Chapter 1
Executive Summary

BACKGROUND

In the nearly two decades since the first oil shock in 1973, both regulatory pressure (the Energy Policy and Conservation Act of 1975 and its new-car fuel economy standards) and market forces drove fuel economy of the U.S. new car fleet from 14 miles per gallon (mpg) to 28 mpg,[1] saving about 2 million barrels per day (mmbd) of oil that ***would have been used*** had fuel economy remained at 1975 levels at today's level of driving.[2] Although gradual retirement of older, less efficient cars and their replacement with new ones continue to raise overall efficiency of the fleet, new car fuel economy has plateaued, and overall fleet efficiency will also plateau unless new car fuel economy once again begins to rise. Because demand for auto travel continues to grow, gasoline use must also increase if fleet efficiency stagnates.

Although there is no current shortage of oil and world reserve levels are high, the prospect of rising gasoline demand is profoundly disturbing to national policymakers. The United States has just concluded a war that it was brought into, at least in part, by its own and its allies' dependence on Middle Eastern oil. Falling U.S. oil production and gradually rising demand will expose our economy to greater risks. Further, even without supply disruptions, increased gasoline demand means an ever rising pressure on our balance of payments: purchase of foreign oil now represents the major component of our large international trade deficit. Finally, continued high levels of gasoline consumption help perpetuate the United States' massive emissions of carbon dioxide, the primary "greenhouse" gas, at a time when the nations of the world are pledging to cut back on greenhouse emissions.

Congress has responded to trends in gasoline demand and auto fuel economy by introducing legislative proposals designed to boost fuel economy of the U.S. fleet, primarily by setting new and more stringent standards for Corporate Average Fuel Economies (CAFE) of automakers selling into U.S. markets. Senator Richard Bryan's bill (S.279), calling for a 20-percent improvement in each company's new car fleet average (over a 1988 baseline) by 1996* and 40 percent by 2001 (yielding overall averages of 34 and 40 mpg, respectively), was one of the first of the 102d Congress, but other bills introduced offer different standards and approaches. S.279 and the other bills have generated substantial controversy: the key issue (aside from the obvious question of whether ***any*** new fuel economy standard is a sensible national policy) is what increase in fuel economy is technically and economically feasible. The relative merit of alternative regulatory ***structures—e.g.,*** level standard, uniform percentage increase, standards based on vehicle interior volumes, and so forth—represents an important issue as well.

This report, requested by the Senate Energy and Natural Resources Committee, examines the major issues associated with developing new fuel economy standards. It builds on work that OTA conducted for its recently delivered report, ***Energy Technology Choices: Shaping Our Future,*** requested by the House Energy and Commerce

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[1] As measured in EPA laboratory tests using the EPA test cycle and assuming 55 percent city/45 percent highway split. According to EPA, actual on-road values are likely to be about 15 percent less than these test values. Unless stated otherwise, all fuel economy values in this report are EPA values.

[2] $\frac{\text{1975 fuel use}}{\text{1975 VMT}} \times \text{1988 VMT} = \frac{\text{4.54 mmbd}}{\text{1 03 trillion miles}} \times \text{1.43 trillion miles}$
= 6.28 mmbd versus 4.24 mmbd actual 1988 automobile oil use. Data from Oak Ridge National Laboratory, *Transportation Energy Data Book." Edition 11*, ORNL6649. *NOTE:* Had new car fuel economy *actually* remained at the 1975 level of 15.8 mpg, the level of driving might not have grown as much as it did, and the real fuel savings would have been less than calculated here.

*In this report, references to particular years in the context of new car fuel economy goals or levels of attainment denote model years, not calendar years.

Committee and its Subcommittee on Energy and Power. The Energy and Natural Resources Committee's request asked us to focus on the 10- to 15-year timeframe defined by current legislative initiatives for increased automobile fuel economy; in light of this short timeframe, our analysis of fuel economy potential accepts the general concept of the automobile and light truck loosely defined by the types and performance of vehicles in today's fleet. We note that this focus leaves out the potential to rethink the nature of our personal transportation system and to possibly design an altered system of significantly higher fuel efficiency. OTA has considered this strategy of changing the nature of personal transportation in the United States in our 1986 report on ***Technology in the American Economic Transition.*** In addition, we will revisit the long-term question of U.S. transportation energy efficiency in an ongoing assessment, ***U.S. Energy Efficiency: Past Trends and Future Opportunities.***

TRENDS IN FUEL ECONOMY AND USE

Energy analysts agree that without significant changes in market conditions or government policy, increases in the fuel efficiency of the U.S. new car fleet will not match the pace of the late seventies and early eighties. Most improvements during the next decade will come from diffusion of technologies already introduced into the new car fleet; and much of the potential fuel economy benefit may be foregone in order to improve performance (most efficiency technologies can be used instead to improve acceleration or to raise top speeds).[3]

These trends stem from the lack of strong market pressures for improved fuel economy. In the United States, unlike most other industrial countries, fuel cost is a smaller part of total automobile operating expense than previously: gasoline prices in inflation-adjusted dollars are at early 1970s levels, and, when improved fuel economy is accounted for, fuel cost per mile is at its lowest point. Surveys have documented that most consumers are not demanding higher fuel economy in vehicles they purchase.

There are other signs that the market is not supporting reduced gasoline use:

- consumers have been turning in growing numbers to less efficient light trucks for passenger vehicles: between 1970 and 1985, light-truck miles tripled while auto miles grew by only 38 percent;
- automakers are building, and consumers are buying, increasingly powerful cars: average O-to-60 mph acceleration times of the U.S. auto fleet have decreased in every year since 1982, at a cost of more than 2 mpg in average fuel economy;
- consumers increasingly order options that reduce fuel efficiency, such as air-conditioning, power accessories, and fourwheel drive;
- new emission and safety standards are likely to have an adverse effect on fuel economy; and
- the growing number of autos creates traffic congestion that lowers on-road efficiency of the fleet.

OTA estimates that a continuation of current trends—which is likely if public policies do not change and oil prices remain stable (and low)–will lead to a 1995 U.S. new car fleet fuel economy of about 29 mpg. If oil prices increase later in the decade[5] and automotive engineers seek optimum fuel economy benefits from technologies they install, we project a rise in new-car fuel economy to 33 mpg in 2001; lower prices or

[3] By failing to reduce engine displacement or increase axle ratios to compensate for reduced loads or increased engine output, instead using the increased power/load ratio to improve performance.

[4] J.D. Powers has documented fuel economy's drop from first to eighth place over the period 1980-87 as a factor U.S. consumers consider in selecting a new car.

[5] Gasoline price assumed to be about $1.50/gallon (1991$) in 2001.

less-than-optimal designs could lead to fuel economy levels well below this value.

Modest increases in new-car fuel economy, and the implied slower rate of increase in ***total fleet*** fuel economy, are particularly worrisome because greater demand for highway passenger travel is expected to continue, though at a slower rate than in the past. This does not bode well for attempts to reduce highway fuel use.

Except during brief slowdowns due to oil price shocks and gasoline supply problems, highway travel demand has grown at a remarkably stable rate—about 3 percent per year. Many recent projections indicate much lower growth rates—between 1.5 and 2.0 percent per year. These expectations are based on a slowdown in the growth of women in the workforce, primarily because of approaching saturation; the passing of the baby boom; and possible saturation of annual mileage among adults (employed adult males between 25 and 54 years of age already spend an average of 1.5 hours per day in their cars).

In OTA's view, these projections appear reasonable but not robust—we believe growth rates for highway travel demand could range between 1 and 3 percent, and possibly below 1 percent if gasoline costs were to escalate rapidly or gasoline supply to become a problem. If the projections prove correct, however, U.S. gasoline use would still continue to rise, even if new-car fuel economy follows our more optimistic projections (29 and 33 mpg in 1995 and 2001, respectively); for this case, though, the rate of growth in gasoline use would be only about 0.3 percent per year. This leveling in fuel use would roughly match U.S. experience of the past decade and a half (but with different causes). Between 1973 and 1987, petroleum consumption of the light-duty fleet increased only 7.6 percent—an increase of about 0.5 percent/year—though this occurred while travel demand increased much faster than it is expected to in the future.

Evaluations of likely future trends in travel demand and fuel use must recognize that the demand for travel responds inversely to changes in travel costs—if variable costs decline, travel demand will increase. A consequence of this relationship is that improvements in fleet fuel economy—which will reduce "per mile" fuel costs —will promote some extra driving. Although there is no consensus on the magnitude of this "rebound" effect, policymakers should expect fuel savings from improved fuel economy to be reduced by perhaps 10 or 20 percent from the savings that would occur had the amount of driving been unaffected.

HOW CAN AUTOMOBILE FUEL ECONOMY BE IMPROVED?

An automobile's fuel use is controlled by two factors: the loads on it created by its use; and the efficiency with which it transforms fuel into the work needed to overcome the loads. The loads are the inertial load (when accelerating and climbing grades), air resistance, and the rolling resistance of the tires. Although the magnitude of the loads is partly dependent on the way the car is driven and the terrain, lowering a vehicle's weight, smoothing its shape, and reducing tire rolling resistance will reduce the loads on the vehicle and its fuel consumption. Improving efficiency involves reducing friction in the drivetrain; reducing auxiliary loads with improved air-conditioning, more efficient power steering, etc.; reducing pumping losses, that is, energy needed to pump air and fuel into the cylinder and push out the products of combustion; and so forth. Although modern automobiles have achieved substantial sophistication and efficiency, numerous opportunities to improve fuel economy remain. Table 1-1 lists key technologies and design improvements that will do so.

Aside from improving technology, materials, and design, fuel economy can be raised by making an automobile smaller in interior space (with an associated decrease in total size and weight) or less powerful. Most current proposals for higher fuel economy standards are predicated on the belief that the standards can be attained ***without*** major changes in vehicle size and power, though most or all presume that recent trends toward higher horsepower cannot be allowed to continue.

Table 1-1 -Fuel Economy Technologies and Design Improvements

Weight reduction. Includes three strategies: substitution of lighter weight materials (e.g., aluminum or plastic for steel); improvement of packaging efficiency, i.e., redesign of drivetrain or interior space to eliminate wasted space; and technological change that eliminates the need for certain types of equipment or reduces the size of equipment.

Aerodynamic drag *reduction.* Primarily involves reducing the drag coefficient by smoothing out the basic shape of the vehicle, raking the windshield, eliminating unnecessary protrusions, controlling airflow under the vehicle (and smoothing out the underside), reducing frontal area, etc.

Front wheel drlve. Shifting from rear to front wheel drive, which allows: mounting engines transversely, reducing the length of the engine compartment; eliminating me transmission tunnel, which provides important packaging efficiency gains in the passenger compartment; and eliminating the weight of the propeller shaft and rear differential and drive axle. Now in wide use.

Overhead cam engines. OHC engines are more efficient than their predecessor pushrod (overhead valve, OHV) engines through their lower weight, higher output per unit displacement, lower engine friction, and improved placement of intake and exhaust ports.

Four valve per cylinder engines. Adding two extra valves to each cylinder improves an engine's ability to feed air and fuel to the cylinder and discharge exhaust, increasing horsepower/unit displacement. Higher fuel economy is achieved by downsizing the engine; the greater valve area also reduces pumping losses, and the more compact combustion chamber geometry and central spark plug location allows an increase in compression ratio.

Intake valve control Shift from fixed-interval intake valve opening and closing to variable timing based on engine operating conditions, to yield improved air and fuel feed into cylinders and reduced pumping loss at low engine loads.

Torque converter lockup. Lockup eliminates the losses due to slippage in the fluid coupling between engine and transmission.

Accessory *improvements.* Adding a two-speed accessory drive to more closely match engine output to accessory power requirements, plus design improvements for power steering pump, alternator, and water pump.

Four- and five-speed automatic transmisslons, and continuously variable transmissions. Adding extra gears to an automatic transmission increases fuel economy because engine efficiency drops off when its operating speed moves away from its optimum point, and the added gears allow the transmission to keep the engine closer to optimal speed.

Electronic transmission control. Electronic controls to measure vehicle and engine speed and other operating conditions allow the transmission to optimize gear selection and timing, keeping the engine closer to optimal conditions for either fuel economy or power than is possible with hydraulic controls.

Throttle body and *multipoint fuel injection.* Fuel injection allows improved control of the air/fuel mixture and thus allows the engine to continually adjust this mixture for changing engine conditions. Multipoint also reduces fuel distribution problems. In wide use.

Roller cam followers. Most current valve lift mechanisms are designed to slide along the camshaft; shifting to a rolling mechanism reduces friction losses.

Low friction pistons/rings. Lowerfriction losses result from better manufacturing control of tolerances, reduced ring tension, improved piston skirt design.

Improved tires and lubricants. Continuation of longstanding trends towards improved oil (in near-term, substitution of 5W-30 oil for 1OW-4O oil), and tires with lower rolling resistance.

Advanced engine frictlon reduction. Includes use of lightweight reciprocating components (titanium or ceramic valves, composite connecting rods, aluminum lifters, composite fiber reinforced magnesium pistons), improved manufacturing tolerances to allow better fit of moving parts, available post-1995.

Electrlc power steering. Used only for cars in the minicompact, subcompact, and compact classes.

Lean burn. Operating lean improves an engine's thermodynamic efficiency and decreases pumping losses. Requires a new generation of catalysts that can reduce NO_x in a "lean" environment.

Two-stroke engines. Unlike a conventional engine, there is a power stroke for every ascent and descent of the piston, thus offering a significantly higher output per unit of engine displacement, reduced pumping loss, smooth operation, and high torque at low speeds, allowing engine downsizing and fewer cylinders (reduced friction losses). Also, operates very lean, with substantial efficiency benefits (if NO_x problems are solved). Compliance with stringent emissions standards is unproven.

Diesel *engines.* Compression-ignition engines, or diesels, area proven technology and are significantly more efficient than gasoline two-valve engines even at constant performance; new direct injection turbocharged diesels offer a large fuel savings. Although the baseline gasoline engine will improve in the future, a portion of the improvements, especially engine friction reduction, may be used beneficially with diesels as well. Use may be strongly limited by emissions regulations and consumer reluctance.

Electrlc hybrids. Involves combining a small electric motor for city driving and a diesel for added power and battery charging. The small size of the diesel eases emission limitations, and the substantial use of the electric motors reduces oil use.

SOURCE: Offlce of Technology Assessment, 1991.

However, a significant ***reduction*** in average vehicle size and performance could offer a substantial benefit in increased fuel economy; and measures to change consumer preferences (especially economic incentives such as gasoline taxes and rebates on high fuel economy vehicles) might be attractive components of a fuel conservation strategy.

To be successful, however, a fuel economy strategy featuring smaller, less powerful cars requires far more change in consumer attitudes than one based on technological changes only; the latter affects primarily a vehicle's price and, in the case of improved aerodynamics, its aesthetics, whereas the former can strongly affect a vehicle's basic utility, comfort, and driving enjoyment.

Fuel economy improvement strategies that rely heavily on changing consumer preferences for more size and power or limiting consumers' choice of vehicles risk consumer disappointment in new car offerings, reduced sales, and a reduced fleet turnover rate—with turnover being a critical factor in improving overall fleet fuel economy and, of course, in maintaining the financial health of the auto industry. Consequently, legislators who believe fuel economy standards should be raised substantially need to identify a fuel economy level and regulatory program design that balances dual goals of pushing hard for improved vehicle technology and design and maintaining a new car fleet that remains attractive to potential purchasers. They should also carefully consider the advisability of economic incentives, such as gasoline taxes, vehicle rebates, and taxes tied to fuel economy, that would tend to align market forces with regulatory requirements.

WHAT IS THE FUEL ECONOMY POTENTIAL OF THE U.S. NEW CAR FLEET?

Congress has been bombarded with a wide range of estimates of the "technological potential" of the fleet. Many differences among these estimates result not from actual differences in technical judgment about the efficiency improvement of specific technologies, though such differences clearly exist, but instead from differences in assumptions about:

- the timeframe of the higher fuel economy levels, thus the lead time available to the industry to make technical and marketing changes;
- the nature of regulations accomplishing the efficiency change;
- future shifts in the size mix of the fleet;
- changes in acceleration capabilities or other measures of vehicle performance;
- passage of new safety and emission regulations;
- time required to develop, perfect, certify, and bring to market new technologies;
- judgments about acceptable levels of economic disruption to the industry in responding to new fuel economy regulations; and
- judgments about consumer response to changes in vehicle costs and capabilities (which are, in turn, a function of oil prices and supply expectations).

These factors must be considered in calculating "technological potential," since each will affect the ultimate fuel economy achieved by the fleet.

OTA has examined estimates of technological fuel economy potential ranging from conservative estimates prepared by domestic automakers to optimistic estimates prepared by energy conservation advocates. The range of views about fuel economy potential can be characterized as follows: At the conservative extreme, further increases in fleet fuel economy are characterized as likely to be quite small, even by 2001, because the major gains have already been achieved, consumer tastes are heading towards vehicle characteristics that conflict with higher fuel economy, and government safety and emissions standards will tend to degrade fuel economy.[6] At the optimistic extreme, large increases in fleet fuel economy, to 45 mpg and higher, are portrayed as readily obtainable by existing or soon-to-be-available technology, possibly as early as the year 2000.

As explained in the text, OTA concludes that estimates prepared by Energy & Environmental Analysis, Inc. (EEA), under contract to OTA and the Department of Energy, provide the best available basis for decisionmaking about fuel economy policy. We note that the EEA analyses must be used in context: each individual estimate of fuel economy potential for a "scenario" of particular circumstances is associated with a set of critical assumptions that determines the magnitude of reported fuel economy values. In some

[6] Quantitative industry mpg estimates are not identified here because the automakers have been reluctant to provide estimates in this form.

regards, EEA estimates may be somewhat conservative for the 2001 timeframe, because they do not consider the possibility that new technologies, not yet commercially available, may begin penetrating the market by that date, nor do they consider the potential for diesel engines to overcome their current negative market perceptions and their problems in meeting emission requirements. On the other hand, the available EEA scenarios all assume that, ***at the worst,*** vehicle performance, use of luxury equipment, and size will not increase indefinitely but instead level off after 1995; other scenarios assume a policy-driven rollback in these characteristics to 1990 or 1987 fleet levels. These assumptions could prove too optimistic.

Table 1-2 provides OTA's estimates for a variety of fuel economy scenarios, ranging from a "product plan" projecting likely fleet fuel economy in a "business as usual" scenario (no new fuel economy regulations, no major shifts in market factors), to a "maximum technology" scenario estimating what could be achieved if regulations forced maximum use of fuel economy technologies and accelerated model retirement rates, to a longer term projection postulating the success of several new technologies such as two-stroke en-

Table 1-2-Scenarios of Automotive Fuel Economy

		Fuel Economy Levels Achievedl
1995	● Product Plan cost-effective technology, continuation of current trends, no new policy initiatives	28.3 mpg domestic[2] 31.1 mpg imports 29.2 mpg fleet
	● Regulatory Pressure fuel economy potential with added pressure of new efficiency regulations, but without size/class shifts	30.0 mpg fleet
2001	● Product Plan at Rising Oil Price no new policy initiatives and no radical changes in market, but higher oil prices ($1.50gal gasoline in 1991$); size/performance/luxury stable after 1995, tier 2 emissions standards not considered	32.0 mpg domestic 34.6 mpg imports 32.9 mpg fleet
	● Maximum Current Technology feasible technology added regardless of cost, size/performance/luxufy rolled back to 1987 levels, normal lifecycle requirements not allowed to limit technology penetration rates, no advanced technologies	37.3 mpg domestic 39.9 mpg imports 38.2 mpg fleet
	● Regulatory Pressure technology added that is cost-effective at $2.00/gal. gasoline (higher than expected price levels), lo-year payback, size/performance/luxury rolled back to 1990 levels, technology penetration limited by normal lifecycle requirements, no advanced technologies	34.5 mpg domestic 37.4 mpg imports 35.5 mpg fleet
2005	● Regulatory Pressure as above	36.5 mpg domestic 38.4 mpg imports 37.1 mpg fleet (38.1 mpg w/2-stroke)
2010	● Advanced Technologies size/performance/luxury rolled back to 1987 levels, no new emissions standards post-2ooo	
	- addition of technologies that most automotive engineers agree would be commercialized by 2000	45 mpg fleet
	- addition of technologies not having general agreement about benefits and commercial prospects.	55 mpg fleet

'EPA tests cycle, combined city/highway; potential credits for alternative fuel vehicles NOT considered.

2"Domestic'' refers t. vehicles made and sold In the United States by the three U.S automakers; imports refers to vehicles sold In the United States by the top five Japanese automakers.

SOURCE: Office of Technology Assessment, 1991, based on analysis by Energy& Environmental Analysis, Inc., 1991.

gines. The "regulatory pressure" results illustrate one example of a set of scenarios that may be viewed by some as a "middle-of-the-road" strategy, although it does assume a rollback in vehicle size and performance to 1990 levels in defiance of current upward trends, and technology additions that will not be cost-effective at expected gasoline prices.* OTA does not, however, believe that there is any "best" fuel economy strategy.

As illustrated by these scenarios, we find neither extreme of fuel economy potential described—"little change" or 45 mpg plus by 2000-credible for that timeframe. Our analysis shows that the application of multiple existing technologies can increase fleet fuel economy by several mpg, and up to about 10 mpg by 2001 if consumers accept some rollback in vehicle size and performance and are willing to pay more for improvements in fuel economy than they will likely be repaid in fuel savings-but such acceptance is not a foregone conclusion given existing market trends, as discussed. Chapter 4 includes a detailed description of the current market trends affecting fuel economy. More detailed description of the alternative fuel economy scenarios and their underlying assumptions are presented in chapters 7 and 9.

Larger gains, to 45 mpg or even higher, ***maybe*** available by 2010 if new technologies could make major gains in the marketplace, although the success of these technologies is by no means guaranteed. For this, the automakers need time to redesign their model lines and to develop and adequately test new technologies.

As noted, changing consumer preferences for fuel economy, vehicle size, and vehicle performance (or, in the extreme, imposing limits in choice of these attributes) offers an alternative approach to improving new-car fleet fuel economy. Moderate changes in purchaser selection of vehicles within size or weight classes toward more efficient models, and shifts in size or weight class to smaller vehicles can substantially increase fleet fuel economy. For example, in the 1990 U.S. new car fleet, had consumers purchased only the dozen most fuel efficient models in each weight class, and shifted their purchases toward lighter weight classes so that average weight was reduced by 6.2 percent, the fleet fuel economy would have improved from 27.8 to 33.2 mpg, a 20 percent improvement. About two-thirds of fuel economy improvement would have been due to consumers selecting the more efficient vehicles in each weight class, with the remainder due to the actual shift in weight class market shares. The "cost" of the improvement (in terms of loss of consumer attributes) would have been a 7-percent decrease in the average interior volume of the fleet (from 107 to 99 cu. ft.), an Ii-percent increase in O-to-60 mph acceleration time (12.1 to 13.4 seconds), and a major shift from automatic to manual transmissions (about 40 percent of the fuel economy benefit would be lost if drivers refused to switch transmission types). The "average car"—the car that attains the average fuel economy of the fleet and is representative of its average characteristics—would have shifted from a Dodge Dynasty to a Toyota Camry.

What, then, should be the targets for a new generation of fuel economy standards? If Congress wishes to set a fleet target for model year 1996 that pushes the industry further than it would otherwise be likely to go, we believe a realistic target would be 30 mpg assuming no significant changes in current trends in vehicle size and performance. With full use of available alternative fuel credits, a reported fleet average[7] of 31 mpg should be feasible. The fleet average could be considerably higher than this if consumers changed their buying preferences for efficiency, performance, and size; legislators will have to weigh the benefits of attaining this higher level with the risks, in particular the potential for customer dissatisfaction with smaller, lower-powered cars, resulting lower vehicle sales, and

*The gasoline price that would yield cost-effectiveness ($2.00/gal) was chosen to represent one possible value of the total societal cost of gasoline, that is, actual market price plus costs of air pollution damage, global warming contribution, national security impacts, and so forth. Different policymakers should have different opinions of what an appropriate societal cost might be.

[7]That is, the tested value plus any available credits.

the consequent impacts on the U.S. automobile industry.* Congress could reduce these risks by coupling higher fuel economy standards with economic incentives—gasoline taxes and rebates and penalties tied to fuel economy—designed to push the market towards higher efficiency.

For the longer term, the choice becomes more difficult because there are more options and more uncertainties. The "maximum technology" value of 38 mpg in 2001 assumes a rollback in size and performance to 1987 levels, an increase in vehicle costs that will ***not*** be offset by fuel savings (unless gasoline prices rise substantially), and the early retirement of several model lines, which could be costly to the industry. The compression of vehicle lifecycles embodied in the maximum technology scenario is not unprecedented, however, and legislators may feel that growing oil imports and the need to reduce greenhouse emissions warrant such measures. Further, a high fuel economy standard may accelerate the entry of new technologies, such as the two-stroke engine, into the fleet-though not without market and technical risks.

For legislators who believe that the market should better reflect societal costs of oil but who wish neither to demand that the industry abandon product lines before their initial costs can be recovered nor to risk requiring major changes in vehicle size and performance, a fleet target of around 35 mpg should be feasible by 2001. Alternatively, a "maximum technology" scenario that assumed a rollback in size and performance only to 1990 levels would yield a fleet average fuel economy of about 37 mpg by 2001. The change in size and performance between 1987 and 1990 cost over one mpg in new-car fleet fuel economy. ***Because of the importance of lead time, these potential fuel economy targets presume passage of new fuel economy legislation by the end of calendar year 1991. Substantial delays in promulgating new rules would Iower fuel economy values attainable in the target year***

For the still longer term (2010 and beyond), there is real potential for fleet fuel economy values of 45 mpg or even 55 mpg,[8] but considerable uncertainty as well because of untested technologies. For this time period, Congress might consider mechanisms to insure continued technological pressure while maintaining enough administrative discretion to reduce fuel economy goals if optimistic forecasts of technology potential turn out to be incorrect.

WHICH TYPE OF STANDARD IS BEST?

Recent proposals for new fuel economy legislation have moved away from the format of current law, which imposes a 27.5 mpg standard on all automakers. With the current format, automakers producing a variety of vehicle sizes or primarily large vehicles are subject to a more demanding technological challenge than automakers who concentrate on small vehicles. This gives the latter automakers more flexibility to capture markets for larger cars and to introduce features (high-performance engines, four-wheel drive, etc.) that are both attractive to consumers and fuel inefficient–putting full line and "high end" manufacturers at substantial market disadvantage.

Many legislators would not approve a new fuel economy standard unless domestic automakers could comply without a drastic shift in their fleets toward small cars—but a "uniform mpg" standard set under a restriction of this sort would be unlikely to force automakers making primarily small cars to improve very much. As a result, the maximum fuel economy the fleet could be expected to attain with a uniform mpg format would be lower than with a format that challenges ***all*** automakers to substantially improve their CAFES.

New legislative proposals ask that automakers raise their CAFES by a uniform percentage over

*New car sales represent about 2 percent of U.S. GNP, and total expenditures for automobile use represent about 10 percent of GNP–illustrating the importance of the automobile industry to the U.S. economy.

[8] Even *higher* values could be achieved, but *Only with* major *changes* in the basic character of the cars, e.g. with large numbers of diesel/electric hybrid vehicles.

what they had attained in a baseline year—1988 in Senator Bryan's proposal (S. 279); 1990 in S. 1220, reported by the Senate Energy Committee. Because the 1988 or 1990 CAFES reflect in some measure the size makeup of each company's fleet, their use as a baseline for assigning fuel economy requirements will account for the differences in size among the various companies—but only to the extent that these differences do not change from the baseline year to the compliance year. If companies seek to gain share in market segments different from their traditional market (e.g., by marketing large luxury cars), the uniform percentage increase approach could prevent them from doing so—and may be viewed as anticompetitive. Furthermore, to the extent that some differences for the baseline year were due to differences in fuel economy technology and design, a uniform percentage increase standard places the most severe new demands on those companies who in the past had tried hardest to improve their fuel economy. There ***have*** been differences in fuel economy technology and design among the different automakers, and several companies have, through deliberate marketing strategy or through loss of market shares, changed their size mix over time—both factors compromising the internal logic of the uniform percentage increase approach to CAFE regulation.

An alternative approach to fuel economy standards is to base company standards on the attributes of each company's fleet at the time the standards are to be met. If based on interior volume, for example, a new standard would place the highest numerical fuel economy target on the company making vehicles with the lowest interior volumes. Such a Volume Average Fuel Economy (VAFE) standard could be designed to place as equal as possible a technological (or financial) burden on each automaker. This type of standard would put no pressure on automakers to build small (low interior volume) cars[9]—a minus with those conservationists who believe most cars are too large, a plus with others who believe consumers should have an unrestricted choice of car size and who may also believe large cars are safer. Instead, a VAFE standard demands that automakers focus on technology, design, and performance to improve fuel economy, removing the contentious issue of car size from the policy debate. A perceived disadvantage of a VAFE standard is that any increase in market share of cars in the larger size classes could reduce the overall fleet fuel economy target, a potential outcome that disturbs some policymakers; however, a uniform percentage increase standard could also have its total fleet target reduced with market changes.[10]

Another potential problem with VAFE standards—and with the original uniform 27.5 mpg standard—is that they are difficult to apply to manufacturers falling outside the competitive mass market. Companies such as Mercedes-Benz and BMW sell products that stress high performance, luxury, and safety at a high price. Traditionally, their vehicles are substantially heavier than other vehicles in their size class, more powerful, and have rear-wheel drive (to achieve the handling characteristics they seek), all of which compromise fuel economy. These companies cannot match the fuel economies of mass market automakers in their size classes at similar levels of technology.

Basing fuel economy standards on a wider group of vehicle attributes could provide more of a move to a "pure technology" standard, that is, a standard that can be met only by improving technology rather than by reducing size or power. Mercedes-Benz, BMW, and Porsche have proposed a standard based on a group of variables—curb weight, the ratio of curb weight to interior volume, and the ratio of curb weight to torque—that would allow companies in a wide range of market niches to comply with a reason-

[9] Because smaller cars will have higher fuel economy targets, and selling more of them will not make it easier for an automaker to achieve its company standard—unless the size-based targets are deliberately set to give smaller cars a less difficult target fuel economy than large cars would have.

[10] For example, if an automaker with a relatively *low* mpg target gained market share, the overall fleet fuel economy target would be reduced'

able standard by improving technology, without being forced to move into other markets to "balance" their production of niche vehicles. The standard is formulated by performing a regression analysis,[11] using EPA data for the 1990 fleet, that defines current vehicle fuel consumption as a function of the above three variables. A standard requiring 1995 fleet fuel economy to be at least 20 percent higher than the 1990 level would simply reduce the 1990-based fuel consumption function by 20 percent and apply this new function to each automaker's fleet. As with the uniform percentage increase and VAFE standards, this system will not guarantee attainment of an exact fuel economy level (because the market can change), but it will force technology improvement and it provides positive incentives for weight and performance reduction.

WHAT IS THE BEST SCHEDULE FOR NEW STANDARDS?

Legislation proposed during last year's (1990) debate focused on setting new fuel economy standards for the (model) years 1995 and 2000. This year, these dates have been changed to 1996 and 2001 to reflect the loss of a year of lead time for the automakers. Are these the best years for a set of new standards?

Generally, the design and product development lead time for new models and major components is about 4 to 5 years, indicating that products for the 1996 model year are now being finalized, while products for 1995 have moved to a stage where tooling orders are being placed. Models of domestic automakers will have a lifecycle of at least 7 to 8 years prior to redesign, during which their large development costs must be recovered. Japanese models tend to have shorter lifecycles, as short as 4 years.[12]

These time horizons imply, first, that 1996 is very early to demand significant improvements in fuel economy beyond that already built into product plans, and second, that 2001, while allowing enough time for major adjustments to be made, is early for a standard that might seek fleetwide redesign ***unless Congress believes energy concerns warrant a redesign schedule that would induce accelerated retirement on several model lines.*** Although OTA has reached no conclusion about what an optimal schedule might be, a set of dates that would allow an interim fuel economy adjustment followed by a full redesign of all model lines ***without forced early retirements*** would be 1998 and 2004 or 2005. A 2001 standard could also be included, predicated on redesign of only a portion of company model lines.

NEW FUEL ECONOMY STANDARDS AND SAFETY

Industry and Administration opposition to new fuel economy standards has included arguments that higher standards, such as those proposed by S.279, would force consumers into a new fleet of smaller cars significantly less safe than a new fleet with an unchanged size mix-and perhaps even less safe than the current fleet.[13] In OTA's view, unless sharp fuel economy improvements are demanded over a period too short to allow vehicle redesign, or the fuel economy requirements are so stringent they can only be met with drastic levels of downsizing, it is unlikely that ***absolute*** levels of safety would decrease. The continued introduction of new safety improvements, and wider use of already introduced improvements should compensate for adverse effects of moderate amounts of downsizing. Further, if given enough time, automakers can significantly improve fleet fuel economy ***without*** downsizing (though with some weight reduction), and probably without an adverse safety impact. Nonethe-

[11] A regression analysis involves a statistical examination of data that seeks to determine functional relationships among variables that the analyst believes to be related, for example, between fuel economy and weight and horsepower (variables that should affect fuel economy).

[12] Light trucks may have somewhat longer lifecycles.

[13] For example, see statement of Jerry Ralph Curry, Administrator, National Highway Traffic Safety Administration, before the Subcommittee on Energy and Power, House Committee on Energy and Commerce, Oct. 1, 1990.

less, there is cause for concern about the relationship between fuel economy and safety, and there is reasonable probability that further downsizing—especially a reduction in exterior dimensions—would cause the fleet to be less safe than it would otherwise be. However, we also find that the debate about the relationship between fuel economy and safety has at times become overheated,[14] and assertions on both sides of the debate seeking to demonstrate the magnitude of risk are frequently flawed or misleading.

Car size can be characterized by weight, interior volume, or exterior dimensions. Each has a different relationship to safety. Added weight may help the heavier car in a vehicle-to-vehicle collision, because the laws of momentum dictate that a heavier car will experience less deceleration force in a crash–but the weight and safety advantage afforded the first car represents a disadvantage to the second car, increasing the force on it. Although accident records have demonstrated a ***statistical*** relationship between ***overall*** fleet safety and average weight of the vehicles in the fleet, the strong association between weight and various measures of vehicle size, especially exterior dimensions, makes it difficult to separate effects of weight and size. Many safety experts think size is more important than weight to overall fleet safety, even though weight may be important to consumers making individual purchase decisions. If carmakers can make vehicles lighter while retaining structural integrity-and with proper materials, they can—there should be no adverse safety impact.

Interior volume may affect safety somewhat because a larger interior makes it easier for vehicle designers to manage the "second crash" —when bodies are flung about the passenger compartment. The average interior volume of the U.S. automobile fleet has been remarkably stable over the past decade, but there is concern this may change if fuel economy standards are set at levels that cannot be attained with technology alone. However, increased airbag use may make differences in interior space less important to overall vehicle crashworthiness, because airbags should reduce movement —and likelihood of secondary collisions—of front-seat passengers in a crash.

Exterior dimensions may be particularly important to a car's crashworthiness, since these affect available crush space, and narrower vehicle tracks and shorter wheelbases appear to affect rollover frequency (rollover accidents are often associated with fatalities). Accident studies have shown that some of the largest vehicles in the fleet consistently have the lowest fatality rates, even when the data are corrected for driver characteristics (especially age). Further, studies by the National Highway Traffic Safety Administration indicate that small vehicles experience more rollover accidents, and more traffic fatalities in such accidents than large vehicles, and the Insurance Institute for Highway Safety claims downsizing has driven up death rates in several redesigned General Motors models.

Will new fuel economy standards decrease automobile safety? It depends, and we believe the risks are less than those characterized by some. First, substantial increases in fuel economy can be achieved with little or no downsizing, although automakers might conceivably choose downsizing over other measures to satisfy new fuel economy standards. Although vehicle ***weight*** would likely be reduced, this need not have negative safety consequences if careful attention is paid to vehicle structural integrity.

Second, even if further downsizing were to decrease safety relative to not changing standards, this need not mean, and probably would not mean, an ***absolute*** safety decrease. During the period when CAFE standards have been in effect, when the median weight of new automobiles dropped by about 1,000 pounds, wheelbase by 10 inches, and track width by 2 to 3 inches, the safety record of the U.S. fleet improved substantially –between 1975 and 1989, death rates for passenger cars ***declined*** from 2.43 per 10,000 registered

[14] The rhetoric has ranged from asserting that safety and vehicle size are essentially unrelated to suggesting that S.279 be referred to as "The Highway Fatality Bill."

cars (*2.5* per 100 million miles) to 1.75 per 10,000 registered cars (1.7 per 100 million miles).[15] In other words, ***at worst*** reductions in vehicle size and weight reduced somewhat the fleet's overall improvement in safety during this period, and new standards might well do the same. Not surprisingly, this outcome can be interpreted in radically different ways: by proponents of more stringent standards as indicating that better fuel economy was achieved without compromising safety, in fact with substantially improved safety, and that this can be the case in the future; and by opponents as indicating that nearly two thousand lives per year that ***could have been saved*** were not, because of forced downsizing of the fleet,[16] and that, similarly, new standards will reduce our ability to improve the safety record in the future. Both viewpoints may be valid.

Third, all differences in safety between small and large cars do not seem irrevocable, as stated by some officials, but instead maybe amenable to correction. Safety technologies now entering the fleet, including airbags and antilock brakes, will work at least as well on small cars as on large ones, and will tend to decrease any safety "gap," measured in fatalities per 100 million miles, between the two. Also, some safety features may focus on problems specific to small cars. A major cause of fatalities in small cars appears to be a high propensity of these cars to roll over, as noted. OTA believes that design improvements should be available to ameliorate this problem and further reduce the safety gap between large and small vehicles.

Fourth, in determining the likely safety outcome of further fleet downsizing, it maybe incorrect to assume that all safety features incorporated into a downsized fleet would have been incorporated had no downsizing occurred. Under this assumption, new safety features don't really compensate for downsizing, since even more lives could be saved with the same features added to a fleet of larger vehicles. In the past, however, government rulemaking, consumer pressure, and automaker design decisions did not occur in isolation from changes in the actual safety situation. They occurred in response to perceived safety problems, not to some absolute safety standard. In other words, had the problems been less severe, fewer safety measures may have been taken. To the extent that future safety responses would be driven by problems emerging from future downsizing, the argument that safety would have been still greater without the downsizing may become, at least in part, disingenuous.

Opportunities to counteract any adverse impacts of new fuel economy standards may be prevented by lack of resources. According to the Transportation Research Board, Federal funding for highway safety research has been cut 40 percent since 1981—to only $35 million per year–despite the enormous cost in dollars and tragedy ($70 billion, 45,000 deaths, 4 million injuries per year) of traffic accidents. Additions to safety research and development resources could go a long way toward mitigating any negative consequences of future fleet downsizing.

We conclude that potential safety effects of fuel economy regulation will most likely be a concern if increases in fleet fuel economy are required over a period too short to allow substantial vehicle redesign–forcing manufacturers to try to sell a higher percentage of small cars of current design. In our view, significant improvements in fuel economy should be possible over the longer term—by 2001, for example—without compromising safety. Over this time period, there are opportunities to improve fuel economy without downsizing, as well as opportunities to redesign smaller cars to avoid some safety problems particular to them. However, the potential for safety problems will still exist, if automakers emphasize downsizing over technological options for achieving higher fuel economy and if they do not focus on solving problems such as increased rollover propensity in small cars of current design. If auto

[15]National Highway Traffic Safety Administration, "Fatal Accident Reporting System 1989," draft, table 1-2B. For all motor vehicles, death rates declined from 3.23 per 10,000 vehicles (3.4 per 100 million miles) to 2.38 per 10,000 vehicles (2.2 per 100 million vehicles), table 1-1.

[16]NHTSA, "The Effect of Car Size on Fatality and Injury Risk."

fatality rates would be lower without new fuel economy standards than with them—even if overall rates decline—then a real tradeoff between new standards and safety does exist and must be addressed explicitly during the fuel economy debate.

FUEL SAVINGS FROM S. 279

The magnitude of fuel savings likely from a new fuel economy standard is both a critical component of the decision calculus for the policy debate about standards and a source of great controversy because of large differences in estimates prepared by opposing interests. The source of these differences is the set of assumptions associated with each estimate. Critical assumptions affecting the magnitude of estimated savings include:

1. ***Fuel economy values without new standards.*** Alternative assumptions about the fuel economy of the new car fleet ***in the absence of new standards*** will play a critical role in estimating fuel savings associated with new standards. Factors affecting future fleet fuel economy include future oil prices and price expectations, fuel availability, consumer preferences for vehicle size and power, new safety and emissions standards, and progress in technology development. The span of credible assumptions about future fuel economy is likely to be quite wide, especially for the late 1990s and beyond.
2. ***Use of alternative fuel credits.*** Manufacturers can claim up to 1.2 mpg in CAFE credits by producing vehicles capable of using alternative fuels. Depending on whether automakers would produce large numbers of alternative fuel vehicles if there are no new fuel economy standards—both the Clean Air Act and new California emission standards provide incentives to do so–the actual fuel savings associated with new standards could be reduced.
3. ***Magnitude of a "rebound" in driving. An*** increase in fuel economy, by reducing "per mile" costs, may stimulate more driving and thus reduce the associated fuel savings. The magnitude of a "rebound" effect is controversial, with estimates ranging up to 30 percent of potential fuel savings lost to increased driving.
4. ***Magnitude of vmt growth.*** Small differences in the growth rate of vehicle miles traveled (vmt) can make a significant difference in the fuel savings estimated to occur from a new standard. In OTA's view, the credible range of future rates is fairly broad, perhaps from 1 percent per year to 3 percent per year, which translates into a variance of 1.3 mmbd in estimated fuel savings for S. 279 in the year 2010.
5. ***Effects of new standards on vehicle sales.*** Some opponents of new fuel economy standards have argued that stringent standards will have the effect of slowing vehicle sales (because of higher vehicle prices and reduced customer satisfaction with smaller, slower, less luxurious cars), reducing vehicle turnover and the positive effect this has on fleet fuel economy. Others consider the likelihood of a sales slowdown large enough to affect fleet fuel economy in a significant manner to be very small. Clearly, an effect on turnover is theoretically possible, and would be likely if policymakers were to miscalculate and set a standard beyond automakers' technical capabilities.

Different estimates of the likely fuel savings from S.279, which requires 20 percent (by 1996) and 40 percent (by 2001) improvements in each automakers fleet fuel economy levels, include:

- American Council for an Energy-Efficient Economy (ACEEE), for the Senate Commerce Committee: 2.5 mmbd by 2005.
- Department of Energy: 0.5 mmbd in 2001,1 mmbd by 2010.
- Congressional Budget Office:O.88 mmbdby 2006 and 1.21 mmbd by 2010 (base case); range of 0.45 to 1.42 mmbd by 2006 and 0.59 to 1.82 mmbd by 2010.

The differences among the above estimates can be readily understood by examining their assumptions. For example, ACEEE assumes that fuel economy levels will remain unchanged from today's in the absence of new standards, i.e., about 28.5 mpg for cars and about 21 mpg for light trucks. The Department of Energy has assumed that, without new standards, new vehicle fleet fuel economy will rise to about 33 mpg for cars and 24 mpg for light trucks by 2001, and remain at that level thereafter. CBO has chosen baseline mpg values of 30 mpg (range 28.5 to 33.0 mpg) for 2001. This difference in baseline mpg assumptions is the most important factor in accounting for differences among the estimates.

Similarly, DOE has chosen assumptions about alternative fuel credits, rebound effect, and vmt growth rate that will tend to yield lower estimated fuel savings than ACEEE, with CBO choosing assumptions somewhat in between. Much of the difference stems from DOE's assumptions of rising oil prices–$29/barrel (1990$) in 2000 and $39/barrel (1990$) in 2010.

OTA concludes that the DOE baseline estimate of 1 mmbd fuel savings from S.279 by 2010 is analytically correct but very conservative. Although none of its assumptions are extreme, virtually ***all*** push the final result towards a low value. In our view, the likelihood of such uniformity is small, although much less improbable if oil prices follow their assumed (upwards) path.

In contrast to the DOE estimate, the Bryan/ACEEE estimate of 2.5 mmbd by 2005 appears very optimistic because it discounts the potential for a driving "rebound" and, more importantly, accepts unusually pessimistic assumptions about likely fuel economy improvements in the absence of new standards.

Although the range of potential fuel savings from S. 279 is wide, OTA believes that the "most likely" value for year 2010 savings lies between 1.5 and 2 mmbd. For a 10 percent rebound effect, 2 percent/year vmt growth rate, baseline fuel economy of 32.9 mpg in 2001 (frozen for the next decade), and no accounting for alternative fuel vehicles, we calculate the fuel savings to be 1.64 mmbd in 2010. Although the 32.9 mpg baseline (no new standards) value is optimistic unless oil prices rise substantially, it is also likely that the automakers will gain some alternative fuel credits in the baseline; these two factors will tend to cancel one another.

Figure 1-1 displays the projected U.S. oil consumption over time with and without enactment of S.279. The figure also displays the consumption projected under OTA's "regulatory pressure" scenario.

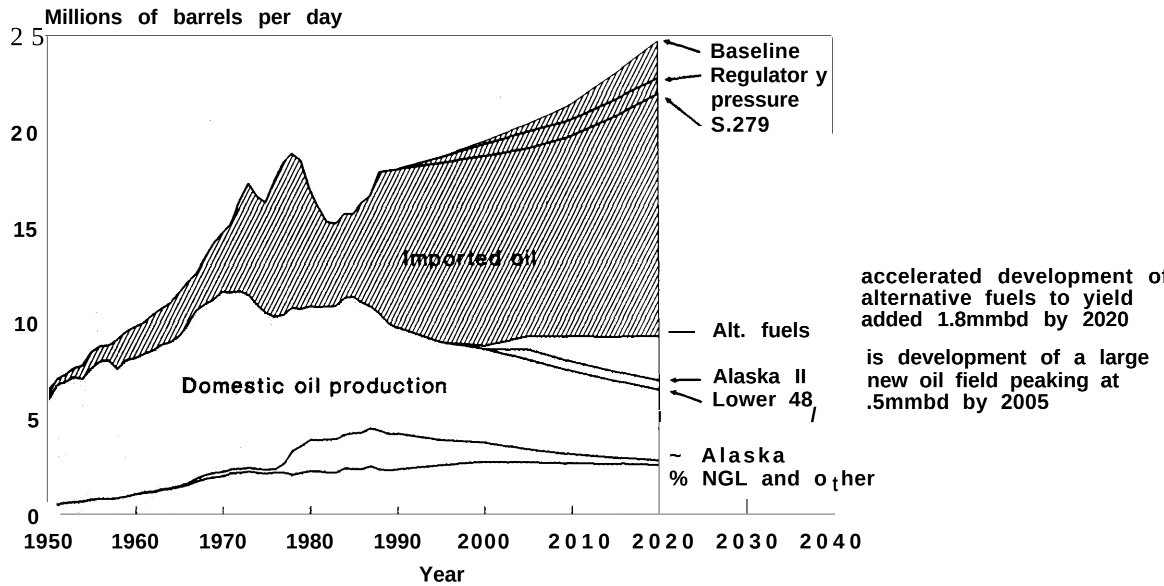
REGULATION OF LIGHT-TRUCK FUEL ECONOMY

Because light trucks make up a rapidly growing proportion of the passenger vehicle fleet, and consumers can readily find transportation alternatives to new cars in the light-duty truck fleet, fuel economy regulations must consider light trucks to assure an effective reduction in total fuel use. Proposed legislation generally recognizes this necessity and sets fuel economy standards for trucks similar to those for automobiles. For example, S.279 proposes that light trucks attain the same 20- and 40-percent fuel economy increases (by 1996 and 2001, respectively) as automobiles.

OTA concludes that currently available technology will not allow automakers to improve light-truck fuel economy to the same extent as they can improve passenger automobiles ***unless*** diesels become more popular in the 6,000- to 8,500-pound category of light trucks. Sources of fuel economy limitations include:

- load carrying requirements that impose structural and power needs that are more a function of payload weight than body weight of the truck—yielding fewer flow-through benefits from initial weight reduction;
- open cargo beds for pickups and large ground clearance that limit potential for aerodynamic improvements;
- need for low end torque, limiting benefits from four-valve engines; and

Figure 1-1 -U.S. Oil Consumption Under Alternate Scenarios-With or Without Higher Fuel Economy Standards



ASSUMPTIONS:
1 Baseline assumes no new policy measures, new car fuel economy reaches 329 mpg In 2001 and stays constant thereafter
2. S. 279 assumes new car fuel economy reaches 40 mpg by 2001 and 50 mpg by 2020,
3. Regulatory pressure assumes new car fuel economy reaches 35 mpg by 2001 and 45 mpg by 2020

SOURCE. Offlce of Technology Assessment, 1991

. likelihood of additional safety and emission requirements, with associated fuel economy penalties.

The use of all available technologies (except diesels in the smaller weight classes) regardless of cost could allow light-truck fleet fuel economy to improve from about 20 mpg to about 26 mpg by 2001.

A "uniform percentage increase" approach to regulating light-truck fuel economy is particularly problematic because of extreme differences in truck fleet composition among different automakers. A format based on truck attributes, similar in concept but not in details to automobile standards based on interior volume, might be preferable. Such standards would have to be individually tailored to truck types-undoubtedly an opportunity for considerable argument about which type each particular model falls into. As a point of departure for further study, appropriate standards might look as follows:

- ***passenger vans***—standards based on interior volume, probably measured somewhat differently than for automobiles;
- ***utility*** vehicles —standards based on passenger interior volume, with an mpg credit for rough-terrain capability; and
- ***pickup trucks and cargo*** vans—standards based on both volume and tonnage[17] of load carrying capacity (e.g., square or cubic foot-tons).

Given the growing importance of light trucks to overall fuel consumption, more attention needs to be paid to the problems associated with regulating these vehicles.

[17] We note, however, that measures of load carrying capacity would have to be carefully developed and monitored to avoid manipulation.