (SOx) by more than 52%.

While this program results in a reduction in local air pollutant emissions in the Los Angeles basin, it doesn’t require that the trucks banned from the Ports be scrapped. Presumably, they are free to operate elsewhere. Without knowing their patterns of use it is impossible to know the impact of this program on fuel use and CO₂ emissions.

Thus, programs designed to accelerate the rate of fleet turnover are not straightforward in the results they produce. While financial incentives can increase the sales of new, more fuel-efficient vehicles - at least temporarily - unless the old, less fuel-efficient vehicles are permanently removed from service, the impact on energy use and GHG emissions worldwide is questionable. Preliminary results from the GFEI study suggest scrappage schemes achieve only very small reductions in CO₂ emissions. They are extremely expensive per ton of CO₂ mitigated unless targeted on a small number of grossly inefficient vehicles (ECMT 1999). Potential safety benefits of replacing older vehicles with new vehicles equipped with electronic stability control are currently being assessed and may be more convincing than the environmental benefits.

27. “Driving in Japan” from the website Japan-Guide.com.

Improving information on the cross-border flow of used cars

For many countries, used vehicles imported from other countries represent a significant share of the total car fleet. Wherever this is the case, determining the degree of progress being made toward achieving the 50by50 goal requires knowing the fuel consumption performance of these used vehicles. The IEA is attempting to shed light on this important issue by commissioning work to estimate world trade in used vehicles.

In a paper published in 2009, Fuse, Kosaka and Kashima described how discrepancies in databases published by the United Nations, Global Insight, and Global Trade Information Services can be corrected and then used to develop such estimates.²⁸ They report estimates of the exports and imports of used passenger cars in 2005 for the top 20 exporting and importing countries. They estimate total trade in used passenger cars in 2005 to have been 5.7 million vehicles. Germany (1.25 million), the US (1.21 million) and Japan (1.15 million) together were estimated to have been responsible for approximately two-thirds of all used passenger car exports.

According to Fuse, Kosaka and Kashima, the leading destination for used automobile exports from the US was Latin America, especially Mexico (480 thousand vehicles.) Indeed, if these authors' estimates are correct, in 2005, Mexico imported almost as many used automobiles (477,000 vehicles) as it did new automobiles (564,000 vehicles) and Mexican sales of imported used cars totaled about 40% of the number of imported plus domestic new car sales. Japan's leading destination for used automobiles was Russia (308,000 vehicles) followed by New Zealand (152,000 vehicles.) The leading country for German used car exports was Italy (258,000 vehicles) followed by Lithuania (131,000 vehicles).

These figures demonstrate that used automobile trade across national borders is highly significant.²⁹ Research such as that by Fuse, Kosaka and Kashima helps us to understand the magnitude of these flows, but it doesn't tell us anything about the size characteristics of the vehicles making up the flows. It might be possible to assume that exported vehicles reflect the composition the exporting nations' domestic fleets. But without additional research, we don't know whether that assumption is at all reasonable.

The GFEI is sponsoring research on ways to regulate the import of second-hand vehicles with respect to fuel economy and safety in Mexico and in other less developed countries. One of the research questions that this study intends to answer is what measures are compatible with trade agreements including Free Trade Areas (i.e.: NAFTA, EC and AFTA).

Building capability

One very important issue arising from this work is the mixed picture of understanding of and policy responses to the issue of Fuel Economy across the globe. In this context, sharing experience and potential ideas for policy action is very important indeed. A feature of the GFEI's activities is its commitment to improving the capacity of countries, especially those in

28. Fuse, Kosaka and Kashima (2009).

29. There is evidence to indicate that Fuse, Kosaka and Kashima may be underestimating (perhaps by a considerable amount) the volume of used vehicles being traded across national borders. Government figures for some African countries show a much higher cross-border flows of vehicles than Fuse, Kosaka and Kashima report.

the less developed countries, to understand the challenges and opportunities they face in trying to reduce the fuel consumption of their car fleets. Two projects undertaken by the GFEI this past year illustrate what the group is trying to accomplish as far as capacity building is concerned.

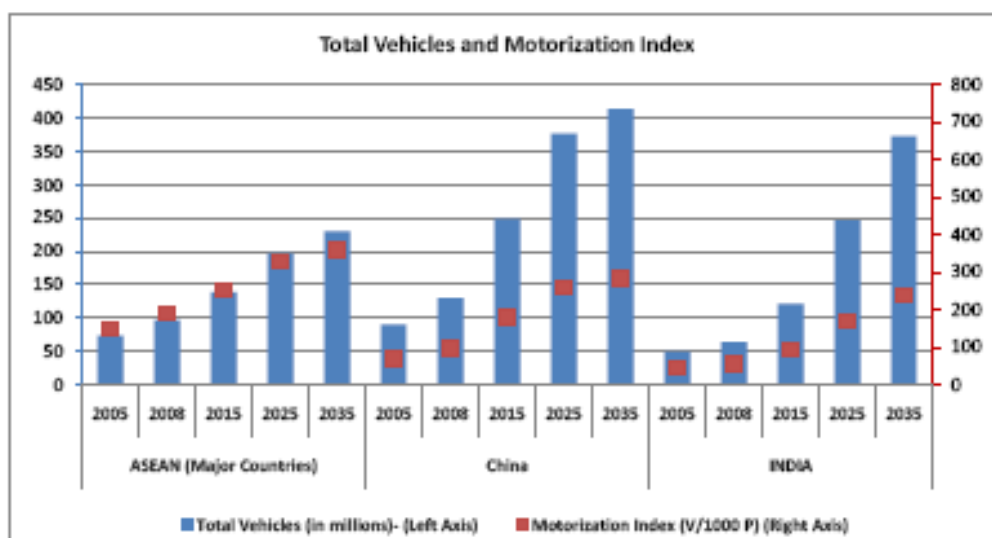
a. Improving Vehicle Fuel Economy in the ASEAN Region.

One of the earliest actions of the GFEI was to begin a process of engaging with key players in the ASEAN region. Working in partnership with the Clean Air Initiative for Asian Cities (CAI-Asia), the GFEI has sought to promote the establishment of a network of interested stakeholders among the members of ASEAN - a federation of ten Southeast Asian countries. Six of the ten countries - Indonesia, Malaysia, Philippines, Singapore, Thailand and Vietnam - participated in the project. The report provides a basis for the need to implement fuel economy policies and measures in the ASEAN. It also explores various environmental and energy-related issues that are important for policy.

Like China and India, Southeast Asia, with its many metropolitan cities, is poised to reach urbanization levels of 70% of the total population in the next decade. With this come the increased demand for mobility and fuel consumption and the associated externalities of transport like increased traffic congestion, air pollution and its health impacts, traffic crashes and also increased transport CO₂ emissions.

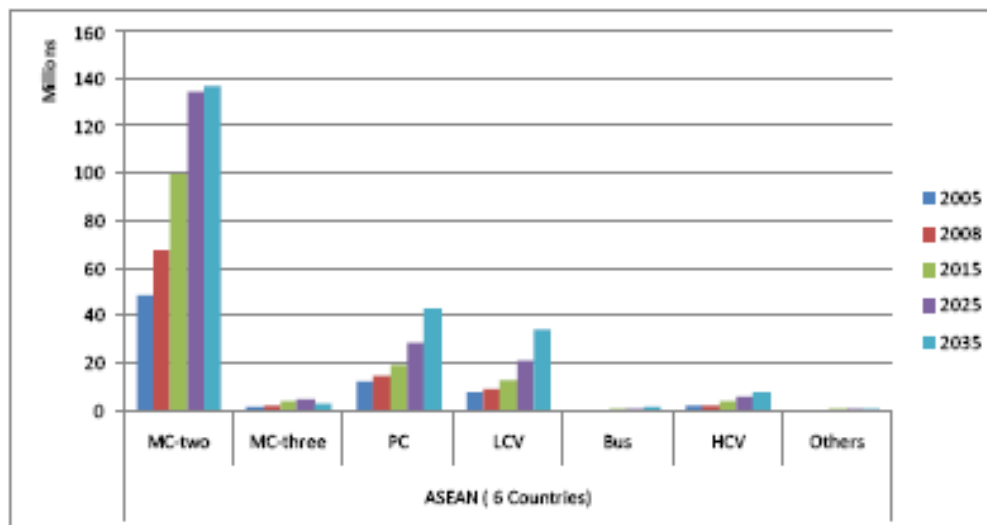
Figure 13 compares the current and projected future (to 2035) motorization index in ASEAN, China, and India. At present, and through 2035, motorization rates in the six participating ASEAN countries (measured in vehicles per 1000 population) are projected to exceed motorization rates for either China or India. And the total number of motor vehicles in the ASEAN countries nearly equaled the number in China until the mid-2000s and is projected to exceed the number in India through 2015. Figure 14 shows the current and projected number of motor vehicles per mode in the six ASEAN countries. The great majority of motorized vehicles are two and three wheelers, but the number of personal cars and light commercial vehicles is projected to grow rapidly.

Figure 13. Comparison of Total Motorized Vehicles and Motorization Index in ASEAN, China, and India



Source: GFEI 2010, p. 9.

Figure 14. Projected Growth of Motor Vehicles per Mode for 6 ASEAN Countries (Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam)



Source: GFEI 2010, p. 9.

The study provides data on vehicle emissions and fuel quality standards, fuel subsidies, vehicle taxes and tariffs, proposed fuel economy standards, and other measures that exist in each of the six countries. It also discusses the support for a common framework for fuel economy and measures in the ASEAN, criteria that this framework should meet, a possible framework structure, and a proposed action plan to establish the framework.

b. The GFEI Toolset

The 50by50 campaign received a boost in 2010 from the Global Environment Facility (GEF) as part of the funding body's efforts to expand its transport portfolio. Through the GFEI, the GEF is supporting support the participation of developing countries (Chile, Costa Rica, Ethiopia and Indonesia) in a global approach to ensuring that cleaner, more efficient automotive technology is available to less developed countries. The 3-year project is focusing on helping countries improve data on existing fleet fuel economy and emissions, while also developing a practical approach to developing policy and technology plans for improving fleet fuel economy in the next few decades. The project, to be implemented with the joint expertise of the GFEI partners - UNEP, the IEA, ITF and the FIA Foundation is targeting target regional and national-level policy-making, and will initiate 50by50 pilots in 4 countries throughout Latin America, Africa and Asia. The GEF contribution is part of a larger USD\$3 million project.

The pilot countries chosen for developing and refining a GFEI approach to national work on improving automotive fuel efficiency represent a spectrum of national challenges and levels of implementation and institutional capacity. They reflect the variety of contexts found today in less developed countries seeking to address road transport emissions, and cleaner, more efficient vehicles in particular.

The GFEI Toolset product is designed to provide policy makers and interested individuals and groups with overviews of policy tools and approaches toward improving fleet-wide auto fuel efficiency and promoting lower CO₂ and non-CO₂ emissions from cars, along with case

studies that depict these approaches from more developed and less developed countries. Designed to answer fundamental questions about the need to set national standards for auto fuel efficiency around the world, the interactive online tool will take the user through the 'Why, What and How' of considering and designing the right policy interventions for a country-specific context.

Conclusions

Based on recent literature, incremental technologies available to improve fuel economy are estimated to be able to cut average new car fuel consumption by around 50% at least for OECD countries -- and possibly worldwide -- across the time frame 2005-2030. These are the findings of well known engineering studies in the US (e.g., Heywood 2008) and Europe (e.g., King 2007) and are confirmed by other relevant work discussed in this report.

This suggests that by around 2030 average new car fuel economy in many OECD countries might be close to 4 L/100km (25 km/L, 60 mpg,) or 90 gCO₂/km.³⁰ An indicative target of 25 km/L also seems feasible around 2030 for large car markets in developing countries such as China and India, given the lower average weight of vehicles in these markets. Although growth in GDP per capita and consequent shifts in consumer demand towards cars at the upper end of the product range is likely to increase the average weight and power of vehicles in these markets, technology improvements are likely to be able to compensate for some of this increase.

However, to meet GFEI 50% target around the world, (and its implication of achieving something close to 4 L/100km on average), it may be necessary in some countries to supplement technology-based improvements with shifts in size mix and performance (i.e. reductions, rather than just holding steady for some OECD countries, and moderated increases in some non-OECD countries). It may also be necessary to introduce plug-in electric drive vehicles in some markets. More research on fuel economy status and trends for various countries around the world will help to better elucidate the pathways to achieving the targets. The GFEI plans to develop vehicle fuel economy baseline and trend data for more countries and regions should play a valuable role in this regard.

From a policy perspective, the key to achieving this scale of improvement is creating a regulatory and fiscal environment that steers manufacturers to using technological improvements to deliver fuel economy rather than enhanced performance and heavier vehicles and that steers consumer demand towards more energy-efficient vehicles. In order for manufacturers to make the necessary investments in engine and auto plants the regulatory framework needs to create certainty. Risks are minimized when binding targets are set well in advance. This underlines the importance of early conversion of the EU's 95 gCO₂/km target into an agreed emissions standard and for other countries to adopt standards that apply 10 or more years in the future.

Finally, it is important for those countries that have not done so, especially those that will experience major growth in their vehicle fleets in the coming years, to start developing national fuel economy initiatives now. This will ensure that the necessary fiscal and regulatory environments are in place to achieve significantly improved fuel economy. The GFEI has begun a process to help regions and countries move forward in this regard.

30. Ignoring changes in fuel types.

The GFEI will also work toward raising awareness and capacity of all stakeholders, including lawmakers and the general public, on the issue of fuel economy. This will be done by supporting labeling programs, public information campaigns and continued use of workshops and conferences to share information and the results of recent research.

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ANNEX 1

Automobile and Light-Duty Truck Categories Used By ICF International

A-class - For markets other than the US, these are “entry” level very small cars with engines of 1 ±0.2 liter or smaller displacement. The Fiat 500, Smart car, and Suzuki Alto are typical models.

B-class - These cars are classified as “sub-compacts” in the US. This size of vehicle is very popular in Southern Europe and India, but is classified as “entry” level in the US. The VW Polo, Peugeot 206 and Toyota Yaris are typical models, and engine displacement is usually in the 1.1 to 1.6 liter range. In the US, these cars have engines at the top of the range, i.e., 1.5 to 1.6L. The BMW Mini is classified as a B-car in the ICFI classification since its engine size and price falls outside the range for entry level vehicles.

C-class - These cars are classified as compacts in the US and are the most popular size in Northern Europe, Japan and China. Typical models include the VW Jetta, Toyota Corolla, Ford Focus and Honda Civic, with engine sizes typically in the 1.5 to 2.2 L range. Somewhat smaller engines (1.3 to 1.7L) are used in Southern Europe and India.

D-class - These cars are classified as midsize in the US and are the largest part of the market there, but are generally regarded as large cars in the rest of the world. The Honda Accord, Ford Fusion and Toyota Camry are typical models and engine sizes range from 2.2L to 3.5L in the US and from 1.8L to 2.5L in the rest of the world.

E-class - These cars are restricted to luxury vehicles in most of the world except North America, and usually include only the large Mercedes, BMW and Jaguar sedans. In the US, Ford, GM, Chrysler, and Toyota offer large non-luxury vehicles, but the market share of these vehicles has been declining for the last 20 years and now accounts for less than 5% of the US light vehicle market.

Micro vans - These are van body derivatives of A-class or B-class car platforms. They are used extensively in China and Southern Europe but are not sold in North America. Typical models include the Wuling utility van (which is similar to the Suzuki microvan) and the Renault Kangoo. Engine displacement is similar to that for the B-class cars. (The Kangoo uses engines generally in the 1.0L to 1.4L category, and its length and wheelbase are very similar to the Wuling van.)

Compact vans and SUVs - These vehicles are popular around the world and typical models include the Honda CR-V, Fiat Ducato and Ulysse, and the Renault Espace and Express. In general, the vehicles are powered by engines in the 2.0 ±0.5L displacement range with the upper end of the range more popular in North America.

Midsize pickup trucks, vans and SUVs - These are largely a North American phenomenon, although some models like the Mercedes M class SUV, the Chrysler van, the Honda Odyssey and the Jeep Grand Cherokee have modest sales in Europe. Engine sizes are typically in the 3.0 to 4.0L range and have six cylinders, although some European versions offer four cylinder engines in the 2.5L range.

Large pickup trucks, vans and SUVs - These vehicles are sold only in North America in any volume and are manufactured only in the US. The market share for these vehicles peaked in 2006, but even in 2008 they have over 10% of the North American market. Typical engines are eight cylinder 4.0+ L displacement range.

Source: ICFI (2009).

ANNEX 2

Incremental technology improvements reviewed by the US NRC Panel

Improvements in gasoline spark-ignition (SI) engines. The Panel concluded that the gasoline SI engine efficiency improvements that could be deployed in large volume in the next decade have the potential to reduce fuel consumption, on average, by approximately 10-15% in the new US vehicle sales mix by 2020 and by an additional 15-20% by 2030. Turbocharged, downsized gasoline engines, which are some 10-15% more efficient than equal-performance, naturally aspirated (NA) gasoline engines, are expected to steadily replace a significant fraction of naturally aspirated (non-turbocharged) gasoline engines, improving energy efficiency and contributing to meeting future fuel economy standards.

Improvements in diesel compression-ignition (CI) engines. Turbocharged diesel engines currently offer approximately a 20-25% efficiency benefit over gasoline SI engines when adjusted for the higher energy density of diesel fuel. The primary challenges for diesel engines in the United States are the added costs and fuel penalties (of about 3-6%) associated with the after-treatment systems required to reduce nitrogen oxide and particulate emissions. The Panel estimated that by 2020, improvements in energy and after treatment technologies have the potential to reduce the fuel consumption of new diesel engine vehicles relative to current diesel vehicles by about 10%, and by an additional 10- 15% by 2030.

Gasoline and Diesel Hybrid-Electric Vehicles (HEV). Hybrid vehicles combine an internal combustion engine (ICE) with electric drive from a battery-electric motor/generator system. Usually both systems can drive the vehicle, and the ICE recharges the batteries. (Hence, these vehicles are also called “charge-sustaining” hybrids.) The Panel observed that the primary fuel consumption benefits of a gasoline hybrid electric vehicle (HEV) derive from regenerative braking, engine downsizing, active management of energy use to maintain the most efficient engine operating conditions, and elimination of idling. The Panel noted that hybrid vehicles are increasingly being classified on the basis of the extent of the functions offered by the electric motor/generator. Relative to equivalent gasoline SI engines, belt-driven starter-generator systems can eliminate engine idle, reducing fuel consumption by 4-6%; integrated starter-generator systems that can recover energy from regenerative braking, along with eliminating engine idling (a mild hybrid), can reduce fuel consumption by 10-12%. A parallel full hybrid with power assist, such as Honda’s Integrated Motor Assist system, can increase this benefit to more than 20-25%, whereas more complex systems using two motors, such as Toyota’s Hybrid Synergy Drive, can reduce fuel consumption by more than 30%. Some prototype diesel HEVs are under development and could be in limited production volumes within a few years. These could have about 10% higher efficiency (which corresponds to 20% lower diesel fuel consumption due to higher fuel density) than an equivalent gasoline hybrid. However, the cost for a diesel HEV would be significantly higher than for a gasoline-fueled version.

The likelihood of significant penetration of other engine technologies in the 2020-2035 time frame. The three types of engines just discussed - gasoline spark-ignition, diesel compression-ignition, and gasoline hybrid-electric - are the ones that the Panel believes will power the overwhelming share of the US new car fleet even in 2035. While other more advanced technologies such as plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV) and hydrogen fuel cell vehicles (HFCV) have the potential to offer even greater

efficiency improvements, the Panel felt that their deployment in numbers large enough to exert a significant impact on the average fuel economy of the US new car fleet was not likely before 2035.

Transmission Improvements. The Panel concluded that transmission efficiency is likely to improve in the near- to mid-term through increasing the number of gears and reducing losses in bearings, gears, sealing elements, and the hydraulic system. Improvements of 2-9% are realizable and provide equivalent percentage reductions in vehicle fuel consumption. Although a continuously variable transmission (CVT) allows the engine to operate near its maximum efficiency, the estimated efficiency of CVTs is lower than the corresponding estimate for six- and seven-speed automatic transmissions. CVTs have been in low-volume production for well over a decade

Vehicle Weight and Size Reduction. Reducing vehicle weight is one obvious way to reduce fuel consumption. A commonly used rule of thumb is that a 10% reduction in vehicle weight can reduce fuel consumption by 5-7%, when accompanied by appropriate engine downsizing at constant performance. Vehicle simulation results suggest that the relative benefits of weight reduction may be smaller than this in some types of hybrid vehicles because the hybrid propulsion system actively manages engine use to stay in areas of higher and more uniform efficiency and also recoup vehicle energy during braking.

Weight reduction can be achieved by substituting lighter-weight materials (such as aluminum) for heavier ones, by redesigning vehicles, and by downsizing vehicles and components. For example, downsizing a passenger car by one EPA size-class (e.g., from large to mid-size) can reduce vehicle weight by between 9% and 12%. Unlike vehicle weight, however, vehicle size is an attribute that consumers value.

Rolling Resistance Reduction. The Panel noted that each reduction of 0.001 in the coefficient of rolling resistance of passenger tires (equivalent to a 10% reduction in overall rolling resistance) can reduce vehicle fuel consumption by 1-2%. After examining the fuel-saving technologies and designs that are being developed for original-equipment tires (those supplied with new vehicles) to assist in meeting U.S. Corporate Average Fuel Economy (CAFE) standards, NRC report relied upon by the Panel (NRC 2006) also concludes that such a 10% reduction in the average rolling resistance of passenger tires is possible over the next decade because many of these technologies can be introduced, not only into the new vehicle market, but also into the much larger market of replacement tires.

Aerodynamic Drag Reduction. In the US EPA's highway driving cycle (average speed of 48 miles per hour), approximately half of the energy required to propel the vehicle is used to overcome aerodynamic drag. Thus, body designs that reduce aerodynamic drag can achieve meaningful reductions in fuel consumption. The aerodynamic drag on a vehicle is the product of a drag coefficient (CD), the vehicle frontal area, the vehicle velocity squared, and the air density (divided by 2). Thus drag increases significantly as vehicle speeds increase, especially above 60 miles per hour. A 10% reduction in the drag coefficient can lower average vehicle fuel consumption by up to 2%. Demonstration vehicles built during the U.S. Department of Energy's Partnership for a New Generation of Vehicles achieved a coefficient of drag as low as 0.22—a 35% reduction from the then-current vehicle.

Improved lubricants. Engine friction has a substantial negative impact on engine efficiency. Friction can be and is being reduced through engine design improvements and use of new materials and surface coatings. It can also be influenced by engine lubricant properties, and lower viscosity oils are increasingly being used. The most commonly used engine oils or

lubricants are mineral oils that contain additives to improve viscosity, inhibit engine oxidation and corrosion, act as dispersants and detergents, and reduce surface friction. There are strong pressures to reduce both engine oil consumption and the additive components that produce ash, in order to minimize degradation of the exhaust system's emission control technologies, such as catalysts and particulate traps. Use of synthetic engine oils rather than mineral oils is growing: although their cost is higher they can reduce engine friction and thus improve fuel economy by a few percent.

Source: US National Research Council (2009).