



JOINT TRANSPORT RESEARCH CENTRE

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# ***Examining Fuel Economy and Carbon Standards for Light Vehicles***

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ORGANISATION  
FOR ECONOMIC  
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on  
The Cost and Effectiveness of Policies to Reduce Vehicle  
Emissions**

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*The views expressed in this paper are those of the author and do not necessarily represent positions of Argonne National Laboratory, the OECD or the International Transport Forum.*

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## **1. INTRODUCTION**

Under the European Union's Voluntary Agreement with car manufacturers, average light vehicle CO<sub>2</sub> emissions in 2004 were 12.4% below 1995 levels but appeared unlikely to achieve the 25% reduction needed to reach the 140 g/km target for "per vehicle" CO<sub>2</sub> emissions for 2008. The EU is now considering a regulatory approach to further reduce average vehicle emissions, in the form of CO<sub>2</sub> emission or fuel economy standards. Such standards have been used by a number of countries, including the United States (although U.S. standards have been little-altered since their 1975 promulgation), Japan, China, and several others, and those that have been in existence for some time – e.g., those in the United States and Japan –have been successful in achieving their targeted levels of new vehicle fuel economy.

The purpose of this paper is to examine various aspects of fuel economy and carbon standards for light vehicles, including their rationale, methods of establishing stringency, regulatory structure, and timing, with the hope of assisting the decision process for new standards. Because the Corporate Average Fuel Economy (CAFE) standards adopted by the U.S. in 1975 are the longest-standing and most studied of the various standards now in existence, much of the focus of this paper will be on the U.S. standards.

## **2. DO FUEL ECONOMY STANDARDS MAKE SENSE?**

Fuel economy standards for light-duty vehicles have been widely promoted as an effective means of reducing oil consumption and, more recently, carbon emissions, and justified on the basis that vehicle manufacturers and purchasers do not seem to properly value fuel economy improvements that would easily pay for themselves in future fuel savings, and do not account for social benefits that would arise from reductions in oil use such as improved energy security and reduced emissions of greenhouse gases.

Nevertheless, there is strong opposition to fuel economy standards, not only from automakers, automobile unions, and auto enthusiasts but also from many in the economics community. This opposition centers around a range of arguments about the limitations of new standards and their impacts on oil use, public safety, consumer choice, vehicle markets, and the economy.

There is an extensive base of economics literature critical of fuel economy standards, and this paper will not attempt to discuss it in any detail. In summary, however, the two key economic arguments against such standards are:

1. They are economically inefficient and have costs to consumers and producers that greatly exceed their benefits; and
2. In reducing the cost of driving, they cause increased travel – the so-called “rebound effect” -- that has externality costs (in terms of increased air pollution, congestion, and traffic injuries and fatalities) exceeding any societal benefits associated with reduced fuel use.

The economic efficiency arguments against fuel economy standards generally depend on the assumption that vehicle manufacturers and purchasers are economically rational and that there are no significant market failures in the market for new vehicles. It is argued that forcing manufacturers to build vehicles that are more efficient than the market demands will inevitably lead to market distortions and large economic losses.

The primary counterargument to this is that, for several reasons, society would choose higher levels of fuel economy than will private consumers:

1. **Society places more value on future benefits than consumers do.** Even for rational, well-informed consumers, society would choose higher fuel economy than private consumers will because private discount rates are much higher than social discount rates. For example, Gerard and Lave (2003) show that society (assuming a 4% discount rate) would be willing to pay about \$400 more than a private purchaser (20% discount rate) for an increase in fuel economy from 22 to 25 MPG.
2. **The net gains to consumers from increased fuel economy may be small even when society gains a great deal.** Several U.S. studies have estimated that the net benefits of fuel economy increases – lifetime fuel savings minus increased vehicle purchase price – are relatively small over a range of fuel economy increases. In other words, although fuel economy increases may be cost effective, the economic reward is not large and consumers may be relatively indifferent to the increases – though society would favor increases because of their energy security,

greenhouse emissions, and other benefits. With the large costs of redesigning vehicles to obtain higher efficiency coupled with the technical risks associated with new efficiency technologies, automakers can be reluctant to undertake these investments in the face of such indifference. Further, automakers face market uncertainty about the extent to which their competitors will pursue greater fuel economy or instead use their resources (and available technology) to increase performance, add luxury features, and increase vehicle size and weight. Fuel economy standards reduce this uncertainty by demanding that all manufacturers pursue some minimum improvement in fuel economy.

- 3. Consumers' aversion to loss will tend to make them wary of betting on fuel economy technology, whereas society's risk of loss is much lower.** The high level of uncertainty in the value to the consumer of fuel economy gains, coupled with the inherent loss-aversion behavior of consumers, implies that consumers will tend to reject bets on fuel economy increases. Greene, German, and Delucchi (2007) point out that fuel economy benefits are inherently uncertain because fuel economy levels actually attained by consumers can vary over a wide range; future fuel prices are highly uncertain (and a fall in prices will cut the monetary benefits of fuel savings); and consumers don't know with certainty how much driving they will do or how long their vehicles will last. The authors then apply loss aversion theory to show that an average consumer would decline an estimated fuel economy increase from 28 to 35 MPG even though its expected net present value is \$405; aversion to the possibility of a financial loss outweighs the greater odds of a gain in this case. In contrast, society averages benefits across all vehicles and their drivers, reducing sharply its risk of losing the fuel economy bet.

Further, there is ample evidence that vehicle purchasers do not behave as "rational consumers," at least in terms of how economists define such consumers. Surveys have shown, for example, that consumers virtually never attempt to evaluate the tradeoff between higher costs for fuel saving technology and money that would be saved from lower fuel bills (Turrentine and Kurani, 2004), and demand extremely rapid paybacks when they are asked explicitly how much they would be willing to pay to save a few hundred dollars a year from reduced fuel use – a survey sponsored by the U.S. Department of Energy in 2004 found that consumers wanted to recover their higher vehicle costs within about 2 years.

The magnitude of the rebound in the developed economies – and its impact (from increased driving) on pollution, accidents effect, etc. – has declined over time with growing income, and recent estimates for the United States set the effect at about 10%, that is, a reduction in per-mile fuel costs will cause about a 1% increase in driving (Small and Van Dender, 2004).

The argument that any increased travel caused by the rebound effect will create costs well in excess of travel benefits can be countered by noting that, where this is the case, it is a problem of fuel pricing and should be solved by adjusting prices, not by forgoing policies that address other problems. Saying that increased travel creates high net costs is synonymous with arguing that transport fuels are seriously under priced (Gerard and Lave, 2003) or interventions to reduce accident or air pollution costs should be strengthened. This argument is especially potent in the United States, which has comparatively low gasoline and diesel prices because its fuel taxes are far lower than those in the EU countries. Whether U.S. (or EU) fuel taxes are too low depends on the magnitude of externality costs, and there is little agreement about their magnitude. The U.S. National Academy of Sciences estimated these costs at about \$0.26/gallon in its 2002 examination of fuel economy standards (NRC, 2002), equivalent to about 1.5 cents/mile at the then-average fleet fuel efficiency of 17 miles/gallon; at the other end of the scale, Lutter and Kravitz (2003) estimated these costs at 10.4 cents/mile (even though they did not include costs for national security and global warming, which were included in the NAS estimate), equivalent to about \$1.75/gallon.<sup>1</sup> Whichever of these estimates may be correct, however, one can argue that the appropriate policy response is not to forgo fuel economy standards but instead to correct the market distortions caused by under pricing of fuel. In European markets, however, it is much harder to argue that the rebound effect will create costs in excess of the benefits of reduced fuel use -- European tax levels on transport fuel are higher than even the upper estimates of externality costs.

Opponents of fuel economy standards have argued that they have caused terrible market distortions, pointing especially to distortions that have occurred in the U.S. market for new vehicles. Fuel economy standards do distort the market; all regulations do, in some sense that's their purpose. However, the worst distortions that have occurred in the U.S. market appear to have been caused by the unusual structure of the U.S. standards (for example, the artificial division between cars and light trucks in the U.S. system), and most of these distortions should be avoidable by paying careful attention to properly structuring a new standard.....see the discussion below ("Structure of a New Standard").

In the United States, automakers and other opponents of more stringent CAFE standards have argued vigorously that the standards have seriously degraded highway safety. Past studies by the U.S. National Highway Traffic Safety Administration (NHTSA) concluded that vehicle downsizing associated with the original U.S. CAFE legislation caused upwards of 2,000 traffic fatalities yearly (Kahane, 2003), and CAFE opponents have argued that new standards would force vehicle weight downwards and cause a wave of new fatalities. This argument has been vigorously disputed, and an evaluation of its merits

deserves *at least* a lengthy paper all its own. The primary counterarguments to the charge that new fuel economy standards will compromise safety are:

- New studies that separate the effect of size and weight changes in vehicle safety indicate that the increased fatalities detected in the NHTSA studies were due to reduced vehicle size rather than reduced weight (Van Auken and Zellner, 2003). These studies conclude that reducing the average weight of the light-duty vehicle fleet would actually lead to *improved* safety if average vehicle size – measured by wheelbase and track width – remained unchanged.
- Examination of the variation of fatality statistics across the fleet coupled with a focus on the combined risk of vehicle to their own passengers as well as to the passengers of vehicles they strike shows that vehicle design plays a more critical role than weight in vehicle safety (Ross and Wenzel, 2002) – for example:
  - Fatality statistics for vehicles in the same weight and size classes vary substantially; in particular, some of the inexpensive subcompacts exhibit twice the risk of safer subcompacts such as the Honda Civic and Volkswagen Jetta. Better-designed vehicles have safety records as good as their much larger counterparts.
  - Pickups and SUVs are about twice as dangerous as cars to vehicles that they collide with, apparently because of their high bumpers and rigid frames.
- A reexamination of the relationship between light-duty vehicle fuel economy and highway fatalities from 1966 to 2002 (Ahmad and Greene, 2005) indicates that, if anything, higher fuel economy is correlated with *fewer* traffic fatalities, not added fatalities.

It is quite certain that the argument about fuel economy standards and safety is not dead and will be vigorously argued in any future debate on new standards. In particular, concerns may be raised about the effect on overall fleet safety of mixing a new generation of lightweight vehicles with their older, heavier counterparts. However, arguments that fuel economy standards will automatically lead to reduced fleet safety should be treated with skepticism.



### 3. HOW AMBITIOUS SHOULD NEW STANDARDS BE?

Policymakers considering new fuel economy standards or their equivalent, e.g. CO<sub>2</sub> emission standards, must consider several aspects of a new standard, including its numerical fuel economy targets and their timing as well as the structure of the standard, that is, how the targets are assigned to different vehicles and different vehicle manufacturers. The magnitude of the targets is often the most contentious issue, but the timing and structure are equally important. The discussion of fuel economy targets that follows focuses primarily on the U.S. fleet, and is followed by a discussion of how conditions in Europe may affect the setting of appropriate targets.

It would be useful if there were a way to calculate an optimum target level for a new fuel economy standard. Unfortunately, there is no such method. Instead, it may make sense to try a few different approaches to setting new standards to get a broad perspective for what options might be open to policymakers.

#### 3.1. “Cost-effective” standards

A common method of identifying fleet targets for a new standard is to identify a fuel economy level that would create fuel savings over the vehicles' lifetimes that, at the margin,<sup>ii</sup> would be greater than the added cost of fuel saving technologies. For example, the U.S.'s National Academy of Sciences, in a recent study of fuel economy standards (NAS, 2002), identified “cost effective” fuel economy gains of 12-27% (depending on vehicle size) for passenger cars and 25-42 % for light trucks in the U.S. new vehicle fleet. The NAS targets were arrived at by establishing baseline vehicles and theoretically adding, one by one, a series of fuel-saving technologies in order of their cost-effectiveness (highest first), until adding the next technology on the list would cost more than would be saved in reduced fuel consumption. Using standard economic methods, future fuel savings were “discounted” to the present. Similar methods have been used by the Office of Technology Assessment in the early 1990s (OTA, 1991), and others.

This method is useful for getting a general sense for what is achievable by available technologies, but it has several problems. First, the method treats the analysis as if it had only two variables, technology cost and fuel savings. In this formulation, both the vehicle designer and purchaser are simply deciding whether adding fuel economy technology to a vehicle is worth the cost in fuel

savings. In reality, however, all fuel saving technologies are dual purpose – they can be used to save fuel, or they can be used to gain something else – better performance, larger size, more luxury, or even greater safety – without having to use more fuel. Thus, an engine improvement that allows more power to be squeezed out of an engine can lead to a more powerful vehicle without increasing engine size, or a more fuel efficient vehicle with a smaller engine and the same power. Or the vehicle designer can compromise and get some of each – more power and better fuel economy, but less than the maximum possible for each. See Box 1 for an illustration of the tradeoff between fuel economy and other vehicle features. Vehicle purchasers attach real value to the attributes that “compete” with greater fuel economy for the benefits of efficiency technology. Consequently, asking them to forgo improvements in these attributes in favor of higher fuel economy won’t be “free” even though fuel savings may outweigh the technology costs.

A second concern with the method is that, as noted above, there is strong evidence that the great majority of vehicle purchasers simply do not perform even rudimentary analysis of the tradeoff between higher first cost and fuel savings over time (Turrentine and Kurani, 2007); in other words, the method by which analysts estimate “reasonable” levels of fuel economy improvements bears little relationship to how vehicle purchasers actually value fuel economy. Further, when consumers respond to surveys that ask direct questions about how they value fuel savings, their answers imply that they want any added purchase cost to be repaid within just a few years. If translated into potential fuel economy savings, this criterion would yield very little improvement. For example, the NAS did an alternative analysis of fuel economy potential using 3-year payback as a criterion. The average improvement was estimated to be -3 to 3 percent improvement for cars and 2-15 percent for light trucks (NRC, 2002).

A third concern is that this method has tended to focus only on currently available technology and generally fails to account for likely improvements in technology performance and cost over time, and the development of new technology that conceivably might play a significant role during the time period of the analysis (if this is 10 years or more). This leads to conservative results, although these factors are hard to quantify.

Finally, the targets identified by this method depend on fuel prices over the lifetime of the vehicles (highly uncertain), the discount rate chosen to represent the value of savings in the future (contentious), estimates of technology costs (hotly debated), and whether or not the value of externalities such as climate change damages and energy security costs – also highly contentious – are included in the calculation. For example, repeating the NAS analysis using fuel prices more in line with recent U.S. prices - \$2.00-\$3.00/gallon – raises the cost effective increase to 30-50% for the fleet.

### **3.2. “Top Runner” Method**

The Japanese essentially avoided this debate by setting standards based on the idea that vehicles that represent the “best in class” of the current fleet – weeding out vehicles that are anomalous in performance or that have especially expensive technology – can be exemplars of what the average vehicle could be in 8 to 10 years. Japan used this “top runner” method to identify a series of fuel economy targets for vehicles in different weight classes for its 2010 standards. This represented a 22% increase in fleet fuel economy over the regulatory period (assuming there would be few changes in average vehicle weight over the period). Although this method (or at least the Japanese version of it) is conservative in that it ignores the potential for newer technologies (such as hybrid drivetrains) to achieve reduced costs and become far more common, it does provide another potential fuel economy target that can inform the ongoing debate. Further, the method can be extrapolated further into the future by conjuring up a vision of a “leading edge” vehicle, that is, the best *mass-market* vehicle that could be available a number of years in the future and call for the fleet average several years later to achieve the same fuel economy as these “top runners.”

The U.S. Environmental Protection Agency has performed “top runner” analyses for the new 2006 U.S. car and light truck fleet (Heavenrich, 2006). Their analysis answers the question: “What would the fuel economy of the new fleet be if the current fleet were replaced by 1) the best four vehicles in each size class (there are nine size classes in both the car and light truck fleets), 2) the best dozen vehicles in each size class, and 3) the best dozen vehicles in each inertia weight class?” The answer is that the car fleet would be 17-20% more efficient, and the truck fleet would be 14-24% more efficient. However, the fleet would be somewhat slower (for the largest boosts in efficiency, cars would take 10.2 seconds to go from zero to 60 mph versus the actual fleet’s 9.5 seconds, though the higher-efficiency trucks would actually shave a second off of their times); trucks would move sharply away from 4-wheel drive, which significantly reduces efficiency; the share of hybrid drivetrains would grow sharply, from 1.6 to 14% for cars and from 1% to 36% for trucks (but only 5% for cars and 12% for trucks for the next best case, with only a 1 mpg loss in fuel economy); and many automatic transmissions would be exchanged for continuously variable transmissions and manual transmissions. Unfortunately, this mixing of the effects of efficiency technology and utility-oriented vehicle attributes limits the usefulness of this type of analysis in setting standards – but it can offer a useful added perspective if interpreted cautiously.

Let’s try to identify what the “top runners” for the U.S. fleet might be in the year 2020. Over the next 10-15 years, large and small changes in the technology embedded in cars and light trucks could have a dramatic impact on fuel economy – a greater than 50% improvement in fuel economy for a “leading

edge” vehicle with conventional drivetrain, and perhaps as much as a doubling in fuel economy for such a vehicle with a hybrid drivetrain.....assuming that the technology is used primarily for fuel economy rather than for performance and other attributes. To understand fuel saving technology and the potential for improving it, it helps to understand a bit about why vehicles need energy and power and how they obtain it. This is discussed in Box 2.

The major part of industry focus on raising fuel economy has been on the powertrain, but vehicle load reduction can play an important role. As noted in Box 2, reducing vehicle weight through sophisticated design and use of enhanced materials – high strength steels, aluminum, plastics, and composites – has considerable leverage on vehicle efficiency because weight reduction reduces both inertial loads and rolling resistance losses. The U.S. Department of Energy’s Vehicle Technologies Program has established the ambitious goal for 2015 of reducing the weight of the vehicle structure and subsystems by 50%.<sup>iii</sup> However, over the past decade a considerable portion of the weight reduction potential of structural redesign and materials substitution has been used for improving vehicle stiffness and structural strength rather than for reducing weight. These attributes yield consumer benefits in better crash protection and a more solid “feel” that is highly valued by vehicle buyers. Assuming that some further gains in these attributes will be sought, weight reductions of 20% or so may be a more realistic estimate for what might be achieved by 2020, assuming strong pressure to maximize fuel economy. More drastic reductions might be possible if vehicle structures of carbon composites become practical for mass market vehicles in this timeframe. A 20% weight reduction could yield a 12-14% fuel economy improvement if vehicle performance was unchanged.

Improvements in aerodynamics are hard to predict because aerodynamic drag is closely tied to vehicle appearance, and consumer acceptance becomes a key issue. However, relatively subtle changes involving smoothing out the vehicle’s undercarriage, reducing body gaps, and making small changes in the vehicle’s rear end can obtain important benefits, and the best coefficient of aerodynamic drag in the current fleet (0.26) is obtained by the Lexus LS430, which is quite conventional in appearance. By 2020, a  $C_D$  of 0.22 may be possible for mass-market cars with side mirrors replaced by cameras, continued improvements in manufacturing tolerances for body panels, smoothing of vehicle undersides, and careful aerodynamic design.

Reducing rolling resistance by improving tire design and materials is also possible. However, a tire’s design and materials affects not only its rolling resistance characteristics but also its resistance to wear and its handling performance, and there can be tradeoffs among these characteristics. The first generation Prius had tires with a rolling resistance coefficient  $C_R$  of 0.006, an excellent value, but consumers complained of their rapid wear and they were replaced with tires that were slightly less efficient but which had better wear and

handling characteristics. There is little publicly available information about tire research; a goal of achieving widespread use of tires averaging about a 0.006  $C_R$  should be considered an educated guess.

Engines have improved dramatically over the past 2 decades, and they will continue to improve. Recent presentations by a number of automakers and suppliers at the 2007 Society of Automotive Engineers World Congress presented a fairly unified picture of the potential future evolution of the gasoline engine. Currently, the most efficient gasoline engines have direct injection fuel systems with continuously variable valve lift and timing on inlet and exhaust valves and variable intakes. Because downsizing will yield significant benefits in efficiency, a “best-in-class” 2020 gasoline engine will probably use a turbocharger with variable geometry vanes; larger engines will shut down a third or half of their cylinders at low load. Improvements in emissions control should allow high air/fuel ratios (“lean burn”) that will further improve efficiency, although this will likely require further reductions in the sulfur content of gasoline. Continued improvements in valve controls and in-cylinder monitoring should allow use of more efficient thermodynamic cycles (than the current Otto cycle) under some load conditions, bringing gasoline engines much closer to diesels in efficiency. Overall, efficiency gains of about 25% should be possible from engine improvements alone.

Advanced direct injection turbocharged diesel engines currently are about 30% more efficient than naturally aspirated gasoline engines of similar performance. Diesels will improve further with improved combustion chamber designs and higher pressure injection systems, but their efficiency advantage relative to gasoline engines should shrink as gasoline engines become more diesel-like.

Hybrid drivetrains will certainly be an important part of the fleet in 2020, but the magnitude of their role is highly uncertain, dependent on fuel prices and on reductions in component costs. Hybrid sales have grown rapidly since the 1999 introduction of the Honda Insight. In the near future, a variety of new hybrid systems, from simple stop-start mechanisms to the General Motors/Allison two mode full hybrid system, will be introduced to the fleet. However, the more efficient systems currently can pay for themselves with fuel savings only if gasoline prices remain high and only for high mileage drivers who spend much of their time in urban stop-and-go driving where hybrids maximize their efficiency advantage over conventional vehicles. The key to making them into a dominant technology is to shift to lithium ion or other energy storage technologies that may be less expensive than current nickel-metal hydride batteries (which have limited cost reduction potential because of high nickel prices), as well as driving down the cost of their expensive electronic controls.

Although plug-in hybrids – hybrids with larger batteries and motors, that can fuel some of their daily miles with electricity from the grid – are not yet commercially available, they might begin to play a role in the new vehicle fleet by 2020 if their battery costs are driven down. Two factors can help accomplish this – first, although their batteries are considerably larger than those used in today’s hybrids, their battery costs will not scale linearly with their storage capacity; and second, batteries will achieve substantial economies of scale as production ramps up. A new report by the California Air Resources Board (Kalhammer, 2007) projects that lithium ion batteries capable of 20 mile range (about 7 kWh of capacity) would cost about \$5,000 at a production rate of 20,000 batteries/year and less than \$3,000 at a production rate of 350,000/year. However, this report’s optimism about the likelihood that these batteries can last a vehicle lifetime is controversial.

Although there will certainly be an argument about what a 2020 “leading edge” or top runner midsize passenger car might look like, a reasonable guess – *assuming a very strong focus on fuel economy, coupled with a very vigorous R&D program* – might be as follows:

- Full hybrid drivetrain, assuming battery and electronics costs are driven down sufficiently for hybrids to become fully mainstream;
- Curb weight reduced about 20% from today’s cars;
- Rolling resistance of the tires at 0.006, compared to about 0.008 for today’s mainstream tires;
- Aerodynamic drag coefficient 0.22, compared to today’s best-in-class 0.26
- Downsized gasoline engine with full (possibly camless) valve control, mode switching from Homogeneous Charge Compression Ignition to Atkinson cycle to Otto cycle depending on load, turbocharging and perhaps super-charging.
- Automated manual transmission.

A 2003 Massachusetts Institute of Technology (MIT) study estimated<sup>iv</sup> that such a car would get about 60 (adjusted) mpg (92 gCO<sub>2</sub>/km) compared to a 26 mpg car (212 gCO<sub>2</sub>/km) in 2001, a 130% improvement; a conventional counterpart, without the hybrid drivetrain, would obtain about 42 mpg (131 gCO<sub>2</sub>/km), about a 60% improvement (Heywood, 2003). A more recent MIT study (Kromer and Heywood, 2007) used a 2005 Camry 2.5 liter 4-cylinder engine as its baseline engine and more sophisticated engine mapping and transmission optimization; for a 2030 advanced gasoline vehicle using similar assumptions about vehicle load reduction as the 2003 study, it found

approximately the same percentage fuel economy improvement for the vehicle with a conventional drivetrain and naturally aspirated engine; 82% improvement for the same vehicle with a turbocharged (and radically downsized) engine; and 187% for the vehicle with a parallel hybrid drivetrain.<sup>v</sup>

The 2007 MIT study also examines a 2030 diesel vehicle, but does not compare it to a 2005 diesel. However, the 2030 diesel attains an emission rate of 111 gCO<sub>2</sub>/km (Kromer and Heywood, 2007), which represents about a 55% increase in fuel economy over a 2005 diesel with the same characteristics (other than the engine) as the 2005 baseline gasoline vehicle.<sup>vi</sup>

### **3.3. Adding it up, for the U.S. light-duty fleet**

The availability of NAS-style calculations of “cost effective” fuel economy targets and visions of future “top runner” or “leading edge” vehicles won’t add up to a certain view of a “correct” fuel economy target, but they are valuable in informing a decision about targets. The suggestion here is to combine the perspectives gained from these analyses with a careful consideration of how urgently society needs to combat climate change and the economic security problems associated with U.S. dependence on an unstable fuel supply. Policymakers must also carefully consider their views on consumer freedom of choice, because a future shift to faster acceleration capability and increased weight (associated with more size or other features) will significantly reduce the fleet’s fuel economy improvement potential. Thus, the NAS-style calculation offers a way to get a sense for a conservative view of what an “economically rational” consumer might want if she didn’t care about getting a bigger or more powerful vehicle – or if policymakers were determined to push the fleet away from the “performance race” characteristic of the past 20 years. On the other hand, fleet targets might be more ambitious if automakers could promote smaller cars by emphasizing safety and comfort in their design. Similarly, growth in sales of four-wheel and all-wheel drive – which have significant weight and fuel economy penalties – might conceivably slow and even reverse as the perceived safety and traction advantages of these systems shrink with universal penetration of electronic stability control and traction control – which do not carry an efficiency penalty. A reasonable conclusion that could be drawn from these considerations is that the type of fuel economy improvement goal derived from an NAS-style calculation – about 30-50% improvement over a 12-15 year period – may be a decent starting point for negotiations. Technological optimism and a strong sense of urgency in reducing oil use and GHG emissions would tend to push the goal upwards; a hard-headed realism about trends in performance and other efficiency-reducing vehicle attributes would tend to push in the opposite direction.

For a longer-term and less conservative perspective, projecting future leading edge vehicles provides a good view for what developing technology could do for fleet fuel economy. For the longer-term – say out to 2025 or 2030 – it makes sense to take a much stronger position towards improving fleet fuel economy. In this time-frame, a doubling of passenger car fleet fuel economy, and somewhat less for the light truck fleet (because towing requirements limit the benefit of hybrid drivetrains) would be quite possible assuming either strong reductions in the cost of hybrid drivetrains or simply the willingness to treat reduction in oil use and GHG emissions as societal requirements in the same way that reductions in emissions of criteria pollutants are treated. A more conservative goal of a 50-60% improvement would reflect less willingness to impose costs on vehicle purchasers and/or less technological optimism.

An important added consideration will come into play if it becomes important for the world to make a strong shift to oil substitutes. The most straightforward substitutes are alternative liquids from unconventional oil sources (e.g., tar sands, heavy oil), natural gas, and coal. These will yield substantial increases in “per gallon” emissions of greenhouse gases, and large increases in vehicle efficiency will be needed to avoid large increases in total emissions. Biomass liquids can represent a strong alternative if they can be obtained from cellulosic materials, but they will provide a large share of transport fuel requirements only if fleet efficiency is greatly improved. And hydrogen and electricity have severe onboard fuel storage problems that are likely to be solved only if less fuel (or less battery storage capacity) is needed – that is, only if overall vehicle efficiency is very high. In other words, greatly increased vehicle efficiency is a crucial requirement if the world needs to move dramatically away from its dependency on imported oil.

### **3.4. *Application to Europe***

The above discussion is quite applicable to an analysis of new fuel economy standards for the European Union, but several adjustments are necessary. The European light-duty fleet and the economic and policy environment that affects it have important differences from conditions in the United States. Among the most important differences:

- The physical makeup of the European fleet is quite different from the U.S. fleet:
  - Engine power (for vehicles of the same size) tends to be considerably lower, on average, in the European fleet
  - Diesel engines make up close to 50% of new vehicle sales in Europe, while light duty diesel sales are negligible in the U.S.
  - Manual transmissions are the norm in Europe, automatic transmissions in the U.S.



- Light trucks are a small part of the new vehicle fleet in Europe, and are over half the new vehicle fleet in the U.S.
- Fuel prices are far higher in Europe, at about double those in the U.S.
- Vehicles are driven more intensively in the U.S. – at about 13,000 miles/year vs. 7,000-9,000 miles/yr in Europe
- Vehicle prices, and the prices of efficiency technologies, in Europe tend to be higher than those in the U.S. because of substantial value-added taxes
- In Europe, a large share of light vehicles is purchased by companies and institutions, often to be resold within 2 to 3 years. According to Kageson (2005), company cars comprise 30-50% of new car sales in Germany, the Netherlands, Sweden and the United Kingdom.

The higher fuel prices in Europe will tend to make new fuel efficiency technologies more cost effective than they would be in the U.S., but this advantage is substantially reduced by the lower intensity of use in Europe and the somewhat higher prices for the technologies (because of value-added taxes).

The technology differences between Europe and the U.S. should reduce somewhat the short-term improvement potential for the European fleet. Manual transmissions already are substantially more efficient than automatics, so the improvement potential of continuously variable transmissions and improved automatic transmissions is significantly lower in the European fleet; however, there remains some efficiency potential for manual transmissions in moving towards 6-speed transmissions from current 5-speeds. Also, the improvement potential of the current generation of direct injected diesels in the European fleet is lower than the potential for gasoline engines.

Ricardo has projected that a baseline 2003 diesel car could obtain a CO<sub>2</sub> emissions (and fuel consumption) reduction of about one third by shifting to a mild hybrid drivetrain (integrated starter-alternator with motor assist, similar to the Honda system used in its Civic), advanced transmission, and substantially downsized engine at a cost of about 3,000 euros; at a lower cost of about 1300 euros, a 23% emissions/consumption reduction could be obtained with a 42 volt belt hybrid, advanced transmission, and a lesser degree of engine downsizing (Owen and Gordon, 2003). Other measures such as weight reduction, improved aerodynamics, and low friction tires could reduce emissions and oil consumption further. The implication is that a fleet CO<sub>2</sub> emissions rate target of 130 g/km, and probably 120 g/km as well, is obtainable; the real issue is how to structure a standard that can achieve the target in a manner that doesn't distort the market, and how to define a reasonable timetable for attainment.

#### 4. THE STRUCTURE OF A NEW STANDARD

The economic impacts of a new standard, and perhaps even its fuel economy improvement potential, will depend not only on the stringency of the standard (the MPG target) but also on its structure – the method by which fuel economy targets are distributed among competing manufacturers, and the boundaries and definitions that identify the types of vehicles to be regulated. Some examples of regulatory structures currently in use are:

- Application of a single target to all passenger cars in each automaker's fleet, regardless of size or other attributes (U.S. passenger cars)
- Identification of a target as an average for the entire fleet of vehicles manufactured by all automakers (EU Voluntary Agreement, though applied separately to European manufacturers, Japanese manufacturers, and Korean manufacturers)
- Identification of targets based on vehicle attributes, e.g. weight (Japan, China) or "footprint" (wheelbase \* track width, U.S. light trucks)

Another important aspect of regulatory structure is the extent to which manufacturers can average the fuel economy achieved by each vehicle type across their fleets. Currently, no standard allows trading of credits (obtained by overshooting fuel economy targets) among different automakers (although the Voluntary Agreement implicitly does this, by requiring only the achievement of a target across multiple companies), and there are different schemes for trading within each manufacturer's fleet. The U.S. allows full averaging within each of three groups of vehicles (domestic passenger cars, imported passenger cars, light trucks) for each automaker. Japan allows averaging within a manufacturer's fleet, but credits for topping a target in one weight class are reduced by half when applied to another weight class. And China demands compliance for every weight class, with no averaging between classes.

Opponents of U.S. fuel economy standards have long complained about the various market distortions that the current standards appear to have created, including:

- The virtual elimination of the station wagon, and its replacement by minivans and sports-utility vehicles that provide similar utility but generally obtain lower fuel economy;

- The advent of very large SUVs whose weight puts them outside of the light-duty fleet (as defined by the regulation), and free from CAFE standards.
- The movement of larger (3/4 and 1 ton) pickup trucks over the CAFE weight limits.
- Among the “Big Three” U.S. manufacturers, pricing of some small car models that appeared to be below production cost.
- Deliberate foreign sourcing of key components of some full-size cars and their resulting inclusion into the “import” fleet.

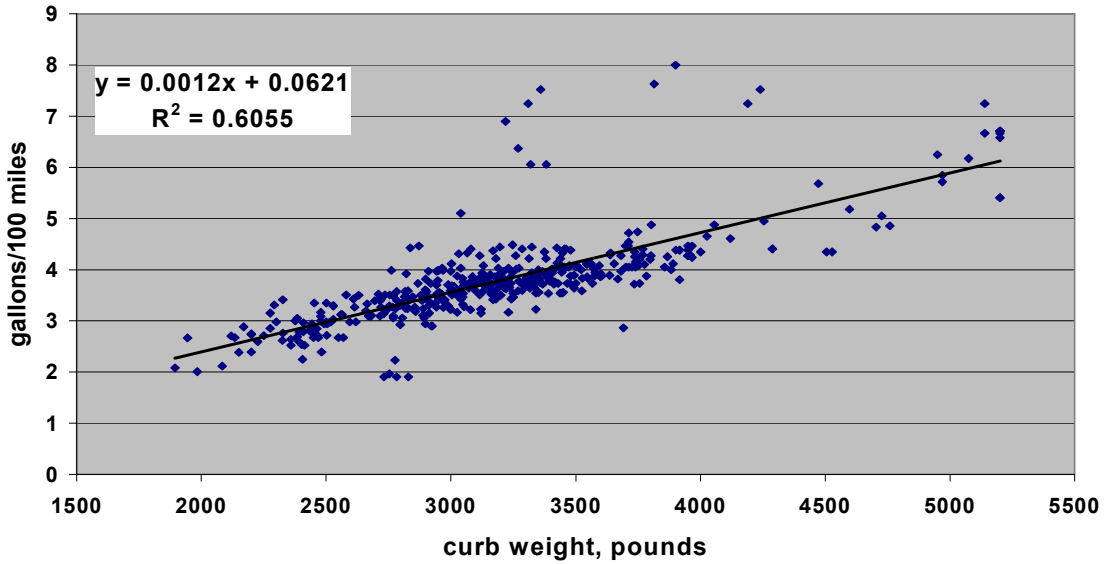
These distortions appear to have little to do with the stringency of the standards, and much to do with their structure, particularly the separation of passenger cars and light trucks with very different fuel economy targets (the light truck target is far more lenient); the separation of “domestic” and “import” fleets, each of which must meet the assigned targets; and the assignment of a uniform fuel economy target to every automaker regardless of the mix of vehicles they produced. For example, the car/truck separation, with light trucks having a much lower standard (20.2 mpg vs. 27.5 mpg for cars) produced a strong incentive for automakers to find a way to move its least efficient passenger cars into the light truck fleet. This incentive should not take sole responsibility for the rise of strong markets for minivans and SUVs, however – minivans turned out to be extraordinarily attractive vehicles for suburban families, and SUVs were terrific for the automakers’ bottom lines – the early SUVs were relatively simple modifications of pickup trucks, relatively inexpensive to manufacture, and could be priced at a large premium to their manufacturing cost.

Many of the problems of the current U.S. system could be overcome by eliminating separate domestic and import fleets (which are an anachronism in an age of multinational automakers), insuring that artificial weight ceilings do not allow vehicles to escape from compliance, and moving away from uniform standards to standards based on the attributes of each automaker’s fleet, as long as the attributes are reasonably related to vehicles’ fuel economy potential. The central idea of attribute-based standards is that they provide individual fleet targets to each automaker that reflect the degree of difficulty faced by that automaker in order to comply with the standard. This can greatly reduce a problem associated with the current standards – that manufacturers of small vehicles may be able to comply with the standard without any action to improve efficiency design and technology, while manufacturers of larger vehicles, or a mix of vehicles, may have to take strong measures for compliance. It also may allow combining car and light truck fleets, because such a standard can shrink

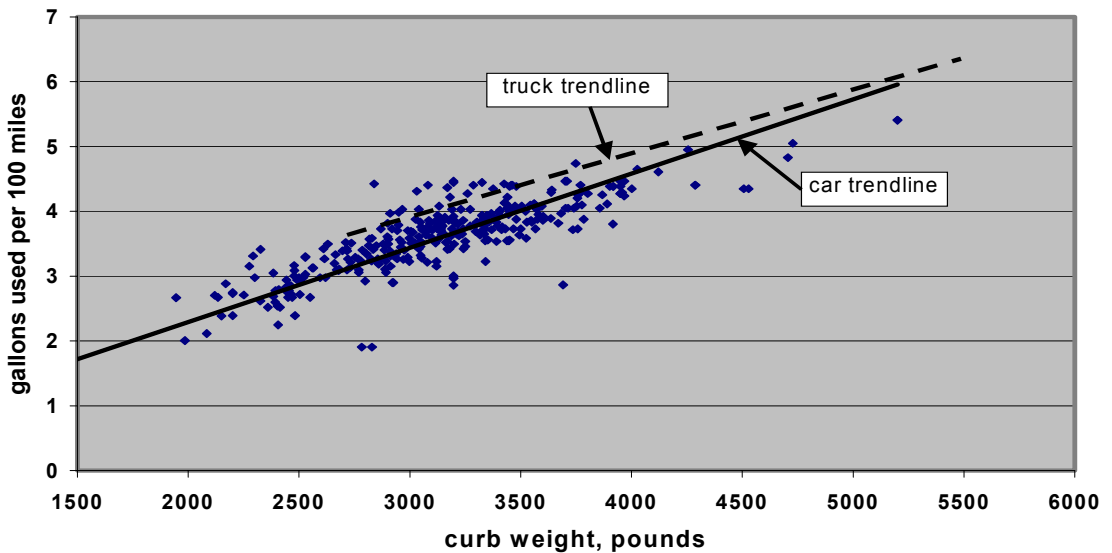
the difference in “degree of difficulty” in compliance faced by cars and light trucks— the primary reason for keeping the fleets separate. Note that policymakers might find it politically impossible to set standards that some domestic manufacturers could not comply with – so that attribute-based standards, by evening out the degree of difficulty faced by different manufacturers, can allow policymakers to set a more stringent standard than would be possible if the standard demanded the same target for each manufacturer.

The attribute most closely related to fuel economy is vehicle weight, and Japanese and Chinese fuel economy standards are weight-based standards (that is, automakers producing larger, heavier vehicles have lower fuel economy targets than automakers making primarily small, lighter vehicles). Studies of the U.S. passenger car fleet show that the relationship between curb weight and vehicle fuel consumption is quite strong; Figure 1 shows a plot of fuel consumption, in gallons/100 miles, versus curb weight in pounds, for the 1999 U.S. new passenger car fleet. The strength of the correlation implies that a weight-based standard is likely to be reasonably uniform in the degree-of-difficulty it applies to a diverse set of automakers (although some companies that stress high-powered sports cars would tend to face a more severe test with this type of standard – or virtually any other). Further, although certain characteristics of light trucks (for example, their boxy shape) tend to make them less fuel-efficient than passenger cars of equal weight, the difference is not especially strong – Figure 2 shows the fuel consumption vs. curb weight correlation line of the 1999 U.S. light truck fleet superimposed on the passenger car plot. As seen in the figure, a fuel consumption standard applied to both fleets combined seems practical.

**Figure 1.**  
Fuel Consumption, gallons/100 miles vs. Curb Weight,  
all cars, 1999



**Figure 2.**  
Automobile Fuel Consumption, gallons/100 miles, vs. curb weight,  
with truck trendline superimposed  
sales>1000



An important shortcoming of weight-based standards, however, is that they tend to reduce or eliminate weight reduction as a strategy for compliance –

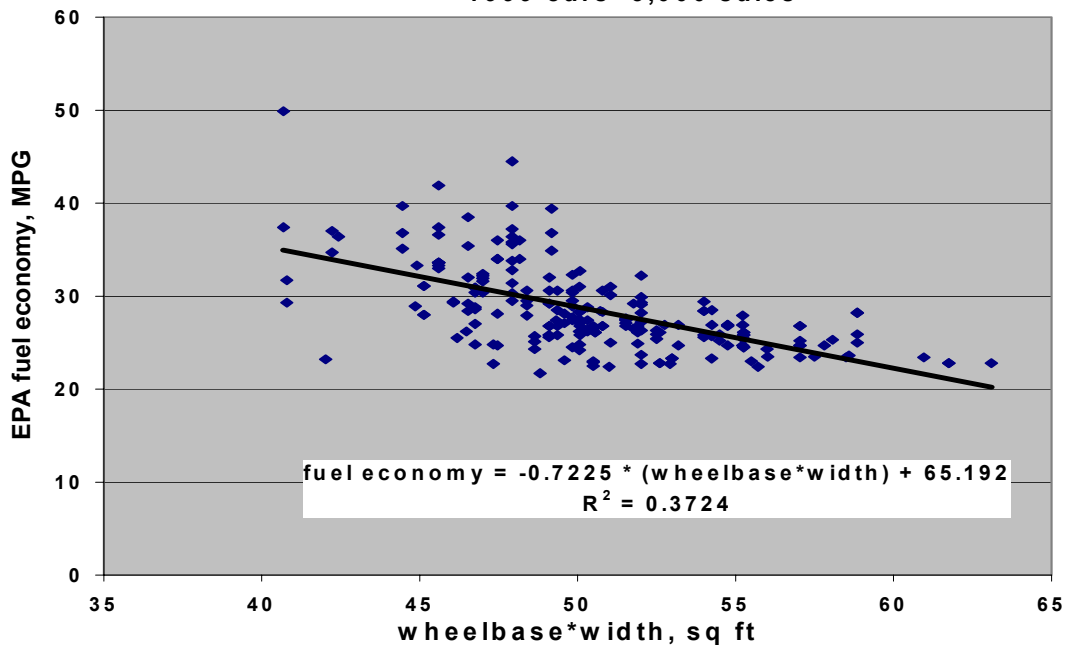
since reducing weight, while improving fuel economy, will make the vehicle's fuel economy target more stringent, with no net regulatory benefit to the company if the targets are set in proportion to the correlation trendline. Weight reduction can be an important component of fuel economy improvement – obviously, since fuel economy and weight are so strongly correlated. Thus, weight-based standards limit the degree of improvement that a new standard can demand. Although fuel economy targets based on vehicle weight can be set to provide some incentive to reduce weight – by deliberately reducing the stringency of standards for lighter-weight vehicles – the effectiveness of this measure will be limited by the need to avoid severe market distortions.

In setting new standards for U.S. light trucks, NHTSA chose standards based on vehicle “footprint” – track width multiplied by wheelbase. Footprint is much less closely correlated with fuel economy than is vehicle weight – in statistical terms, a plot of fuel economy vs. weight for the 1999 passenger car fleet (Plotkin, Greene, and Duleep, 2002) had an  $R^2$  of about 60%, versus about 37% for footprint (see Figure 3). However, footprint is attractive as the basis of a standard because it preserves the incentive to reduce weight; it resists distortion -- any tendency to increase either track width or wheelbase will be limited by the need to essentially redesign the vehicle (not the case with weight); and because increasing either of these dimensions would tend to be beneficial to vehicle safety. Wider track width will reduce a vehicle's potential to roll over, and a longer wheelbase may provide more space for crash management and improve directional stability.

Attribute-based standards are favored by some because they tend to equalize the degree of difficulty of meeting fuel economy targets among competing manufacturers regardless of the size mix of vehicles they produce. This feature of attribute-based standards may not, however, be seen as a positive factor by all groups. Vehicle mix is an important determinant of fleet fuel efficiency, and many would like to exert pressure on manufacturers to shift their mix towards smaller, more efficient vehicles. Uniform standards such as those in the United States do exert such pressure, while attribute-based standards do not. However, there is no evidence that the U.S. standards have been effective in pushing the fleet mix towards smaller vehicles, and little expectation that such a standard, if applied in Europe, would succeed in significantly changing the mix there either.

**Figure 3.**

Fuel economy vs. wheelbase\*width,  
1999 cars >5,000 sales



## 5. TIMING OF A NEW STANDARD

The question of *when* fuel economy targets must be achieved is as important as how stringent the targets should be. Companies adopting a new technology will have to go through a product development process to fit the technology to its vehicles, and will want to introduce the technology cautiously – introducing it into a limited number of models, gauging its performance over a few years, and then – if the introduction is successful – rolling it gradually into the fleet as model redesigns are scheduled. Product development will take at least 2 or 3 years, *after* the technology is deemed ready to leave the laboratory. Proving the product after its initial introduction (in a limited number of models – sometimes just one) will take another 2 to 3 years. And spreading the technology across the company's fleet will likely take a minimum of 5 more years.

Companies adopting a commercial technology may shrink this timeline, but the degree to which they can move more quickly depends on a number of factors, including overall industry experience, whether the technology is an “add on” component or must be carefully integrated into vehicle systems, and whether the technology is owned by a competing automaker or else by a supplier capable of providing extensive design consulting.

Translating the above into a schedule for moving *multiple* technologies into the fleets of multiple vehicle manufacturers is not straightforward, and there does not appear to be much literature on the issue of scheduling for fuel economy standards. Nevertheless, it appears that regulators should allow about 10 to 12 years for a standard with targets based on technology already introduced into the commercial marketplace, with more time allocated for rigorous targets requiring redesigns that might strongly test consumer preferences – assuming that the targets are based on an underlying assumption that the entire fleet of new vehicles is extensively redesigned. Shorter periods would be reasonable for intermediate targets that could be satisfied with redesign of only a fraction of the fleet or with less extensive changes to most models.

The EU faces a somewhat different challenge from the one that faces the U.S., which currently is debating standards that would presumably require redesign of the entire fleet over a time period of 12 years or more. The European industry clearly will not achieve the 140 g/km CO<sub>2</sub> target set for 2008, and current discussion of a target for 2012 focuses on 130 g/km, a 13% reduction in emissions (or 15% increase in fuel economy) if the industry emissions average is around 150 g/km for the 2008 model year (as predicted by Kageson, 2005). This is a quite ambitious target for such a short time period; although a fleetwide target of a 15% fuel economy improvement probably could be achieved with a redesign of about half of each manufacturer’s fleet *and* an attribute-based system that narrowed the differences in degree-of-difficulty among competing automakers, four years is a short period to achieve such a redesign. On the other hand, some have argued that the industry has been well aware for a number of years that greater effort at fuel economy improvement is required and has failed to take adequate measures to achieve the current 2008 target.



## 6. ON-ROAD VERSUS TESTED FUEL ECONOMY

As currently structured, fuel economy standards will improve the *tested* fuel economy of the vehicle fleet. The actual onroad fuel economy of the fleet will tend to follow the direction of these tests, but with important differences that should be understood in considering new standards.

The U.S. Environmental Protection Agency fuel economy tests involve operating the vehicle on a dynamometer – sort of a treadmill for cars – while a driver uses the accelerator and brake to match a speed/time profile called a driving cycle. There are two profiles on the test, a relatively slow cycle designed to simulate city driving, and a faster one designed to simulate highway driving. However, partly because of the limited capabilities of dynamometers at the time the tests were designed, both driving cycles are “gentle” cycles with modest rates of acceleration and braking, and the highway cycle never tops 60 mph. The tests are conducted with heating, air conditioning, lights, and other accessories turned off, and the temperature is held at 68-86 °F. To obtain an “average” fuel economy, it is assumed that 55% of driving is on the city cycle and 45% on the highway cycle, with the average calculated by applying these weights to the vehicle’s fuel *consumption* (the inverse of fuel economy) on the cycles.

EPA quickly discovered that the test gave fuel economy values that were considerably higher than drivers were actually obtaining, and using the data available at the time, reduced the city test result by 10% and the highway result by 22% for the fuel economy estimates actually communicated to consumers. The value calculated this way is the one that appears on the window sticker of new cars and light trucks. However, even this adjusted fuel economy has proved to be optimistic for most drivers,<sup>vii</sup> especially as congestion has spread, highway speeds have increased, and air conditioning has become almost universal. EPA has instituted new requirements for the “window sticker values” on new cars to be based on a series of 5 driving cycles, some of which are driven with air conditioning on or at cold temperatures (20°F), some of which duplicate driving that is considerably faster (up to 80 mph) and more aggressive (2.5 times the acceleration on the original tests) than the original 2 cycles. This new method is expected to reduce estimated city fuel economy values by an average of 12% (and maximum drop of 30%), and highway values by 8% (25% maximum) (Edmunds, 2007).

Although there remain doubts about whether the new testing series will yield accurate results, they will *at least* take some account of measures that manufacturers can take to improve “real world” fuel economy but that will not make a difference on the formal 2-cycle test. For example, improving the

efficiency of the air conditioning system, insulating the vehicle, or adding special coatings to the windows to reduce heat gain during the summer will all improve actual fuel economy but will be ignored by the 2-cycle test. In other words, automakers that incorporate energy-saving designs that won't "count" on the test will at least be rewarded by having the benefits of these measures appear on the sticker.

If new standards are formulated, this modest incentive could be strengthened by awarding credits towards satisfying the standards for the "invisible" technologies and designs. Although it might seem more logical to simply change the official test driving cycles to accurately reflect these factors, such a change is problematic without considerably more confidence in the new tests.

Europeans face precisely the same issue regarding the difference between tested fuel economy and actual onroad values. The New European Duty Cycle (NEDC) used to test fuel economy is a bit slower than the U.S. combined city/highway cycle but is similar, including its failure to include air conditioning loads.

## **7. MAINTAINING FUEL ECONOMY "AFTER THE SALE"**

Fuel economy standards generally have been aimed at new vehicles, and have not tried to affect what happens to vehicles after they are sold.

Vehicle fuel economy can degrade significantly after a vehicle is sold. Some of the causes are:

- Underinflation of tires, which increases rolling resistance (and, because the added resistance causes more tire heating, can adversely affect safety)
- Replacement tires generally are less efficient than original equipment tires. Automakers have a strong incentive to install high efficiency tires to maximize reported fuel economy values. There is no rating system for tire efficiency, however, and no way for the vehicle owner to know the added "price," in increased fuel costs, of a less efficient replacement.
- Poorly maintained vehicles will lose fuel economy through loss of engine efficiency.

- Added weight from heavy materials left in the trunk add to inertial losses, and vehicle body add-ons such as ski and bicycle racks add weight and reduce aerodynamic efficiency
- Driving style greatly affects fuel economy – as noted previously, aerodynamic loads grow with the square of velocity, so high speed driving can be very inefficient, and rapid acceleration and failure to stay even with the flow of traffic – demanding frequent braking and acceleration -- also reduces fuel economy.

Technology requirements can address some of these issues. Requirements for automakers to incorporate tire safety warning systems should reduce the incidence of severely underinflated tires; however, the current U.S. requirements do not demand actual measurements of tire pressure, so mild underinflation is unlikely to be affected.

Efficiency requirements for tires may be regulatory overkill, but NHTSA or EPA (and the EU for Europe) could try to develop a tire efficiency rating and labeling system that communicated the likely value of excess fuel use over the tires' lifetime.

Another possibility is to give a fuel economy credit to vehicles that incorporate real-time fuel economy indicators on their vehicles' dashboards. U.S., European, and Japanese studies have indicated that fuel economy improvements on the order of 10% or more can be obtained if drivers are aware of the effects of their driving style on efficiency and adjust their driving accordingly (ECCJ 2003, ECMT/IEA 2005). Similarly, policymakers might consider awarding credits for "economy" switches for automatic transmissions that optimize shift points for fuel savings – although driver use of such switches should be studied to verify their value.

Vehicle inspection systems tied to emissions and safety should tend to reduce some of the maintenance problems, but these inspections are limited in geographic coverage and may be a difficult sell, politically. And convincing vehicle owners to remove unnecessary material from trunks and dismantle detachable vehicle racks when not in use may be difficult, though it certainly is worth an information campaign to communicate just how much fuel these changes can save.

## 8. COMPLEMENTARY POLICIES

Vehicle purchasers generally can choose among a wide range of features that affect fuel economy and CO<sub>2</sub> emissions, both across the fleet and within individual vehicle categories and even specific models. These features include vehicle size, fuel type (diesel or gasoline), engine power (with the same model, there usually are two or more engine options), type of transmission, luxury accessories, choice of 2-wheel or 4-wheel drive, etc. Unless vehicle manufacturers sharply restrict consumer choice, satisfaction of fuel economy and CO<sub>2</sub> emissions standards depends on *both* the manufacturers' design and technology choices *and* on consumer purchasing decisions favorable to vehicle efficiency. Consequently, the market environment influencing vehicle choice decisions – fuel prices, consumer knowledge, vehicle sales taxes and registration fees, advertising, etc. – will play an important role in determining the degree of difficulty faced by vehicle manufacturers in complying with these standards.

A key criticism of U.S. standards has been that they exist in a policy environment distinctly unfavorable to consumers' choice of improved efficiency – with low fuel prices and sales and annual taxes that do not distinguish between efficient and inefficient vehicles.

In Europe, a variety of policies exist that would be complementary to new fuel economy standards, in that they share the basic aim of promoting higher efficiency vehicles. Kageson (2003) has cataloged these policies:

- **Fuel taxes** – which are quite high in EU countries, and clearly have an effect on vehicle fuel economy. Because diesel fuel taxes are considerably lower than taxes on gasoline in the majority of EU countries, sales of (more efficient) diesel vehicles have soared, with subsequent improvements in fleet fuel economy (and reductions in CO<sub>2</sub> emissions/km). Kageson has noted a potential concern with the diesel/gasoline price differential – that the rebound effect (increase in driving caused by more efficient vehicles' lower driving cost/km) has appeared to be quite strong in shifts to diesel vehicles, with apparent increases in vehicle kilometers driven for diesel vehicles. Whether this effect is as strong as portrayed is uncertain, however, because drivers who would ordinarily take longer trips, or who are contemplating a shift in driving habits towards greater driving, would tend to prefer diesel vehicles, and, in a multi-vehicle household, a new diesel vehicle might absorb some of the trips of other vehicles in the household. These effects make it difficult to separate out a “rebound” from a preference for diesels among higher-mileage drivers.

- **Annual circulation taxes based on engine power, cylinder capacity, vehicle weight, and fuel consumption.** Kageson argues that these taxes have generally been too low to affect market preferences significantly; however, increases in these taxes could be effective in supporting fuel economy standards. The form of the taxes is important – fuel consumption (or CO<sub>2</sub> emissions) as a basis should provide the most direct support of standards, weight and power somewhat less so. Basing taxes on cylinder capacity would help some; wide use of such taxes would likely tend to promote highly boosted engines and manufacturer focus on increasing engine power density (kW/cc), which should tend to reduce fuel consumption.
- **Sales and registration taxes based on cylinder capacity (Belgium, Greece, Ireland, Portugal, and Spain) and fuel consumption (Austria).** Kageson also mentions taxes based on power and weight but does not identify any. Because purchasers of many new vehicles will not keep them more than a few years, these taxes should be more effective than annual circulation taxes in affecting buyer decisions about vehicle fuel efficiency.

It might be argued that fuel economy standards should be adequate *by themselves* to boost fuel economy to desired levels, since standards require compliance. The obvious counterargument is that economic incentives that align consumer interests with the vehicle manufacturers' responsibilities under standards make ambitious standards politically feasible. The risk that lack of consumer interest might damage a vital industry would likely limit government support for such standards. Further, continued improvements in vehicle efficiency will demand substantial and continuing investments in new technology that can only be made by a financially healthy industry.

## 9. CONCLUSIONS

The process of developing new fuel economy standards is inherently more complex than can be done justice in a short paper. The timing of standards was discussed only briefly here, but timing is clearly a crucial element of any new standard – redesigning vehicles is a time-intensive and very expensive process that requires large engineering teams. Redesigning the large part of the new vehicle fleet will require at least a decade, and automakers must

proceed cautiously in introducing new technologies to avoid maintenance and operational disasters. Another issue not discussed in depth here is the economic impact of new standards. In the past, economic analyses of proposed standards have tended to follow a common script – the industry and its consultants forecast huge negative impacts, the environmental community forecasts large positive impacts. In all cases, the results flow primarily from the input assumptions, not robust analysis – the automakers tends to assume that consumers will resist purchasing new models or that they will have to shift to less profitable market segments, while the environmental community assumes that sales will remain robust and the greater vehicle content will generate new jobs (OTA, 1991). And as noted, safety has been and will be a crucial factor in negotiations about new standards in the U.S., and the subject is complex enough to deserve its own paper.

The decision-making process that will create new fuel economy standards is intensely political, and it should be. Scientific analysis can define the possibilities, but in the end the process is about trading off competing societal values – the relative importance of global warming and energy security concerns, the value of the free market, the ability of consumers to drive whatever kind of vehicle they want, the value of future savings versus present costs. Scientists can inform this process, but they should not rule it. Further, as anyone who has watched this debate over the years knows intensely well, there are strongly variable scientific positions about all of the issues in the debate. What does seem certain, however, is that the extremes of the debate – that fuel economy standards don't work and don't save fuel, or that fuel economy standards can be cost-free – are both incorrect.

The extent to which fleet fuel economy can be improved is controlled not only by technology but also by consumer desires. In the United States, over the past 20 years, in the absence of more stringent standards, a cascade of fuel efficiency technologies have been widely disseminated in the fleet, but their potential to improve fuel economy has been totally cancelled by changes in vehicle attributes desired by vehicle buyers, especially increased performance, larger size, and higher weight (due to both the larger size and increased luxury and safety equipment). Similar trends have occurred in Europe, but there at least a portion of the benefits of new technology has gone to improving vehicle fuel economy. The tendency to use new technology for attributes other than improved fuel economy can continue in the future. New standards might constrain trends to larger, heavier, more powerful vehicles, but vehicle manufacturers (through advertising and design decisions) and government and civic leaders (through their ability to inform and influence the public) have a strong role to play.

In the near-term (12-15 years), fuel economy improvement goals of 30-50% seem to be a reasonable starting point for negotiations between government and industry, though higher values would be possible if governments felt that

the urgency of energy security and climate change issues justified asking consumers to pay more for new technologies than they would likely save in future fuel savings. In the longer term, considerably higher increases appear quite feasible, especially if adverse vehicle attribute trends are stopped and if progress continues in cutting the costs of hybrid drivetrains and other new technologies.

In Europe, the approaching decision appears to be a shorter-term one. Because it appears that the industry will not achieve the 140 gCO<sub>2</sub>/km target for 2008 (or 2009 for the Japanese and Korean automakers), the EU has proposed to set mandatory targets, perhaps for as early as 2012. The EU must make difficult decisions about the stringency and timing of the targets as well as their format – and the two are related, because a format that places very different challenges on different segments of the industry is likely to cause some segments to fail or, to avoid this, to limit how stringent the targets can be. This paper examines some alternative formats, but none is without difficult tradeoffs. As for timing, policymakers must wrestle with the knowledge that 2012 is very early for a demanding redesign of a major portion of the fleet, but at the same time it has been clear to the industry for some time that this challenge is coming. There is no simple technical analysis that can simplify this difficult political decision.

As a final point, there are actions that policymakers can take aside from new fuel economy standards that can add to overall fleet efficiency and fuel savings. Some of these actions address the limits of current vehicle compliance testing and the effect of post-sale consumer decisions on efficiency. These actions include:

- Developing a measuring system for tire efficiency that could be used for labeling or as a framework for standards;
- Awarding credits to automakers for improved air conditioning systems and other accessories whose efficiency is not measured on the testing cycle (A regulatory agency would have to determine a method for estimating the average emissions savings associated with such accessories and award a credit in relation to the tested fuel economy to be factored into the rating of the vehicle in relation to a standard or incentive system);
- Awarding credits to automakers for onboard fuel economy/consumptions displays and possibly for “economy” modes for automatic transmissions.

Policymakers can also promote economic incentives that are in alignment with new standards, such as registration and circulation taxes tied to fuel

efficiency. To the extent that such incentives make higher efficiency vehicles more attractive to vehicle purchasers, they may significantly reduce the market risks to automakers of new standards.



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## APPENDIX

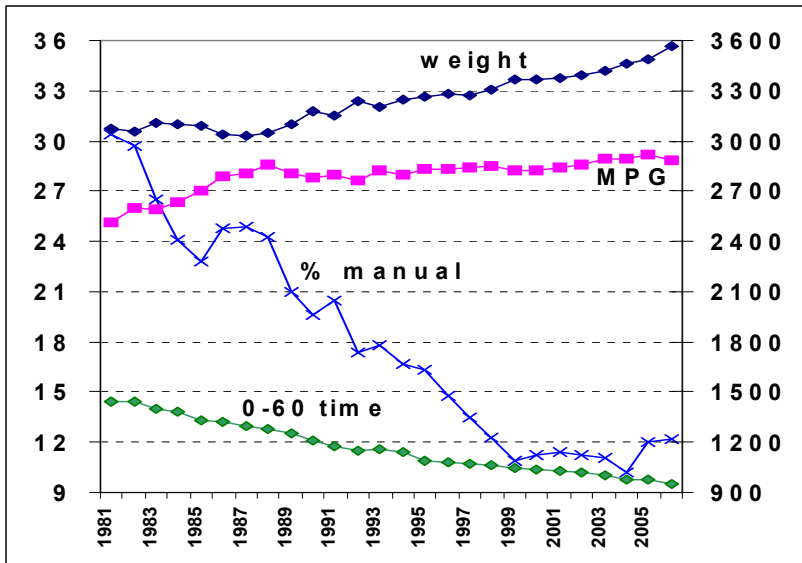
### Box 1. The tradeoff between fuel economy and other vehicle attributes

This tradeoff between fuel economy and performance is well illustrated by examining Toyota's stable of hybrid electric cars and the different decisions made by their designers about trading off fuel economy and performance. In the Prius, Toyota designers chose to use the hybrid technology primarily to increase fuel economy. They use a small, very efficient engine and use the added power of the electric motor to achieve performance similar to other vehicles in Prius's size category, with much better fuel economy (city/highway fuel economy of 60/51 mpg vs. 30/38 mpg for the smaller Corolla).<sup>viii</sup> In the Camry hybrid, the emphasis is still on fuel economy, but the designers chose to forgo downsizing the Camry's 4-cylinder engine, creating performance a bit better than the hybrid's conventional sibling (187 hp vs. 157 hp) but with clearly superior fuel economy (40/38 mpg vs. 24/33 mpg for the conventional 4-cylinder with automatic transmission). And in the Lexus GS450h, the designers pushed the tradeoff considerably more towards performance (5.2 second 0-60 mph, vs. 5.7 seconds for the GS 350 with the same engine), creating an ultra-powerful luxury car with fuel economy comparable to or a bit better than a less powerful car of the same size (25/28 mpg vs. 21/29 mpg for the GS 350).<sup>ix</sup>

In the U.S., the tradeoff between fuel economy and other vehicle attributes has delivered a 2007 model year fleet of cars and light trucks that, over the past 20 years, has added a staggering array of fuel efficiency technologies including supercomputer design of vehicle body structures coupled with new lightweight materials and higher strength steels; significant improvement in aerodynamics and tires; new engine technology ranging from valves that adjust their timing and lift (degree of opening) in response to changing power demand, to fuel injection systems that can respond instantly to changes in cylinder conditions monitored by sophisticated sensors and controlled by more onboard computer power than was available in the lunar module. And the net effect of this technology on fleet fuel economy has been.....**zero**. Every bit of fuel economy *potential* represented by this technology has been traded away for other things. There is no ideal way to measure the impact of this tradeoff, but using a simple measure – “how efficient would the fleet have been had it remained at the average acceleration performance and weight of the 1987 fleet? – the EPA has concluded that the tradeoff “cost” of the years 1987-2004 has been about 5.5 mpg, or 22.5%, for the combined car/light truck fleet

(Hellman and Heavenrich, 2004).<sup>x</sup> Figure B-1 shows the changes in average vehicle weight, 0-60 mph time, and percent of manual transmissions from 1981 to 2006 for the U.S. new passenger car fleet.

Figure B-1. **Changes in passenger car attributes, U.S. new car fleet, 1981-2006**



Similar trends have occurred in European vehicle markets. From 1990 to 2003, average power for all light vehicles increased by nearly 30%, from 61 to 79 kW, while the share of 4-wheel drive vehicles tripled, from 2.6 to 6.3% of sales.<sup>xi</sup> Average vehicle weight also increased substantially, with the ACEA reporting an increase of 10% during the period.<sup>xii</sup> However, the European fleet was able to sustain a reduction in average carbon emissions during this period, compared to the U.S. fleet's small increase in average emissions. A key difference between the U.S. and European fleets appears to be the large increase in diesel share in the European fleet, from 13.8% in 1990 to 43.7% in 2003. This accounted for about a third of the fleet's emission improvement; the remainder of the improvement was primarily due to other technical improvements, with changes in vehicle size mix playing a small share (for the ACEA, the primary source of vehicles in the EU, dieselization accounted for a 3.8% emissions reduction, other technical improvements accounted for an 8.3% reduction, and mix shift 0.3%.<sup>xiii</sup> Still, a substantial further reduction in emissions would have occurred – according to a cited ACEA study, the approximately 12% reduction between 1995 and 2003 could have doubled – had weight, power, and other vehicle attributes not changed.<sup>xiv</sup>

## **Box 2. A short primer on vehicle energy use**

All fuel saving technology is designed either to reduce the power needed at the wheels to move the vehicle and power to run accessories, or to improve the efficiency by which the vehicle obtains power from its energy source – generally gasoline or diesel fuel.

Vehicles need energy to provide the power at the wheels needed:

to overcome the force of inertia when they accelerate either from rest to a desired speed or from one speed to a higher one;

to overcome the forces of air drag and tire friction that would otherwise slow it down; and

to overcome the force of gravity when climbing a grade.

Energy is also needed to power the accessories that maintain comfort (air conditioning, heating), provide entertainment (radio, CD player), or enhance safety (lighting).

Ignoring accessories for the moment, the forces a vehicle needs to overcome vary a great deal with the type of driving one does. On the highway, air drag is especially important because the energy/mile needed to overcome it varies with the square of speed – air drag at 70 mph is  $(70/35)^2$ , or four times what it is at 35 mph. The energy required to overcome tire friction (“rolling resistance”) is relatively constant with speed (though it does go up a bit at higher speeds) but varies directly with vehicle weight. And inertial forces, which also vary directly with weight, are a function of changes in speed – they’ll be low on a smoothly flowing freeway, and high if there’s lots of slowing down and speeding up.

In the city, you’re mostly going at slower speeds and air drag is low. Tire resistance is just a bit lower than it was on the highway. But every time you stop at a red light or slow down for traffic and then accelerate, you’re overcoming inertia – so inertial forces are high in city driving.

What this means is that weight reduction is an excellent way to reduce the energy needed by a vehicle, because weight is directly proportional to two of the three primary sources of energy use in driving (inertial losses and tire rolling resistance). If a vehicle designer achieves a weight reduction of 10% and maintains constant performance by using a slightly smaller engine, fuel economy will be improved by about 6-7%, measured by the standard EPA fuel economy test, which assumes that 55% of driving is in the city and 45% on the highway, all of it fairly gentle.<sup>xv</sup> Improving the efficiency of tires and aerodynamic performance by the same 10% is less effective but will still

achieve about 2 % increases in fuel economy for each (again, maintaining constant performance and measured on the EPA test).

Improving the efficiency of accessories will also help improve fuel economy, although much of this improvement will not show up on the EPA test, which does not include use of heating, air conditioning, lights, or entertainment systems. A 10% reduction in accessory energy use could improve fuel economy by about 1%.

As noted above, the other way to improve fuel economy is to improve the efficiency with which the vehicle translates fuel energy into power at the wheels. An average passenger car or light truck powered by a gasoline engine loses more than 80% of its fuel energy between its fuel tank and its wheels in typical driving. The most losses come inside of the engine, through friction of air and fuel pumped through tubes and valves (“pumping losses”), friction of moving surfaces (e.g., pistons against cylinder walls), heat losses through cylinder walls, loss of heat in the exhaust, fuel used to keep the engine running during idling and deceleration, and so forth. Some of these losses arise because of design compromises caused by material limits, requirements of emission controls,<sup>xvi</sup> and limits to measuring capability and allowable complexity in engine adjustments.

Engine efficiency also depends on the transmission. Internal combustion engines can generate the power and torque needed to operate the vehicle at a wide variety of engine speeds; the transmission chooses the “best” speed as a compromise among fuel consumption, vibration, and other factors, but is limited in its choice by the number of speeds in the transmission. This limitation is particularly important because engine efficiency can fall off substantially as the engine moves away from its most efficient operating mode. The more speeds in the transmission, the easier it is to keep the engine operating near its most efficient mode.

Finally, engines, especially gasoline engines, operate most efficiently at high loads, that is, when the power demanded from them is a substantial fraction of their maximum power. However, engines are “sized” to satisfy driving conditions such as accelerating from zero to sixty mph or from 50 to 70 mpg (highway passing) that require far more power than what is needed during average driving. In other words, engines are normally operated at a small fraction of their maximum power, with substantial penalties in efficiency. This opens up a strategy to improve fuel economy – find a way to artificially boost the power of a small engine for the limited time high power is needed, through turbocharging or supercharging (or use of the electric motor in a hybrid system), or to shut down part of the engine at lower loads so that it behaves like a lower-powered one.

Although most losses occur in the engine, friction losses occur in the transmission and elsewhere in the driveline. Friction losses are reduced by improving engine oils, by making moving parts lighter, by substituting rolling surfaces for sliding ones, by developing special coatings for moving parts, and by improving manufacturing tolerances.

## NOTES

1. Discussed in Gerard and Lave, 2003.
2. In other words, the last increment of added technology cost will be more than balanced by added fuel savings. Note that it might be possible to add technology to gain still higher fuel economy without having total added vehicle costs exceed total fuel savings....but the cost of the added technology might exceed the fuel savings associated with that technology.
3. For more information, see the Vehicle Technologies Program website, <http://www1.eere.energy.gov/vehiclesandfuels/index.html>. The 50 percent weight reduction would be available for use in a leading edge vehicle; the 2015 date does not assume that the new vehicle fleet could achieve such gains at this time.
4. Using the ADVISOR vehicle simulation model, developed by the National Renewable Energy Laboratory.
5. The 2030 midsized passenger cars obtained 5.5 L/100km for the naturally aspirated engine with conventional drivetrain; 4.84 L/100km for the turbocharged version; and 3.08 L/100km for the hybrid version. In CO<sub>2</sub> terms, these values are 121 g/km; 106 g/km; and 68 g/km.
6. Assuming the baseline 2005 diesel achieves a 35% higher volumetric fuel economy than the gasoline vehicle.
7. Fuel economy is extremely sensitive to driving styles – how gently one brakes and accelerates, how much the driver anticipates speed changes and avoids unnecessary braking – and the type of driving she does. As a result, multiple drivers using the same vehicle model typically will get a wide range of fuel economy results. Other factors that affect fuel economy results are average temperature and accessory use. Fuel economy values typically drop substantially in severely cold weather, for example.
8. Toyota, 2007. Corporate website <http://www.toyota.com>
9. Lexus, 2007. Corporate website, <http://www.lexus.com>



10. Hellman, C.H. and Heavenrich, R.M., 2004. *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2004*, U.S. Environmental Protection Agency, EPA420-R-04-001
11. P. Kageson, *Reducing CO<sub>2</sub> Emissions from New Cars*, European Federation for Transport and Environment, 2005.
12. Kageson, op.cit.
13. Kageson, op.cit.
14. Kageson, op. it.
15. A key reason that the test driving cycle is so gentle is that the testing machines – dynamometers – available at the time the test was established had limited capacity to simulate more aggressive driving.
17. Because of extremely precise fuel control and advanced catalysts, most fuel economy penalties associated with emission controls have disappeared. However, stringent standards for nitrogen oxides have led to avoidance of the use of lean burn in gasoline engines, which creates an efficiency loss, and new standards for diesels may also cause some loss in fuel efficiency.