Developing a Market Creation Program to Promote Efficient Cars and Light Trucks

John M. DeCicco

August 1997

American Council for an Energy-Efficient Economy
1001 Connecticut Avenue NW, Suite 801, Washington, DC 20036

DeCicco, J.M.
Developing a Market Creation Program to Promote Efficient Cars and Light Trucks
Washington, DC: American Council for an Energy-Efficient Economy, August 1997.
Transportation Efficiency Program, Report T971

The American Council for an Energy-Efficient Economy (ACEEE) is a non-profit organization dedicated to advancing energy efficiency as a means of achieving both economic prosperity and environmental protection.

For a publications catalog and ordering information, please contact:
ACEEE Publications
1001 Connecticut Avenue NW, Suite 801
Washington, DC 20036
Phone 202-429-8873, Fax 202-429-2248
http://www.crest.org/aceee

Table of Contents

List of Tables

List of Figures

Developing a Market Creation Program to Promote Efficient Cars and Light Trucks

EXECUTIVE SUMMARY

Transforming the light vehicle (car and light truck) market toward greater fuel efficiency is a crucial step for addressing public concerns linked to rising transportation energy use, both in the United States and worldwide. Concerns range from the adverse economic and national security impacts of petroleum dependence and imports to environmental problems such as urban air pollution and greenhouse gas emissions. Research has been underway for many years to develop vehicles of greatly improved efficiency without compromising other vehicle attributes. In 1993, the U.S. government and domestic automakers announced a collaborative research and development (R&D) venture known as the Partnership for a New Generation of Vehicles (PNGV). This initiative is refocusing R&D efforts on a set of ambitious goals, including the development of prototypes having three times the fuel economy of today's cars.

To date, technologies that offer greatly improved vehicle efficiency have not progressed beyond R&D and into production, except in response to an energy crisis or as required by regulation. This paper explores the potential role for a market creation program ("Green Machine Challenge") emphasizing a voluntary, demand-based approach to accelerate commercialization of cars and light trucks having fuel efficiencies substantially higher than those typical today along with much lower emissions and comparable utility, safety, performance, and affordability. Market creation efforts are already underway to promote vehicles using alternative fuels, such as natural gas, alcohols, and electricity. Such efforts could be expanded to encourage a market for more efficient vehicles, particularly vehicles using technologies under development by the PNGV. Advanced technology efficient vehicles would face some of the barriers that face introduction of AFVs, but not the barriers related to the need for new fuel systems and infrastructure.

The first major section of this report (Section 2) examines the market and scale of vehicle production. Six vehicle classes dominate the light duty market in terms of fuel consumption share: compact, mid-size, and large cars, small vans, small utility vehicles, and large pickup trucks. Mid-size cars, on which the PNGV focuses, would be a first priority for market creation efforts. Small vans (minvans) would be a good second priority. Large cars or small utility (sport utility) vehicles could be considered if additional classes were to be targeted. In any case, fairly large numbers of vehicle purchases would have to be aggregated in the program in order to enable automakers to offer advanced vehicles without incurring high risks. A viable scale for a single vehicle type and one automaker appears to be 30,000 – 50,000 vehicles per year. The numbers would increase multifold if more than one automaker or more than one vehicle type were involved. For example, a program involving mid-size sedans and attempting to move advanced efficiency designs into production by three automakers, could require nationwide purchase commitments on the order of 100,000 – 150,000 vehicles per year.

Section 3 indicates that aggregating such numbers appears possible with fleet purchases not otherwise committed to AFVs. Greater reach could come from the general market, although the degree of buyer interest is uncertain and likely varies by market segment. Available preference survey results suggest that some significant share of the market could be captured by vehicles offering higher fuel economy at a higher vehicle price. However, such *stated* preferences do not appear to be influencing the current marketplace, where overall fuel economy has stagnated since the early 1980s. A promotional effort could help tap into the preferences for higher fuel efficiency that some buyers appear to have and convert them to sales in a way that is not happening under traditional marketing. Extrapolating from surveys of general consumer interest in "greener" products, and focusing on major vehicle classes, a program might ultimately be able to reach 3%–6% of the overall light duty market, or ½–1 million vehicles. A sustained and concerted promotional effort is likely to be needed to achieve such a participation rate.

Section 4 reviews the status of technologies that could be used to improve efficiency, both through refinements of conventional designs and by use of new, advanced designs. Best-in-class analyses indicate that modest levels of efficiency improvement (10%–15%) can be reached with vehicles currently offered. Best-in-class purchases could from the basis for a widespread, low-risk promotional effort for such vehicles, but may involve trade-offs of other vehicle attributes. However, of themselves, best-in-class guidelines are unlikely to pull advanced technologies into the market. Near-term conventional vehicle technology assessments suggest potential fuel efficiency improvements of 30%–80% depending on assumptions and timing. Costs of such improvements appear to be relatively modest, for example, with payback times well under vehicle lifetimes. Such assessments examine fleetwide potential, but also suggest that such degrees of improvement feasible within one product redesign cycle for a specific model.

Advanced technologies, including drivetrain types and body structures not yet in production, offer efficiency levels that are double or more than those of current vehicles. However, from the present vantage point, costs appear to be significantly higher, with payback times approaching or exceeding vehicle lifetimes. Thus, a prudent target for the first phase of a market creation program might be premised on efficiency-optimized applications of conventional vehicle technologies, to insure likelihood of automakers being able to meet the challenge, while encouraging introduction of more revolutionary technologies. If a program has more than one stage, with a latter stage requiring fuel economy levels beyond those achievable with conventional technologies, then automakers could be encourage to offer advanced technologies sooner in order to gain experience and stake a strategic claim on a future next-generation vehicle market.

Based on these considerations, we identify three primary elements of a potential "Green Machine Challenge" market creation program for efficient vehicles:

(1) A best-in-class vehicle purchasing initiative. This program element could start without delay, operate on an ongoing basis, and encourage both fleets and general buyers to select the most efficient vehicles that meet their needs. Costs would be relatively small, involving organizational and promotional efforts; vehicle incentives would not be needed.

(2) An advanced-technology test marketing program. This initiative would involve close coordination with automakers for limited, pilot introductions of vehicles incorporating various advanced technologies with selected buyers. Given higher costs and risks for both buyers and automakers, commercialization incentives would be desirable for this element of a program.

(3) A step-forward vehicle efficiency challenge. The effort would involve organizing an advance purchase aggregation, ranging from several tens of thousands and upward, of vehicles meeting specifications for high fuel economy and other attributes. The program would be announced several years in advance and automakers would compete to supply the vehicles. Incentives would be helpful but not essential for this program element.

Element (2) is prelude to (3), the step-forward program, which would be the most challenging aspect of the overall initiative.

Given leadership and supportive information, a best-in-class program could be pursued within the context of existing institutions and programs. On the other hand, a step-forward challenge involves greater risks for automakers as well as greater organizational hurdles. Therefore, a new entity, either independent or within an agency, is likely to be needed to carry it out. The step-forward challenge would involve obtaining memoranda of understanding or letters of intent for advance purchase of vehicles yet to be mass produced, and doing so in a way that is sufficiently convincing that automakers would meet the challenge. A test marketing program (item 2) would be less costly, since fewer vehicles (e.g., several hundred) would be involved, even though unit costs would still be high. Such a pilot effort would enhance the likely success of the step-forward challenge, since it would give both potential buyers and automakers some experience with designs that could be used to meet the challenge.

In addition to these primary elements, other supportive measures could be pursued by federal, state, and local governments and non-governmental organizations. It would be important to have a credible information on what types of vehicles should qualify for different aspects of the program and on the benefits (economic and environmental) of buying vehicles that qualify. Vehicles are already labeled for efficiency based on city and highway fuel economy estimates. Ideally, a higher profile "green" vehicle labeling system could be developed, authorized by a neutral third party that would allow special recognition for vehicles having substantially better than average efficiency along with other improvements in environmental performance.[1] States and regions may wish to offer special recognition or use privileges (e.g., preferential parking) for qualifying vehicles. Finally, financial incentives (rebates, tax credits, reduced registration fees, etc.) would clearly bolster the impact of any program. Although examining options for incentive-based efforts is beyond the scope of this report, we note that incentives amounting to $2500 per vehicle for a limited program of 150,000 vehicles per year would cost $375 million, a sum that could be raised by an oil import fee of just under 11¢/barrel, for example.

[1] In related work, ACEEE is developing a technology-neutral "green" vehicle rating system that could be used for consumer information and market creation program promotional efforts.

Potential Impacts of a Green Machine Challenge in a 2010 Time Frame			
	Lower bound for any impacts	Best-in-Class Program	Step-Forward Program
Number of vehicles involved	--	1.5–3 million	680,000
New Fleet MPG Improvement	0	1%–3%	2%
Petroleum Savings (10^3bbl/day)	0	63–126	38
GHG Reduction (MTc/yr)	0	3.6–7.2	2.2
Added Vehicle Costs (savings) (10^6\$/yr)	0	(3500)	480–3100
Savings in Fuel Costs (10^6\$/yr)	0	1200–2400	700

New fleet fuel economy (MPG) improvements are relative to the recent overall light duty vehicle average of 25 mpg. Petroleum savings are in thousand barrels (10^3bbl) per day and greenhouse gas (GHG) emissions reductions are in million metric tons of carbon-equivalent (MTc) per year; cost estimates are in 1995$.

The direct impacts of any of the elements of a Green Machine Challenge would be small in the context of overall national energy use and greenhouse gas emissions. Like R&D, a market creation effort cannot by itself be counted on to yield a widespread transformation of the market to vehicles of substantially higher efficiency. However, a market creation effort would increase the probability that R&D efforts will pay off and it could lower the risks to automakers for developing and investing in advanced technologies needed to meet more directed initiatives such as regulations or widespread incentives. Stronger CAFE standards, or equivalent regulatory pressures linked to vehicle CO_2 emissions, would be needed to ensure significant fleetwide fuel economy improvements.

Given the caveat that one cannot reliably project benefits from a program such as this, plausible scenarios can illustrate the possible impacts of a Green Machine Challenge. Our range of estimates is summarized in the adjoining table. We give a lower bound of zero impacts for all cases to emphasize the preceding point and in light of current policies (including the CAFE standards constraint) and market trends which are running strongly counter to energy efficiency improvement.

A best-in-class program would have small impacts, inducing fleetwide fuel economy increases of no more than 1%–3% through 2010. Because of the small number of vehicles initially involved, a step-forward challenge would have fleetwide fuel economy impacts of no more than 2% through 2010. However, as years go on, much larger impacts can be foreseen if a combination of R&D, market creation efforts, and supportive regulatory and incentive measures result in widespread acceptance of next-generation vehicles. A hypothetical range of impacts is for a 35%–67% fleetwide fuel economy improvement by 2030 (not shown above), although one could not reliably attribute such progress to market creation efforts alone. By 2010, the corresponding GHG emissions reductions range up to 7 MTc (million metric tons of carbon-equivalent) for the best-in-class program and about 2 MTc for the step-forward program.

Cost estimation is also highly uncertain. A best-in-class program could result in savings to purchasers due to the trade-off of other features for higher efficiency. The vehicle purchase price savings could amount to $3.5 billion for a program of the scale; however, depending on manufacturer responses, the savings could be zero. A step-forward program would surely involve added vehicle costs, but the range is wide, from $700 to $4600 per vehicle depending on the technologies used to meet the challenge. The result is a wide range of added costs, from $480 million to $3.1 billion in 2010. Fuel cost savings would be $1.2–$2.4 billion for the best-in-class program and $700 million for the step-forward challenge, based on the illustrative scenarios summarized in the table shown above.

The potential value of a Green Machine Challenge should not, however, be evaluated only on the basis of impact estimates for even an ambitious program such as that outlined here. A market creation initiative is but one component of a broader market transformation strategy for motor vehicles. Other steps include R&D as well as regulatory measures such as CAFE standards and various incentive programs that could be devised. Working together, such an array of policies could have enormous impact, leading to widespread adoption of new-generation vehicle technologies that could go a long way toward mitigating the fuel consumption related problems of cars and light trucks. A Green Machine Challenge could cultivate a new sensibility of "green" buying in the automotive marketplace and create a market pull for advanced technologies, beyond those likely to be required even by renewed regulatory approaches. Thus, such a program could begin to engage competitive forces in the service of environmental goals. The resulting change in attitudes about what is valued in a vehicle, by both automakers and consumers, would be profound, and could prove to be a crucial turning point down a road that leads to an environmentally sustainable transportation system for generations to come.

ACKNOWLEDGEMENTS

The author is grateful for review comments provided by Carmen Difiglio, Barry McNutt, Steve Nadel, David Rodgers, Marc Ross, and Martin Thomas. Work on this report was principally supported by the U.S. Department of Energy under a subcontract with Lawrence Berkeley National Laboratory; additional support was provided under grants from the U.S. Environmental Protection Agency and the Energy Foundation. The author assumes full responsibility for the results and recommendations presented.

1. INTRODUCTION

A number of public concerns motivate the need for higher motor vehicle efficiency, particularly for light duty vehicles (cars and light trucks), which account for nearly 60% of U.S. transportation energy use. The benefits of higher fuel efficiency would include reduced oil use (lessening pressures on this import-dependent market), reduced air pollution, and reduced greenhouse gas emissions.

Light duty vehicles saw substantial efficiency improvements from 1973-82, with new fleet fuel economy rising 80% in just 9 years. These efficiency improvements were motivated by the energy crises and oil price rises of the 1970s as well as by the Corporate Average Fuel Economy (CAFE) standards established in response to the energy crises. The new light duty fleet average efficiency continued to slowly improve through the mid-1980s, peaking at 25.9 mpg in model years 1987-88, just after oil prices fell (Heavenrich and Hellman 1996). Subsequently, new vehicle fuel economy has essentially stagnated, averaging just above the CAFE standards, currently 27.5 mpg for cars and 20.7 mpg for light trucks (NHTSA 1996). The fleet average has declined somewhat due to the increased market share of vehicles classified as light trucks and held to a lower CAFE standard, with the most recent new fleet average being 24.6 mpg (1994-96), about 5% lower than the 1987-88 peak. Given current and expected market conditions, no significant improvement appears to be in sight.

Although many of the motives for public action to improve efficiency are long standing, global warming provides new sense of urgency. Anthropogenic greenhouse gas (GHG) emissions are causing a warming of the earth's lower atmosphere, creating risks of climate disruption and adverse ecologic and economic impacts (IPCC 1996). The United States issued a Climate Change Action Plan (CCAP 1993) to return GHG emissions to the 1990 level by 2000 and establish a declining emissions trend thereafter. Although transportation accounts for one-third of U.S. greenhouse gas emissions and is the most rapidly growing sector, transportation actions accounted for only 12% of the reductions identified in the Climate Plan. The Clinton Administration acknowledged the need for additional policies and chartered a Federal Advisory Committee to develop recommendations for returning U.S. car and light truck GHG emissions to their 1990 level by some future year (Resolve 1995). Informally dubbed "Car Talk," this Committee terminated without reaching consensus in late 1995. Many options were discussed, covering measures to reduce travel demand and switch to lower-carbon fuels as well as to improve fuel efficiency. The Majority Report (1995) issued by 17 of the 30 committee members did present recommendations for returning light vehicle GHG emissions to the 1990 level as soon as 2005. Stronger CAFE standards figured prominently among the recommendations, which also included a market creation program for promoting efficient vehicles.

A number of policy options for improving vehicle efficiency have been identified and explored in recent years (Ross et al. 1991; OTA 1994; Majority Report 1995; DOE 1996b). Options include: regulatory measures, such as stronger CAFE standards, variants based on other vehicle attributes, or a marketable permit scheme; vehicle pricing measures, such as gas guzzler taxes and expansions thereof, including fee and rebate ("feebate") systems linked to fuel economy; fuel pricing measures, such as higher gasoline taxes; government-supported research and development (R&D); and market creation efforts. Most analysts and observers of the issue, including the Car

Talk majority, concur that no one option is a "silver bullet" that will solve environmental problems related to vehicle use. Rather, an effective strategy should incorporate a set of mutually reinforcing measures that motivate both automakers and consumers to make choices that result in adoption of progressively "greener" vehicles.

A market creation program, which could involve coordinated procurement by fleets and other interested parties and a competition among automakers for introducing advanced-technology efficient vehicle designs, is the subject of this report. Such a program has been among the policies recommended by environmental and conservation organizations for a number of years (e.g., Sustainable Energy Blueprint 1992). The American Council for an Energy-Efficient Economy (ACEEE) highlighted a "Green Machine Challenge" as a recommended option for the climate action plan (DeCicco 1993). In an earlier phase of the project leading to this report, ACEEE completed a concept paper that further described the policy context and outlined the general elements of a market creation program for efficient vehicles (DeCicco and deLaski 1995).

Although automakers have historically resisted policy interventions in the vehicle market, they have more recently come to acknowledge the need to cooperate with the public sector in developing new technological solutions to the problems related to rising motor vehicle energy consumption. In September 1993, U.S. automakers (Chrysler, Ford, and General Motors) joined the Clinton Administration in announcing a major R&D initiative, called the Partnership for a New Generation of Vehicles (PNGV). The PNGV is a joint agreement for public/private research and development efforts involving the Departments of Commerce, Defense, and Energy, the Environmental Protection Agency, and the national laboratories with the "Big 3" automakers, suppliers, and other technology firms. The Partnership has three main development goals (PNGV 1995):

(1) improved automotive manufacturing methods;

(2) technologies for near-term efficiency and environmental improvements; and

(3) prototypes of "new generation" vehicles having a fuel economy three times that of today's vehicles while maintaining safety, utility and affordability.

Because the PNGV is strictly an R&D initiative, it does not provide a mechanism to help pull advanced technologies it might develop into the marketplace so as to provide measurable energy efficiency and environmental benefits.

Although R&D is an important enabling measure, the inherent weakness of market forces for addressing what are fundamentally non-market problems makes it doubtful that widespread adoption of substantially more efficient vehicle designs will occur without other interventions. On the other hand, traditional interventions such as CAFE standards, or even a gas guzzler tax expanded into a feebate program, may not be sufficient for inducing more than incremental changes in technology. Moreover, these options have been difficult to pursue in a political climate which looks askance at new regulation or taxation. Such limitations suggest a role for a special program to create an initial market for advanced vehicle technologies, which could pave the way for their introduction to the broader market. Nevertheless, just as R&D has limited reach, past experience does not support the notion that a market creation initiative could replace regulation as a means of inducing higher vehicle efficiency throughout the fleet.

A "Green Machine Challenge" can also be rationalized within a "market transformation" paradigm. DeCicco and deLaski (1995) listed the elements of a market transformation strategy for efficient vehicles, drawing on the experience in other sectors, wherein the technology "push" of R&D can be valuably complemented by technology "pull" measures such as coordinated procurement, incentives, and traditional regulatory measures. Among such measures, coordinated procurement activities can play a strategic role by organizing future-oriented buyers who are willing to specify challenging product performance requirements that can entice manufacturers to commercialize innovative technologies (see Westling 1996, who presents an overview of cooperative procurement actions for energy-efficient appliances and equipment). A market transformation paradigm is also implicit in the strategy being pursued for introducing alternative fuels into the transportation sector, a process which to date is relying heavily on market creation and incentive efforts.

This report assembles available quantitative information relating to the structure of the light vehicle market, consumer preferences, production scales, and technology options as needed to develop preliminary design recommendations for an efficient vehicle market creation program. Following this introduction, the material is organized in four major sections covering market overview, potential participants, technology assessment, costs, and program design recommendations. Although most published fuel economy assessments (covering both advanced and conventional technologies) focus on passenger cars, and mid-size cars are the focus of the PNGV, vehicles classified as light trucks are a major part of the market and are expected to account for half of all light duty fuel use in the coming years. Therefore, we engaged a consultant to analyze the light truck market and its fuel economy characteristics; results of that work are provided in an adjunct report (Murrell 1995) on which we draw throughout the discussions here.

The next section of this report analyzes the light vehicle market to identify vehicle classes that would be appropriate targets of a market creation program and identifies current production scales for major classes. Since fleets (groups of vehicles under common ownership or management) are an important pathway for introducing new vehicles, we then examine the structure of the fleet market and its relation to vehicle classes that might be considered in a program. Because efforts to introduce alternative fuels focus on fleets, we also analyze the extent to which efficient vehicle introductions might be feasible at the same time as alternative fuel options are being pursued. Section 4 of the report investigates the likely availability of technologies for improved efficiency, based mainly on a review of previous fuel economy assessments, in order to develop potential target efficiency levels for a market creation program. Finally, we lay out a set of options for structuring a market creation program, address questions related to costs, benefits, and other impacts of a program if implemented, and provide suggestions for next steps if a program is to be pursued.

2. MARKET OVERVIEW

The ultimate goal of a market creation program is to pave the way for eventual widespread sales of ultra-efficient vehicles in the mass market. Therefore, the initial buyer pools at which a program aims should show a clear connection to larger portions of the market which are likely to have influence on the overall direction of the car and light truck market. We can think of the market transformation process as a way to link niche or early-adopter, "bottom up" aspects of the market to an aggregate market outcome. The latter is the overall sales outcome, the sum of all segments of the market. The bottom-up view reveals the segments, by vehicle type and buyer type, on which a market creation program should focus. A successful program would work up from the bottom to create a new, efficiency-oriented market base and then expand through increasing market shares, leading to a broad influence in the long-term.

Market Scale and Volume Production

An overview of the automotive market confronts one with the large scale of production which must be influenced it a program to be effective. Recalling that the objective is market transformation, not just technology demonstration, the number of vehicle purchases influenced must be sufficient to induce automakers to make product development investments (as opposed to only research and technology development investments). Although technology R&D feeds into product development, the latter is a far greater financial commitment, since it involves investments in plants, tooling, and supplier arrangements. The U.S. light vehicle market runs at 12-15 million cars and light trucks per year. Year-to-year fluctuations depend largely on the state of the economy—indeed, new vehicle sales are commonly tracked and reported to indicate the health of the economy. As a mature market, long-term growth in overall volume is slow. In fact, for the past two decades average U.S. auto market growth has lagged population growth due to lengthening vehicle lifetimes. (Recent projections of future sales are reviewed below.) Practically speaking, widespread marketing of an ultra-efficient vehicle would probably involve conversion or partial conversion of an existing automotive production plant. Examining the current production capacity provides guidance on the number of vehicles needed for a demand pool that could justify investments of this scale.

Automotive News (1994) tabulates car and truck production levels and plant capacities. Figure 2-1 shows the distribution of annual production capacity for U.S. and Canadian automobile plants. The average capacity is 211,000 cars per year, with the vast majority of plants having capacities in the range of 200,000 - 300,000 units per year. Only seven plants have annual capacities as small as roughly 100,000 units or less. The smallest line in 1993 was for Chrysler's Dodge Viper, with a rated capacity of 11,300 units, although less than 2,000 were produced in 1993. Manufacturers generally build several variants of a model on a given production line.

The common denominator for automobile production is the vehicle platform, which refers to an integrated design including a common chassis and compatible sets of drivetrain components. Different wheelbases and body styles can be built on a single platform. More than one platform might be produced at a given plant. On the other hand, a given platform may be produced at several plants. For example, Ford's Taurus/Sable models are produced in two locations (Chicago and Atlanta), each with nominal capacities of 250,000 units/year. Strong sales years can have

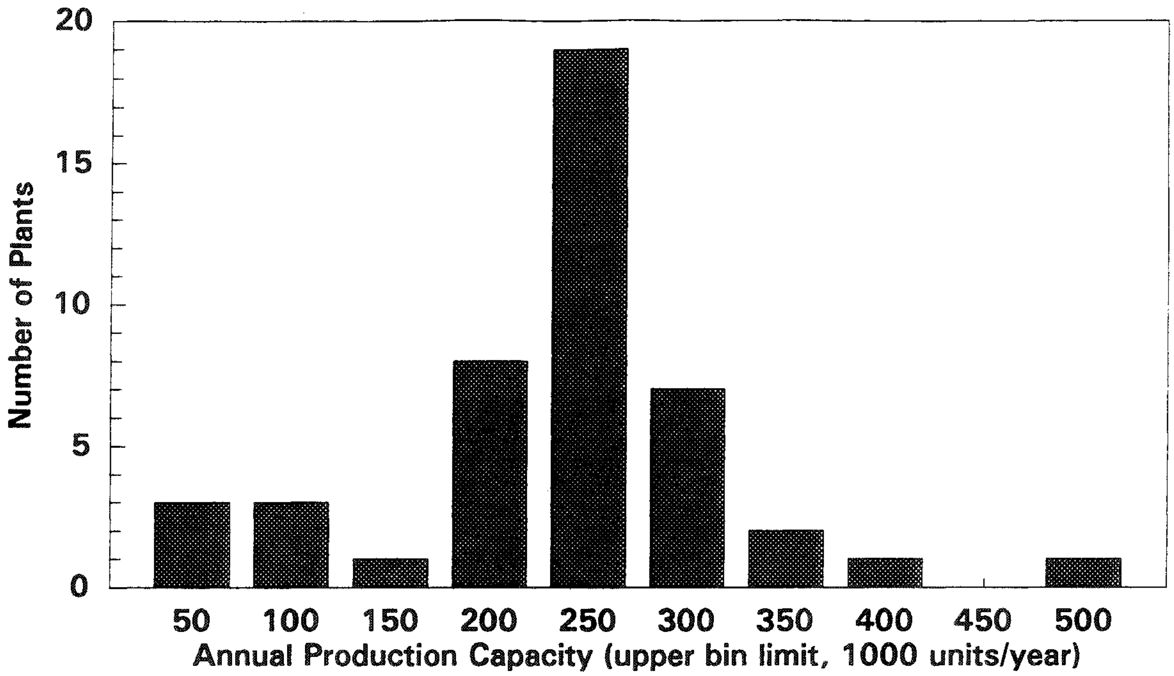

Figure 2-1. Production Capacities of North American Automobile Plants in 1993

Source: derived from *Automotive News* (1994).

annual production figures higher than nominal plant capacity, e.g., due to use of overtime. In fact, platforms may span continents, and the trend has been toward automakers consolidating designs to share parts and cut development costs. Currently, the Toyota Corolla platform accounts for roughly one million vehicles, built mainly in Japan and the United States. It is likely that as many as seven platforms of the million-unit scale will exist worldwide by the year 2000 (Chew 1996). This trend toward larger platforms would tend to raise the threshold for the numbers of advanced vehicles needed for a market creation program, unless they are introduced in specialty segments (such as luxury or sports cars) that can bear higher prices. In such segments, however, consumers typically have less than average interest in fuel efficiency.

Some automakers have had success with speciality vehicles developed to be profitable at relatively low volumes but carrying modest (non-luxury) prices. For example, the Mazda Miata, priced at $18,000 - $22,000, has been profitable at volumes of 20,000 - 30,000 vehicles per year (U.S. sales). In recent years, Japanese automakers put a high premium on productivity and development cost savings, due to trade pressures as the exchange rate fell below 100 yen/$. According to Johnson (1994), Toyota's RAV4 sport utility was designed to be profitable at a production volume of 2,000/month (24,000/yr). It was developed in 28 months, including 15 months from prototype to production. The RAV4 used an existing 2.0*l* engine, but otherwise, had 60% new parts, and followed a design philosophy emphasizing simplified assembly rather than automation. It is notable that the RAV4 was chosen by Toyota as the platform for its first electric vehicle in the U.S. market. Thus, a new design targeted by a market creation program could be viable at several tens of thousands per year if it involves both energy-efficient technologies (perhaps including new structural materials) and highly efficient manufacturing.

Different engine and transmission combinations can be used on a platform, as well as different body styles (coupe and 4-door, pickup truck and sport utility, etc.). Nevertheless, the variations must be compatible in terms of assembly procedures so that production efficiency can be optimized. Using the 1993 statistics for Chyrsler's LH platform, for example, one plant produced 256,000 vehicles, breaking down roughly as 90,000 Intrepids, 80,000 Concordes, 53,000 New Yorkers, and 33,000 Eagle Visions. Among these models, moreover, were a number of drivetrain and body type variants. Thus, if a "green" variant can be designed which can still utilize much of a platform's parts and tooling, it could be produced on an existing line without major disruption and at relatively modest cost impact.

Conversations with industry representatives indicated some of the considerations that would arise in attempting to introduce a new technology offering significantly better environmental performance into product plans. A fundamental issue is the degree of departure from a platform, particularly if the production facility has been optimized for a relatively limited range of variants. If the new vehicle requirements represents a radical shift from the designs for which a platform was optimized, then a massive new investment could be entailed. On the other hand, if the new design is within the range of flexibility designed into the line, e.g., if basic welding tools can be used, then variants on the order of "several tens of thousands of vehicles" can be "competitively" produced (meaning, with price impacts within the typical range seen for various configurations of a model). One industry representative noted 30,000 – 50,000 vehicles as a viable number for production of a specialized variant on a major production line. Numbers in this range are also consistent with the lower production levels of model variants built on a common platform. Of course, viable scale also depends on a model's price segment. Large volumes are needed for lower priced vehicles, for which margins are slim. Smaller volumes can be tolerated on higher priced vehicles; luxury models can be profitable at relatively small volumes.

Another issue arising when considering the possibilities for introducing a "step-forward" green vehicle is the need to balance manpower resources within a plant. If a variant involves assembly steps that are more labor intensive than the rest of the configurations on the line, then the required intervals of extra labor needed are difficult to manage. An example is early introduction of anti-lock braking systems (ABS). Only a subset of the production was to get ABS, and installing the ABS involved significantly more labor time than required for the rest of the models. When different assembly modes, involving more complex steps, periodically come down the line, it is difficult to keep the workers balanced in terms of level of effort. It might be handled through clever planning or perhaps utilizing supervisors for the periodic specialized tasks. In any case, the result can be that the specialized assembly need can be accommodated, but will entail a disproportionately greater cost due to the resulting imbalance in overall production. Situations of this sort have arisen when handling limited production of AFVs. For example, it may be possible to handle CNG tank installation with minimal disruption using programmable robotic assistance. However, the extra leak checking required for the CNG fuel system requires specialized labor; this periodic manpower requirement for quality control can be more difficult to handle than the components installation.

Major Vehicles Classes

Table 2-1 summarizes the fuel economy of the light duty vehicle market by major vehicle class (derived from Murrell et al. 1993). From an energy use perspective, the impact of the market is captured by the sales-weighted average light duty vehicle fuel economy, which since model year 1981 has been 25 ($\pm$1) mpg (EPA composite test value; accounting for shortfall,[2] average on-road fuel economy is closer to 20 mpg). Clearly, influencing this outcome means incorporating more efficient technologies and designs into all of the major market classes. Vehicles classified as light trucks (including pickups, minivans, and sport-utility vehicles) have comprised a growing share of the overall market. The light truck share rose from 19% in 1975 to 34% by 1993 (the principal year used for statistics in this report) and has continued to rise, reaching 40% as of 1996 (Heavenrich and Hellman 1996). Given their lower average fuel economy (26% lower than cars in 1993, compared to 13% lower in 1975), light trucks account for a disproportionate share of fuel consumption and emissions. As shown in the table, 1993 light trucks account for 41% of overall model year 1993 fuel use; for model year 1996, the expected light truck fuel use share is 51%.

The PNGV targets mid-size cars, which have a current average fuel economy of 26 mpg. The PNGV long-term goal is for tripling the fuel economy of a mid-size car without compromising other desirable consumer attributes, while meeting future safety and emissions standards, and maintaining affordability. Ultimately, similar degrees of efficiency improvement would be applicable throughout the light duty fleet, since the basic physics of energy use is similar for all light duty vehicles (as opposed to heavy trucks, which have much higher payload weight ratios). The representative vehicles being discussed and analyzed for the PNGV are the GM Chevrolet Lumina, Ford Taurus, and Chrysler Concorde, which had 1993 nameplate average fuel economies in the 25-27 mpg range. (The Concorde is technically a large car based on EPA's interior volume classification scheme.) Clearly, because they are the focus of the PNGV and their market importance, mid-size cars should be one focus of a market creation program.

Table 2-1 also lists estimated fuel use shares by vehicle class. As noted above, a lower-than-average fuel economy results in a higher fuel use share for a vehicle class relative to other classes. Thus, with a 13.7% sales share, large pickup trucks have the highest fuel use share (17.2% in 1993). This class includes top-selling vehicles such as the Ford F150 and Chevy/GMC C1500 models. Minivans, which grew in popularity through the 1980s and remain popular today, fall into the small van class, with a 8.9% fuel share in 1993. In recent years, the popularity of sport utility vehicles has pushed the small utility class up to a 6.2% market share and a 7.4% fuel use share. The fuel use shares shown in Table 2-1 assume that cars and light trucks are driven equal average distances. Historically, light trucks have shown higher mileage patterns as well as longer vehicle lifetimes. Statistics in Davis (1995), for example, suggest that average annual light truck vehicle miles of travel (VMT) is 25% higher than average annual passenger car VMT. It is unclear whether this difference in usage will persist as light trucks displace cars. On the other hand, some light trucks appear to have worse fuel economy shortfall than cars (Mintz et al. 1993).

[2] Shortfall refers to the discrepancy between fuel economy (MPG) measured on EPA's standardized laboratory tests and the lower MPG observed in average real-world driving (EPA 1980). A 15% adjustment is the average used in the *Gas Mileage Guide* but recent estimates (e.g., Mintz et al. 1993) are somewhat higher for cars (about 18%) and significantly higher for some light trucks (over 20%).

Table 2-1.	U.S. Light Vehicle Sales and Characteristics by Size Class in 1993					
Vehicle Class	Sales (1000s)	Sales share	MPG	Fuel share	Example models	MPG
Small Cars	2,564	18.5%	31.3	14.8%	GM Saturn Coupe	34
Compact Cars	2,745	19.9%	29.5	16.8%	GM Chevrolet Corsica	29
Mid-size Cars	2,338	16.9%	26.0	16.3%	Ford Taurus	27
Large Cars	1,451	10.5%	24.3	10.8%	Ford Crown Victoria	24
Small Pickup	328	2.4%	25.4	2.3%	GM Chevrolet S10	25
Large Pickup	1,893	13.7%	19.9	17.2%	Ford F150	19
Small Van	1,121	8.1%	22.9	8.9%	Chrysler Dodge Caravan	24
Large Van	241	1.7%	17.8	2.5%	GM Chevrolet Sportvan	18
Small Utility	854	6.2%	21.0	7.4%	Chrysler Cherokee 4wd	20
Large Utility	290	2.1%	17.6	3.0%	GM Suburban 2wd	17
Sum/Average	**13,825**	**100.0%**	**25.0**	**100.0%**		
Cars	9,098	65.8%	28.0	58.8%		
Light Trucks	4,727	34.2%	20.8	41.2%		

Notes:

Fuel economy (MPG) is EPA composite test average (55% city, 45% highway), unadjusted for shortfall.

Small cars include two-seaters, minicompacts, subcompacts, and small wagons;
mid-size and large cars include respectively sized wagons.

Fuel use shares are calculated only on the basis of relative fuel economy and sales share, without adjustments for possible differences in fuel economy shortfall and average distance driven.

Source: derived from Murrell et al. (1993).

Murrell (1995) includes a mileage-adjusted tabulation of fuel use shares by vehicle class. Considering both lower rated fuel economy and higher distance driven, expected fuel use shares reach 19.6% for large pickups, 10.1% for small vans, and 8.4% for small utility vehicles. Conversely, fuel use shares drop to 15.2% for compact cars and 13.9% for mid-size cars.

From an energy conservation perspective, the classes accounting for largest shares of fuel use should be targeted for a market creation program. Although mid-size cars do not have the largest share of fuel use, they do have a substantial share (16.3%, or third highest as reckoned in Table 2-1). As noted earlier, they are the focus of the PNGV, and so if a program is to focus on just one vehicle class, it would be mid-size cars. Also, their middle-of-the-range load characteristics make mid-size cars an appropriate class for launching a program that could eventually include multiple classes.

Large cars might also be considered for a green machine challenge. Large cars are often used as taxicabs, typically in urban settings already burdened by air pollution and involving congestion, stop-and-go driving, idle time—factors which are particularly amenable to energy savings from advanced designs using an electric drivetrain and regenerative braking. The greater components packaging space afforded by a large car would also be attractive for early commercial introductions of new technologies. (Some recent natural gas vehicle introductions have included large cars for this reason.) As for light trucks, the lower fuel economy of large cars implies a greater energy savings and GHG emissions reduction from a given percentage improvement in MPG.

Compacts and subcompacts are generally more fuel efficient than average and so make less attractive targets from a technical point of view. On the other hand, these segments already attract buyers who value efficiency, and so improved efficiency compacts may be easier to promote than improved efficiency large cars. As a class, compact cars have outsold mid-size cars for some time, with a 20% market share in 1993 compared to 17% for mid-size cars. Moreover, smaller cars are an important segment for the global market, so stimulating the development of ultra-efficient compacts may be attractive for reasons of competitiveness.

The substantial fuel use share of light trucks suggests that a second target should be one of those classes. As shown in Table 2-1, large pickups are the largest vehicle class according to sales and fuel use. However, traditional uses of pickups as well as the traditional buyer tastes in this class suggest that it might be a difficult target for a voluntary "buy green" initiative. Moreover, the growth factor behind the doubling of overall light truck market share over the past two decades was not sales of full size pickups. In fact, until 1993, new large pickup sales volumes were well below the 1.8 million unit annual average sold in 1976-79, which was just recently exceeded by the 2 million unit per year average of 1994-96 (Heavenrich and Hellman 1996).

The first major growth factor behind the rising prominence of light truck classes was the minivan. The small van class was negligible (well under 1% sales share) before 1984, when Chrysler introduced its first minivans. The small van share has since grown rapidly, with annual volumes averaging 1.2 million in the past five years (an 8.1% sales share in 1993). Average minivan MPG was 12% lower than that of mid-size cars in 1993. Minivans are family-oriented vehicles, and so their purchasers should have at least average concern for the environment. Minivan designs are in some ways converging toward car designs (for example, GM recently replaced its truck chassis based minivans with new designs using unibody construction), and would offer packaging flexibility for new drivetrain components. Thus, minivans may make a good second choice for inclusion in market creation efforts.

The second growth factor has been the sport utility vehicle. The EPA small utility class had a roughly 1% market share prior to 1983, but its share had grown to 8% by 1995, with average annual volumes of 1.1 million in 1993-96. This class includes what are commonly considered to be medium sport "utes," such as the Jeep Cherokee, Ford Explorer, and Chevy Blazer, as well as truly small sport utes such as the Geo Tracker, Suzuki Sidekick, and Toyota RAV4. The large utility class, with models such as the Chevy Suburban and Ford Expedition, has seen a more recent sales surge; its market share reached 5% in 1996. Large sport utes are commonly built on a full size pickup truck platform, although there are some are unique models such as the Range Rover. The medium sized vehicles in the EPA small utility class often share a common platform with compact pickup trucks and the combined market share of these two classes has averaged 11% in recent years. Sport utility vehicles have appeal for their "outdoorsy" style, and it seems plausible that many of their buyers might have better than average concern for the environment, even though they may be unaware of sport utility vehicles' below average environmental performance and apparently have little concern for fuel economy. Furthermore, given their below average fuel economy and lower than average use of available technologies for efficiency (Murrell 1995), sport utilities are likely to offer a relatively greater opportunity for energy savings through application of new technologies.

Based on these considerations, the target classes for a market creation program would be, in order: mid-size cars, minivans, large cars (perhaps for a taxi fleet focus), compacts (because of more likely buyer interest and their importance in the global market), sport utilities, and large pickup trucks. These six classes account for roughly 75% of light duty sales. For the technology discussion (Section 4, below), we develop estimates for these six major classes under various technology advancement assumptions, so that any of them can be considered for inclusion in a market creation program. Station wagons, for which EPA has three classes (small, mid-size, and large), are typically built on similarly sized car platforms (they are counted with their corresponding car classes in Table 2-1). Thus, they need not be separately addressed in a program; a successfully introduced efficient car design could be readily built with a station wagon body as its market expands. In any case, station wagons' market shares have greatly diminished because many automakers have created vehicles of similar function in the minivan or sport utility classes (which is yet another reason why minivans would be a good second choice for program efforts).

Section Summary

Mass production of automobiles and light trucks based on current designs involves substantial economies of scale. Typical assembly plant production volumes amount to 200,000 units per year. Mass-market vehicle platforms often greatly exceed that volume, with vehicles sharing common chassis and drivetrain features being built at multiple plants. In some market segments, particularly lower and mid-cost sedans for which consumer concern for efficiency is highest, the trend is toward even higher production volume platforms. On the other hand, a given line can produce variants of a model in the range of 30,000 - 50,000 vehicles per year. Thus, if an introductory design of a vehicle using next-generation technologies can be made compatible with an existing platform, it could be offered without incurring a severe additional costs.

Six light duty vehicle classes dominate in terms of market importance for fuel consumption: compact, mid-size, and large cars, small vans, small utility vehicles, and large pickups. The fact that the mid-size car class is targeted by the PNGV (linked to the rationale that technologies developed for it can be readily scaled up or down for use in other classes) makes it the first choice for a market creation effort. Several options exist for other choices. Minivans may be a good second choice, since they are the most car-like of the light truck segments, with their buyer interest in efficiency likely to be higher than for other light trucks, and because they have relatively low fuel economies compared to cars.

3. POTENTIAL PARTICIPANTS

The participants which a market creation program could recruit include a variety of new vehicle buyers. A program might involve federal, state and local governments; businesses and other institutions operating their own vehicle fleets; vehicle leasing and rental firms; private buyer pools that might be created through civic or environmental organizations, as well as private individuals interested in acquiring a "green machine." In contrast to market creation efforts for AFVs, a program oriented toward vehicles that are generically cleaner and more efficient, perhaps including AFVs but also allowing gasoline vehicles, need not be limited to centrally fueled fleets. Thus, the potential scope of participation is quite large; the question becomes one of how many and which buyers from any segment of the overall light vehicle market would be sufficiently interested to participate. Answering this question is difficult and the type of survey research which might provide some quantitative guidance is beyond the scope of this study. On the other hand, fleet buyers can form an important core of a efficient vehicle market creation program. Surveys of the fleet market do exist and so examining these statistics provides information on an important subset of potential program participants.

Commercialization of AFVs faces a number of market barriers which are unlikely to be surmounted without a concerted strategy (McNutt 1989). Market introduction programs for AFVs have focused on fleets for several reasons. Clearly important for early introductions of AFVs are fleets with an availability of central refueling facilities. Fleets have other advantages, in addition to central fueling capability, that make them an important transition path for greener vehicles generally. These advantages include fleets' relatively large share of the new vehicle market, bulk purchasing ability, their relatively fast mileage accumulation and turnover rates, as well as central management, maintenance, record keeping, and other organizational resources. Moreover, government fleets can form an important core of a program, since the public can expect government leadership in advancing public goals ("do as we do") and since government fleets collectively large purchasing power can be an important force for innovation and product improvement (Lewis and Weltman 1992; Westling 1996).

An overview of fleet vehicles in use in the United States is given by Miaou et al. (1992), whose analysis was oriented to exploring the fleet market potential for AFVs. Miaou et al. note that different definitions are possible for what constitutes a fleet. A functionally important characteristic is that fleet vehicles are for non-personal use and operated under some type of unified control (e.g., by a business, government agency, or other institution). Fleet vehicles are also likely to be purchased in bulk. Available statistics, however, are generally based on a numerical definition, such as purchase or operation in groups of at least 4 vehicles or at least 10 vehicles. The latter, 10-vehicle threshold is used by key sources such as the *Automotive Fleet Fact Book* issued annually by Bobit Publishing Company (e.g., Bobit 1994). We follow this convention here, using "fleet" to refer to groupings of 10 or more vehicles unless otherwise specified. Fleet sales comprise a substantial portion of overall U.S. new vehicle sales and that portion has grown in recent years. The number of new cars registered in fleets reached 24% of total new car retail sales in 1990 and there was steady growth of the fleet share throughout the 1980s, averaging 6.6%/yr from 1981-90 (Miaou et al. 1992, 16).

Table 3-1. Comparison of Fleet and Overall New Light Vehicle Sales by Size Class

Vehicle Class	1993 Fleet Registrations (1000s)	Fleets as Fraction of 1993 EPA Total Sales	Class Share of Fleet Regs	Class Share of 1993 EPA Total Sales	Fleet/ Overall Share Ratio	Bobit Overall 1993 Regs (1000s)	Fleet Regs as Fraction of Overall 1993 Regs
Small car	317	12.4%	13.1%	18.5%	0.71	1768	17.9%
Compact car	591	21.5%	24.5%	19.9%	1.23	1835	32.2%
Mid-size car	610	26.1%	25.3%	16.9%	1.49	2151	28.4%
Large car	309	21.3%	12.8%	10.5%	1.22	1300	23.8%
Pickups	169	7.6%	7.0%	16.1%	0.44	2251	7.5%
Vans	306	22.5%	12.7%	9.9%	1.29	1370	22.3%
Utilities	112	9.8%	4.6%	8.3%	0.56	1375	8.1%
TOTAL	2414	17.5%	100.0%	100.0%		12050	20.0%
Cars	1827	20.1%					
Light trucks	587	12.4%					

Notes:

Mid-size fleet registration estimates are based on the "Intermediate" category listed in Bobit (1994); large cars include Bobit's "Full-Size" and "Luxury" categories. The Luxury category is based on price rather than size, but inspection of nameplate listings shows that at least 92% of the Luxury models fall into the EPA Large Car class.

Bobit does not separate small from large vehicles among the light truck classes (pickups, sport utility vehicles, and vans), so we treat these in aggregate here. Inspection of nameplate listings indicates that 65% of the fleet pickups are large.

Bobit's categories are based on truck weight Classes 1 (up to 6,000 lb gross vehicle weight [GVW]) and 2 (6,001-10,000 lb GVW), while the EPA-based listings in Table 1 include only trucks up to 8,500 lb GVW. However, relatively few vehicles fall into the 8,501-10,000 lb GVW range, so the discrepancy is minor.

Source: derived from Bobit (1994, 28-30) and Murrell et al. (1993).

If fleets are to be seen as a transition path to the overall market, the question arises of how well fleet vehicle attributes match the overall market. A market overview was shown in Table 2-1, which lists model year 1993 sales and average fuel economy by size class. Table 3-1 compares 1993 fleet vehicle sales and overall new light vehicle sales by size class. In this comparison, we use EPA data (Murrell et al. 1993) for overall sales, resulting in a different denominator than obtained from the AAMA data used by Miaou et al. (1992). For example AAMA (1994, 16) places U.S. passenger car retail sales at 8.5 million in 1993, 94% of the 9.1 million EPA figure from Murrell et al. (1993, 5). On this basis, fleet sales accounted for 20% of new car sales, 12% of new light truck sales, and 17.5% of total light vehicle sales in 1993. As shown in the last two columns of Table 3-1, the Bobit (1994) statistics imply that fleet sales accounted for 20% of total 1993 light vehicle retail sales (Bobit's overall 1993 new light vehicle registrations estimate is 87% of the EPA 1993 new sales tally). One reason the Miaou et al. estimate—that 24% of 1990 sales were for fleets—is higher than these more recent estimates may be that 1990 was a slow sales year overall, but fleet sales continued to climb while overall sales had dropped substantially compared to preceding years. Nevertheless, the differences in data sources would not affect comparisons between the fleet and overall market at the broad level that is of interest here.

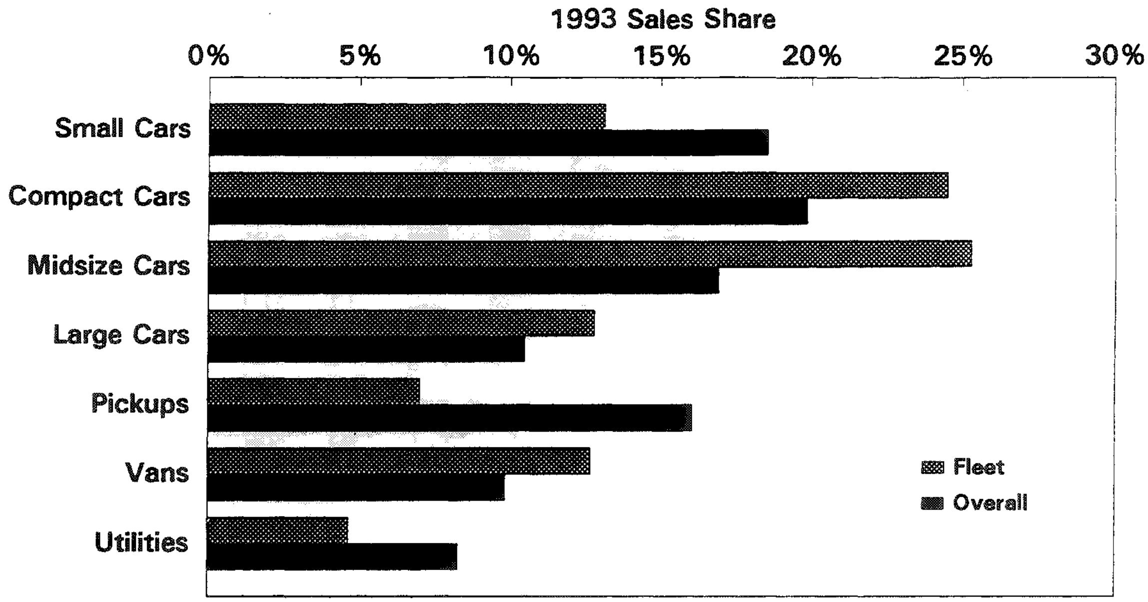

Figure 3-1. Comparison of Fleet Sales to Overall Light Vehicle Sales by Size Class in 1993

Using the statistics from Table 3-1, Figure 3-1 compares fleet sales to overall sales. Fleet sales are most concentrated in the mid-size car class, which accounts for 25% of fleet registrations as opposed to 17% of overall sales. The fleet share is also higher than the overall new vehicle market share for compact cars, large cars, and vans. Pickup trucks have the lowest ratio of fleet share to overall share, and fleets also buy relatively fewer small cars and utility vehicles than does the market at large.

It would be valuable to have an estimate of the typical number of new vehicle purchases by size class for each type of fleet purchaser (business, car leasing firm, government, utilities, etc.). However, published and available survey data do not provide such a cross tabulation. The NAFA *New Vehicle Acquisition Survey* (e.g., NAFA 1995) does not disaggregate by size class; it provides only a three-way type classification (commercial, public service, and law enforcement); and its voluntary response-dependent survey of members covers less than 5% of annual fleet purchases. The Bobit *Fact Book* lists cars by type of fleet, providing registration statistics for all fleet vehicles in use as opposed to new purchases. However, since fleets hold their vehicles for less than four years on average, the registration statistics are a good indication of new vehicle purchases by fleet type.

The statistics by fleet type for 1993 are summarized in Figure 3-2. The largest category, 34% of cars in fleets of 10 or more, is business fleets, shown broken out between vehicles leased and vehicles owned (22% and 12%, respectively, of the total fleet stock). Thus, among businesses not themselves in the car making or leasing business, nearly twice as many cars are leased as are owned directly. Individually leased vehicles, which includes vehicles owned by commercial

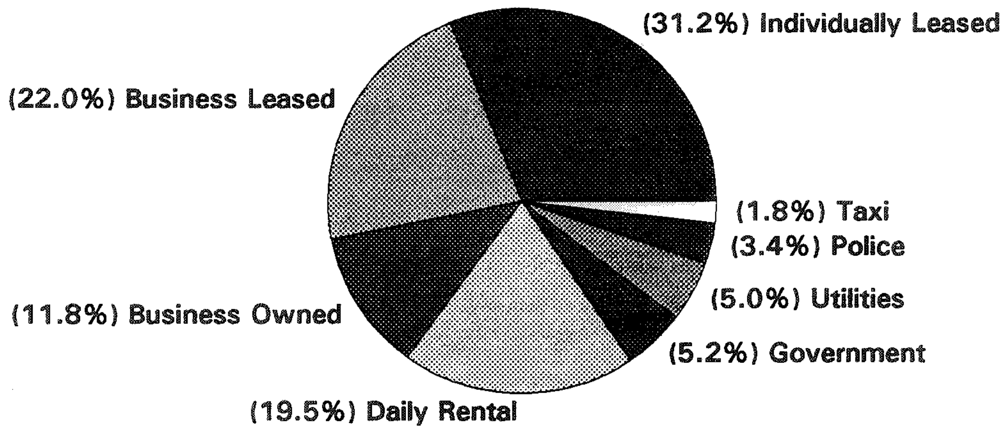

Figure 3-2. U.S. Fleet Vehicle Stock by Ownership Type

Source: Bobit (1994, 24).

enterprises which lease vehicles on an individual basis to consumer and business markets, comprise 31% of the fleet stock. Such leasing firms include automakers plus a number of companies specializing in leasing as the main or one aspect of their business. Car rental companies have nearly 20% of the fleet stock. Much smaller portions are held in the other categories, including government and utility fleets which each have about 5% of the stock of cars in fleets of 10 or more. Data are not readily available, however, for the composition by vehicle class among these fleet vehicle ownership categories.

Lacking adequate survey data, we combine the fleet statistics from Figures 3-1 and 3-2 in order to develop an approximation of the number of new vehicle purchases by size class and fleet type. Multiplying fleet type shares by fleet vehicle size class shares for passenger cars yields the estimates shown in Table 3-2. We eliminated police and taxi fleets from the estimation and combined owned and leased business fleets into a single category. The resulting table, which covers 95% of the U.S. stock in fleets of ten or more vehicles, shows estimates of annual purchase volumes and corresponding percentages of the new car fleet market. Estimated sales of compact and mid-size cars to fleets of 10 or more vehicles number approximately 600,000 annually; estimated subcompact and large car fleet sales are about half as large, roughly 300,000 annually. Thus, if fleets alone were the target of a market creation program that attempted to aggregate modest mass-production scale volumes for several competing automakers (90,000–150,000 per year), the program would have to absorb roughly 15%–20% of fleet purchases for compact or mid-size cars, for example. Of course, the burden on fleets could be lower if a market-creation program were to include a mechanism to organize individual purchases for aggregation with the fleet purchases. Motivating broad market interest would also be crucial for obtaining participation from rental and leasing fleets, which serve a general market.

Table 3-2. Estimated New Fleet Automobile Purchases and Market Shares by Fleet Type and Car Class

Fleet Type	Fleet Stock (1000s)	Stock Share	Shares of Overall New Fleet Market Small 17.35%	Compact 32.35%	Midsize 33.39%	Large 16.91%
General Business	2,607	35.74%	113,000 6.20%	211,000 11.56%	218,000 11.93%	110,000 6.04%
Leasing Firms	2,400	32.90%	104,000 5.71%	194,000 10.64%	201,000 10.98%	102,000 5.56%
Daily Rental	1,501	20.58%	65,000 3.57%	122,000 6.66%	126,000 6.87%	64,000 3.48%
Government	401	5.50%	17,000 0.95%	32,000 1.78%	34,000 1.84%	17,000 0.93%
Utility Companies	386	5.29%	17,000 0.92%	31,000 1.71%	32,000 1.77%	16,000 0.89%
TOTAL	7,295	100.00%	316,000	590,000	611,000	309,000
New Fleet Sales	1,827					
Stock/Sales Ratio	3.99	*(average number of years that fleets retain their vehicles)*				

The preceding statistics provide a picture of the current situation. For a market creation program that would operate into the future, it is necessary to project how the new vehicle market will evolve over the coming years, which is the subject of the next section.

Vehicle Sales Projections

For future growth in light duty vehicle sales, we use the projections developed by EIA for the *Annual Energy Outlook* (EIA 1996a). Table 3-3 lists these projections in millions of vehicles per year through 2015, separately for cars and light trucks. The EIA forecast sees a near-term continuation of the trend toward increasing light truck share. Thus, car sales grow relatively slowly, at an average rate of 0.6%/yr over the 20-year forecast period, while light trucks sales growth averages 1.8%/yr, for an average of 1.1%/yr growth in overall light duty vehicle sales. Most of the increase in light truck sales happens by 2005 under this forecast. EPA statistics indicate that the light truck share had already reached 39.5% by 1994, but since then has not increased as rapidly as in the preceding years; shares were 38.7% in 1995 and 40.4% in 1996 (Heavenrich and Hellman 1996). Of course, year-to-year sales and market shares are subject to fluctuations in the economy and other market factors that are difficult to capture in forecasting models. Recent reports in the trade press suggest that the light truck share will continue to grow and may soon exceed 50%. In any case, given the maturity of the U.S. market and an apparently

Table 3-3. Light Vehicle Sales and Stock Projections, Fleets and Overall

(million vehicles)	1995	2000	2005	2010	2015	Avg growth 1995–2015
Overall LDV Sales	14.446	15.421	16.500	17.178	17.938	1.1%
Cars	8.921	9.099	9.427	9.660	10.049	0.6%
Light Trucks	5.525	6.322	7.073	7.518	7.889	1.8%
truck share	38%	41%	43%	44%	44%	
AFVs (all LDVs)	0.039	0.103	1.076	1.409	1.740	20.9%
EPACT	0.015	0.023	0.179	0.313	0.436	18.4%
ZEVs	0	0.059	0.314	0.327	0.341	
AFV share of overall	0.27%	0.67%	6.52%	8.20%	9.70%	
EPACT AFVs share	0.10%	0.15%	1.08%	1.82%	2.43%	
ZEV programs share	0.00%	0.38%	1.90%	1.90%	1.90%	
Fleet sales, total	2.837	2.989	3.173	3.286	3.425	0.9%
Cars	2.066	2.107	2.185	2.236	2.324	0.6%
Light Trucks	0.771	0.882	0.988	1.050	1.101	1.8%
truck share	27%	30%	31%	32%	32%	
Fleet share of overall	20%	19%	19%	19%	19%	

Source: EIA supplemental tables for AEO 1996.

ongoing lengthening of average vehicle lifetimes, the overall volume of car and light truck sales will only increase modestly for the foreseeable future, reaching about 18 million per year by 2015 compared to recent levels of just below 15 million per year.

Table 3-3 also shows EIA's forecasts of fleet vehicle sales. These fleet forecasts refer to fleets of 10 or more, consistent with the statistics reported by the *Automotive Fleet Fact Book* (Bobit 1994, and annual), which was a key source used to calibrate the EIA model. Figure 3-3 summarizes car and light truck sales projections, with the fleet portion of each shown as the dashed lines. EIA's projections show fleet sales as an essentially constant fraction of overall sales. Since Bobit (1994) does not separate light trucks from total trucks in their *Fact Book* statistics, readily available data do not permit a recent historical comparison of overall light duty fleet share trends. Looking at cars only, recent statistics show a sharp rise in the fleet share of new vehicle sales. From a 15%–17% range in 1984–87, new fleet (10+) registrations as a fraction of total car sales jumped to 24% in 1990 and 30%–32% in 1991–92. However, preliminary estimates were back down to 20.5% for 1993 (comparing car fleet registrations from Bobit 1994 with total new car sales from Heavenrich and Hellman 1996). Truck sales to fleets also increased during this time, so the fleet share increase does not appear to be related to a lesser car-to-truck sales shift occurring in the fleet market than in the overall light vehicle market. It is possibly related to fleet purchases being less sensitive to recession than the overall new vehicle market. Although available data do not reveal a clear ongoing trend, it may be that EIA's projection of a fixed 20% fleet share is on the low side.

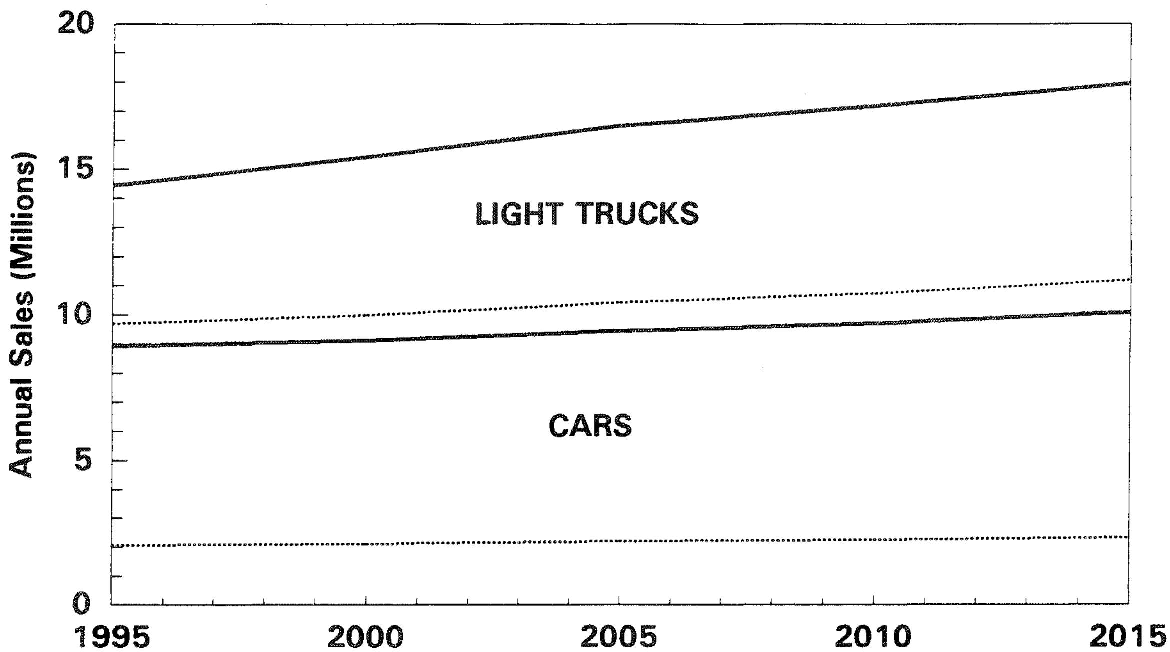

Figure 3-3. New Light Vehicle Sales Projections, Fleet and Overall

Source: EIA (1996a); dotted lines show fleet (10+) portions.

The single largest category of new fleet sales is for rental fleets, which have accounted for over 1 million of new passenger car sales in recent years. EIA does not separately project rental fleets from other categories, so we use the Bobit statistics to estimate an average share. The number of rental vehicles has expanded in recent years, and so then has the share of fleet vehicles sales attributable to rental fleets. The Bobit (1994) statistics show the rental share rising from 30% or less in the mid-1980s to over 40% in recent years. The 1990–92 average share was 45%, which we assume for future projections. Thus, the "non-rental" fleets projection line in Table 3-3 was derived as 55% of the total (10+) fleet sales projection. The result is growth in non-rental fleet sales from a current estimate of approximately 1.6 million to roughly 1.9 million by 2015. This population represents the "universe" of vehicles, which, by virtue of managed operation, has been considered as an initial target market for new vehicle technologies, in particular, AFVs. Of course, other restrictions, such as type of ownership, range of operation, and availability of central refueling, further restrict the fleet considered for AFV program. Below, we review estimates that have been made of fleets for the purposes of AFV program planning.

Alternative Fuel Vehicle Programs

Market-oriented government programs relating to motor vehicle energy use developed in recent years have had two major drivers, clean air and fuel diversification. Clean air programs generally have been based on environmental performance standards capable of being met with improved gasoline vehicles and reformulated gasolines. Alternative fuels can help with reducing air pollution, and so have been part of clean air efforts. However, the various clean fuel vehicles initiatives established by the Clean Air Act Amendments (CAAA) of 1990 are not of themselves likely to result in large numbers of AFVs. With the exception of California's Zero Emission Vehicle (ZEV) mandate, most clean air programs do not strongly foster a transition to alternative fuels. Alternative fuel programs for which reformulated gasoline or diesel fuels do not qualify, such as those established by EPACT (1992), do provide a more concerted push to non-petroleum fuels. Most efforts are oriented to centrally fueled fleets, based on a set of reasons noted above why such fleets represent a critical path for making a transition to non-petroleum fuels and vehicles. The rationale for focusing on the fleet market has been to stimulate the development and introduction of AFVs which can eventually enter general vehicle market and to simultaneously help establish the fuel distribution infrastructure needed to make alternative fuels accessible to the general market.

For the transportation sector, EPACT emphasizes fuel diversification; Title V of the law contains provisions on displacing conventional, petroleum-based motor fuels with non-petroleum sources. Section 502 of the title set goals for displacing petroleum in U.S. motor fuels, at least 10% by 2000 and at least 30% by 2010, with replacement fuels (see DOE 1995, p. 30, for the definition of replacement fuels). The goals are measured on an energy-equivalent basis, and one-half of the replacement fuels are required to come from domestic sources. A key focus of Title V is light duty vehicle fleet operations. Table 3-4 and Figure 3-4 (based on Singh 1996) summarize projected annual fleet AFV acquisitions as implied by EPACT. These estimates assume that a late (January 2000) rulemaking is issued to require municipal and private fleets to purchase certain numbers of AFVs. The graph shows only government and fuel provider fleets. Private, non-fuel provider fleets would amount to a much larger potential population, exceeding 300,000 AFV acquisitions per year by 2005-2010 (compared to estimated local government AFV acquisitions reaching about 55,000 vehicles per year, as shown in the figure).

The federal government is expected to substantially convert much of its own fleet to alternative fuels. EPACT also includes provisions for mandatory acquisitions of AFVs by certain other fleets, including state government fleets, fuel providers, and certain private and local government fleets. In addition to the various mandatory AFV acquisition programs, EPACT also instructed DOE to pursue a voluntary program for coordinating larger numbers of AFV purchases as a way to meet petroleum displacement goals. To carry out this aspect of the act, DOE launched the "Clean Cities" program, to provide a systematic process for coordinating local plans for expanding the AFV market. The program essentially creates and coordinates a network of stakeholders, working with local governments as primary points of contact and enable specific goals to be better tailored to meet local needs. Although AFV purchases under the Clean Cities umbrella can involve parties other than the fleets having mandatory programs, the program need not result in additional numbers of AFVs beyond those that would be expected under the fleet rulemaking requirements (as shown in the second part of Table 3-4).

Table 3-4. Projections of Overall Light Vehicle Fleet Sales and EPACT Requirements

	1995	2000	2005	2010
(a) Overall LDV Fleet Sales				
Federal	50,000	50,000	50,000	50,000
State	61,500	65,600	69,900	74,500
Local	139,800	149,000	158,700	169,100
Electric Utilities	20,100	20,100	20,100	20,100
Non-Elect. Fuel Providers	28,500	28,500	28,500	28,500
Private	1,505,800	1,505,800	1,505,800	1,505,800
TOTAL	1,805,700	1,819,000	1,833,000	1,848,000
(b) EPACT commitments, late rulemaking				
Federal	4,900	22,400	22,400	22,400
State	0	19,600	31,400	33,400
Local	0	0	52,500	55,900
Electric Utilities	0	4,800	6,100	6,100
Non-Elect. Fuel Providers	0	8,700	8,700	8,700
Private	0	0	355,700	355,700
TOTAL	4,900	55,500	476,800	482,300

Source: Derived from Singh (7/3/96, as updated 8/9/96) and rounded to nearest hundred.

Federal Fleet AFV Efforts

The most ambitious AFV fleet conversion program is for the federal fleet. The federal government purchases approximately 44,000 new LDVs each year, about equally divided between cars and light trucks (DOE 1992). EPACT set targets of federal AFV purchases increasing rapidly, beginning in 1993. By 1999, AFV requirements reach 75% of covered federal LDV acquisitions. Federal fleet AFV purchases were accelerated under Executive Order 12844 of April 1993, which was to have required federal purchases of roughly 15,000 AFVs in 1995. Actual acquisitions have lagged plans, in part because of limited funds to cover added incremental costs of AFVs compared to conventional vehicles which federal agencies would otherwise purchase. Nevertheless, the number of federal AFVs in use has expanded rapidly since EPACT was passed, rising from 3,360 LDVs in 1992 to 16,811 by 1994, with an estimated 1996 federal inventory of 36,300 AFVs (EIA 1996, 20). When the EPACT goal of 75% of covered federal acquisitions being for AFVs is reached, federal agencies would be buying an average of approximately 22,000 new AFVs each year (now targeted for 1999 and beyond).

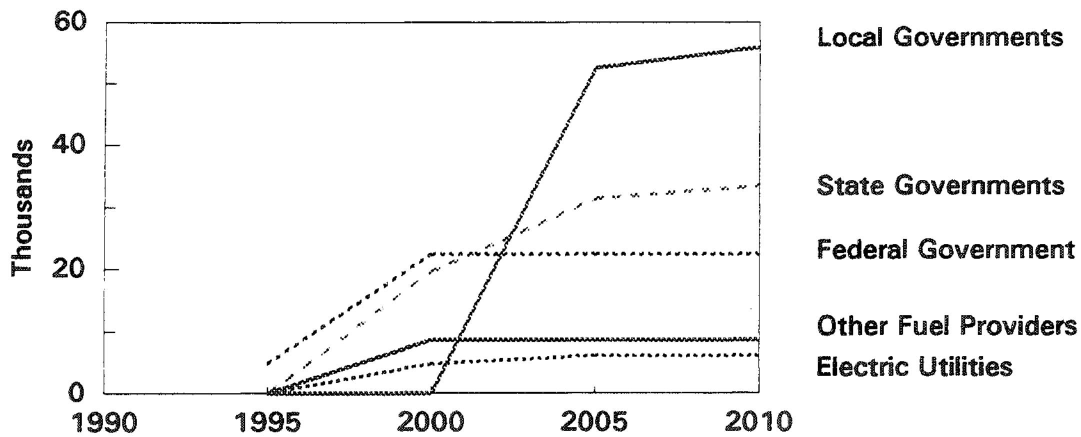

Figure 3-4. Estimated Fleet AFV Acquisitions under EPACT

Source: Singh (7/3/96, as updated 8/9/96).

As shown in the first part of Table 3-4, overall federal fleet purchases are on the order of 50,000 vehicles per year. Thus, the EPACT-mandated federal fleet conversion plans are expected to eventually cover 45% of overall federal fleet vehicles. This share does leave room for promotion of other vehicles, such as ultra-efficient vehicles which need not use an alternative fuel. Much of the overall federal fleet is exempt from EPACT requirements (e.g., since some facilities lack central refueling capability). These vehicles could be considered as available for efficient vehicle procurement efforts that do not require alternative fuel use. An issue that would remain to be addressed is how disruptive of basic fleet missions it would be to impose additional purchase restrictions beyond those already established for AFVs.

AFV Requirements for Other Fleets

State government fleets are also required to purchase increasing numbers of AFVs. Covered fleets include those of 20 or more vehicles capable of being centrally refueled in metropolitan areas of greater than 250,000 population. For these state fleets, 75% of their covered purchases are required to be AFVs starting in 2000. The resulting purchase implications exceed 30,000 vehicles by 2005 (see Table 3-4), amounting to 45% of overall state fleet purchases (when considering those not covered by virtue of location or local fleet size). A state government can coordinate with municipal government and private fleets within the state to incorporate voluntary purchases by these parties as a way to meet the state requirements.

EPACT mandates for private and local fleets may be instituted through a rulemaking if DOE finds that such mandates are necessary to meet the legislation's oil displacement goals. DOE was given two deadlines for issuing additional fleet rules. The first ("early rulemaking") date, December 15, 1996, is now past. The second ("late rulemaking") date is January 1, 2000. We use estimates developed for this late rulemaking as estimates of the numbers of private and local government fleet vehicle purchases that may be required to be AFVs. As shown in Table 3-4, by 2005 over 50,000 local government fleet acquisitions and over 350,000 private fleet acquisitions would be AFVs. Fuel providers are also expected to purchase AFVs, with numbers reaching nearly 15,000 vehicles per year nationwide by 2005.

Clean Cities Program

As noted above, EPACT also requires DOE to solicit voluntary AFV purchase and use commitments, in geographically diverse regions of the United States, as needed to achieve the 30% petroleum displacement goal. The initiative which DOE launched to carry out this requirement is termed the Clean Cities Program. Through it, the Department establishes locally-based government and industry partnerships and provides technical assistance in order to further purchase of AFVs and establishment of supporting infrastructure in urban areas targeted by the program. To carry out the program and pursue local objectives, DOE develops memoranda of understanding with private and local government stakeholders about actions they will take to help build AFV markets in their locale. To date, most efforts have focused on establishing the partnerships, with over 40 cities participating by early 1996. The Clean Cities Program is not expected to result in higher numbers of AFV purchases than would result from the mandatory programs, but would contribute to meeting the overall EPACT goals. Therefore, we do not add additional AFV numbers to those given in Table 3-4.

Fleet Purchases Available for Higher Efficiency Vehicles

In terms of acquisition of efficient vehicles, neither EPACT nor the Clean Cities Program have guidelines addressing vehicle efficiency *per se* as a petroleum displacement option. A market creation program for efficient vehicles that focused on acquisitions above and beyond those specified by EPACT could be made compatible with AFV programs and might provide additional petroleum displacement. As noted under the federal fleet discussion, it would be important to organize voluntary efficient vehicle efforts for any fleets so as to avoid disruption of basic fleet missions, considering the purchase commitments already established for AFVs. On the other hand, some fleets might find it attractive if credit could be given for the fuel savings resulting from acquisition of more efficient conventional gasoline vehicles than they might otherwise acquire. Here we examine the fleet purchases that would be available without impinging on AFV commitments.

In fact, substantial numbers of fleet vehicles remain unaffected by EPACT and other existing clean fuel vehicle programs. EPACT covers only fleets of 20 or more vehicles capable of being centrally refueled, that are parts of larger fleets of 50 or more vehicles and are located in metropolitan statistical areas (MSAs) having a 1980 population of over 250,000 residents, along with a number of other stipulations and exceptions (EPACT 1992, Section 301). Table 3-5

Table 3-5. Estimates of LDV Fleet Sales Remaining after EPACT Commitments

Fleet Sales Remaining	1995	2000	2005	2010
Federal	45,100	27,600	27,600	27,600
State	61,500	45,900	38,500	41,000
Local	139,800	149,000	106,200	113,100
Electric Utilities	20,100	15,400	14,000	14,000
Non-Elect. Fuel Providers	28,500	19,800	19,800	19,800
Private	1,505,800	1,505,800	1,150,000	1,150,000
TOTAL	1,800,900	1,763,500	1,356,200	1,365,600

summarizes the numbers of fleet vehicles remaining after EPACT purchase commitments have been met, based on differencing the two parts of Table 3-4. For all fleet categories, more than half of annual purchases are expected to remain uncommitted for meeting EPACT requirements. The federal fleet has the most stringent AFV conversion requirements, but even in this case, 55% of expected sales would remain after accounting for those portions of the fleet not covered by AFV requirements because of their location or small size. Similarly, 55% of state government fleets would remain, and 67% of local government fleets. About 75% of private fleets (other than fuel providers) would remain uncovered. Post-2005 overall, at least 1.3 million vehicles in fleets of 10 or more would remain as new purchases each year not covered by EPACT AFV requirements. Approximately 180,000 of these would be in government fleets (mostly local governments).

Reaching the General Market

As noted earlier, one advantage of an efficiency-oriented market creation program is that it need not be limited to centrally fueled fleets, since improved efficiency gasoline vehicles would be able to qualify. Generally, however, making a transition to ultra-efficient next-generation vehicles (as opposed to improved efficiency conventional vehicles) involves many of the same transition barriers faced by alternative fuels. Such barriers can be viewed as resulting in cost hurdles, above the direct costs of new technologies, which must be faced during the early years of a transition (Singh and Mintz 1997). Table 3-6 compares transition issues faced by AFVs with those that might be faced by next-generation vehicles utilizing technologies substantially different than those of today's gasoline-powered, stamped-steel vehicles. In particular, many of vehicle manufacturers' likely perceived risks would remain, due to the newness of the technology, and its potentially revolutionary nature compared to the gasoline reciprocating engine technology that has been evolving for the past 100 years. A similar set of risks would exist on the consumer side. Only fuel-related barriers are removed; these barriers are, of course, fairly substantial, since they involve the need for independent investments by parties other than those traditionally active in the motor vehicle market.

Table 3-6 Comparison of Transition Barriers faced by Alternatively Fueled Vehicles and Advanced Technology Gasoline Vehicles

	For introducing vehicles using:	
	Alternative Fuels	Advanced Technologies
Issues for Vehicle Manufacturers		
New product development needs	X	X
Different supplier requirements	X	X
Specialized training needs	X	X
Marketing and customer loyalty	X	X
Coordination with new fuel suppliers	X	
Issues for Fuel Suppliers		
(various)	X	
Issues for Vehicle Purchasers		
New operating characteristics	X	X
Different maintenance requirements	X	X
Uncertain resale value	X	X
Different refueling convenience	X	

Absence of refueling issues implies that, in addition to the substantial portions of the fleet market that could be incorporated into a market creation program, outreach could be made to the general car-buying public as well as rental fleets (which were excluded from the previously discussed fleets). The general market can include individuals as well as institutions and businesses with small (e.g., less than 10 vehicle) fleets. However, little information is available for estimating possible participation rates, since the issue has not been explored in surveys or through other approaches. Two types of information exist which can provide limited guidance. One is consumer surveys for broader "green product" markets. The other is vehicle choice modeling (e.g., qualitative choice analysis) such as those that have been used for exploring potential AFV market shares. No information is available on possible participation by rental fleets; further research involving discussions with car rental firms is needed. It should be noted that some rental firms are either owned by or have particularly close relationships with automakers, so automaker support for a market creation program could be helpful in persuading car rental companies to participate (e.g., by offering "green" rentals for environmentally conscious customers).

Market Awareness of Environmental and Fuel Efficiency Concerns

EPA (1994) reviewed studies regarding the effectiveness of various environmental labeling and certification programs (including the fuel economy labels), which were oriented to influence consumer or manufacturer behavior. The report noted an overall lack of conclusive results or data giving evidence of actual consumer purchase changes or measurable environmental quality improvements. On the other hand, surveys did indicate consumer awareness and self-reported purchasing decisions that were based on environmental factors. The EPA study classified environmental labels into three types: positive (labeling that highlights environmental benefits of a product); neutral (labeling that simply discloses information, such as the existing fuel economy labels); and negative (labeling that points out environmental risks). A Green Machine Challenge would involve some sort of positive labeling (based on neutral information, such as fuel economy ratings) that would identify particular vehicles as being better for the environment than others. Various surveys regarding products labeled as "green" in some way (e.g., on basis of recycled content) report increases in sales of the greener products. However, evidence for the effectiveness of the labeling efforts *per se* has not been reported.

Surveys indicate good consumer awareness of the fuel economy label, but its influence on purchase decisions cannot be estimated given all of the other factors that affect vehicle choice. Hill and Larsen (1990) evaluated the U.S. Federal Fuel Economy Information Program, which includes the fuel economy labels that appear on new vehicle stickers and the *Gas Mileage Guide* (EPA 1997 and annual) that is distributed through car dealers. Based on their review of past work on the subject, interviews with automaker and dealer representatives, and a limited consumer survey, they found a steady consumer interest in fuel economy information. Two-thirds of those surveyed recognized the fuel economy label and the level of awareness has remained high over the past decade in spite of the drop in fuel prices and ascendancy of other factors influencing vehicle choice. One notable finding of the Hill and Larsen study is that decisions about fuel economy are made very early in the new-car purchasing process. Choices about vehicle attributes that determine fuel economy are typically made before the consumer starts visiting dealerships. Thus, while labeling is valuable, information about fuel efficiency and its importance would have to be introduced at much earlier stages, before the consumer is on the dealer's lot looking at vehicles and their labels, suggesting a potential role for public information and awareness campaigns such as a Green Machine Challenge. The Hill and Larsen study, like earlier federal evaluations of its fuel economy program, did not probe how well consumers associate fuel economy with concern about the environment, but did note that linking fuel economy information to emissions could be one way to enhance the effectiveness of the government's fuel economy program.

General product marketing surveys have also revealed a growing sense of environmental awareness in product choice. This can be reflected in several ways, including "green image" marketing as well as actual "green product" choice. A Roper "Green Gauge" Survey tracked changes in attitudes between 1990 and 1993 (Stisser 1994). The study characterized a group of consumers who—based on their survey responses—said that they had made substantial changes in their shopping behavior for the sake of the environment; this group rose from 11% in 1990 to 13% in 1993 of the survey population. The survey generally found growing awareness of environmental factors among most other consumer groups, a result consistent with the broad-based environmental consciousness identified by Kempton et al. (1995). It also noted a "backlash" among some consumers who may have become confused or skeptical regarding product environmental claims. Also reported was an increase from 12% in 1989 to 18% in 1993 of consumers who indicated that they factor a product brand's environmental record into their purchase decisions. The survey ranked product categories by the relative importance of environmental factors in brand selection. Cars came out below average in this consideration; gasoline came out slightly above average ("lawn-and-garden" products headed the list of products for which environmental considerations are stated to be important in product selection).

Of course, "greener" cars have not yet seen a systematic, widespread promotion effort, which would be a key element of the type of program being investigated here. In any case, such survey results based on general environmental sentiments suggest an upper bound on the order of 15% for participation rates among the public at large. However, it would probably be overly optimistic to presume that such sentiments would translate to a willingness for many buyers to pay significantly more for a cleaner and more efficient vehicle.

Inferences from Consumer Demand Modeling

A number of econometric models have been developed to represent automobile demand. Several are based on the qualitative (discrete) choice methodology developed by Train (1996) applied in various versions of his "CARS" model. Such a model was used for an analysis of market incentives ("feebates") to promote higher efficiency (Davis et al. 1995). The resources for this study did not permit detailed modeling the choice of improved efficiency vehicles using these techniques, but such explorations might be a useful exercise. DOE has used such modeling to estimate potential market shares of various alternatively fueled and next-generation vehicle technologies, and this approach is also included in NEMS. To date, most such studies of advanced vehicles have addressed designs differing in a number of attributes (range, fuel availability, emissions, etc., in addition to fuel efficiency and incremental cost). Thus, such studies have not explored improved efficiency conventional vehicles, which would be among the likely candidates for the first phase of a market creation program. On the other hand choice models can be used to examine a fuel efficiency vs. incremental cost preference trade-off, holding all other vehicle attributes equal.

To examine this relationship, we reduced a single-class version of an aggregate logit model to hold all attributes constant except vehicle purchase price and fuel efficiency. The model was based on the stated-preference analysis by Bunch et al. (1993), which involved a household survey conducted in 1991. The structure of the model implies a linear trade-off of vehicle price vs. fuel cost per mile (inverse of efficiency at a constant fuel price), with a slope based on the preferences stated in the survey (Figure 6 of Bunch et al. 1993). The form of this trade-off is, of course, dependent on the econometric model structure used to represent market behavior. However, a linear form can arise under quite general conditions (Greene 1983). In disaggregate formulations, other factors such as income complicate the relationships, but as noted above, sophisticated modeling is beyond the scope of this report.

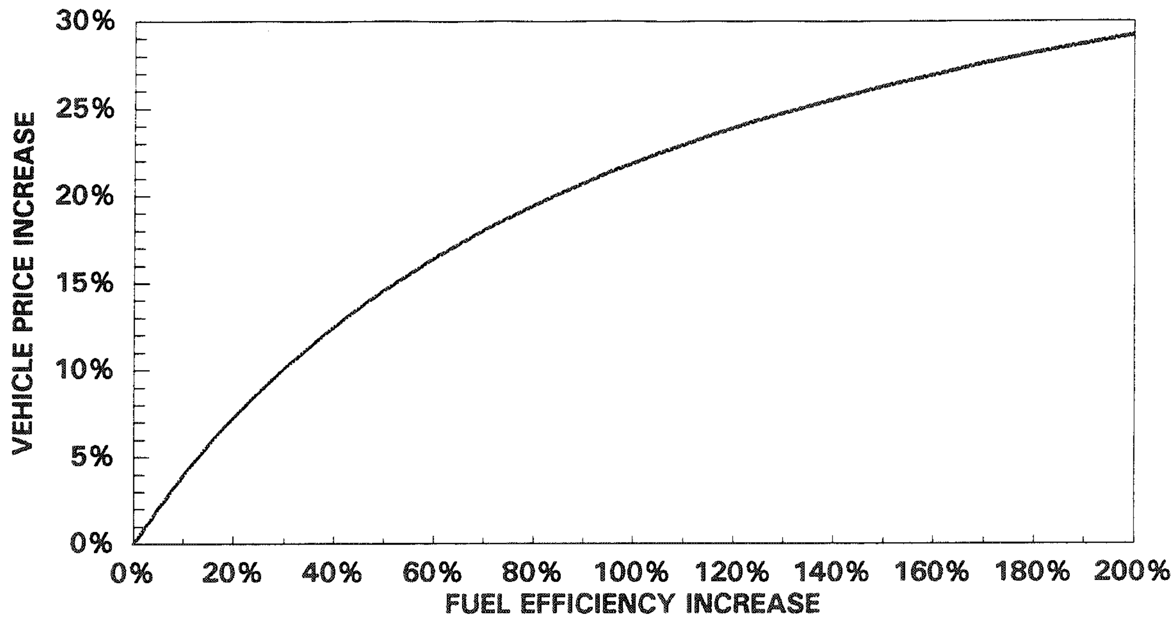

Figure 3-5. Willingness to Pay a Higher Vehicle Price for Higher Fuel Efficiency

Source: Author's derivations from a reduced-form qualitative choice model based on stated preference results of Bunch et al. (1993).

In order to represent the relationship for current market characteristics, we assume that the stated preference coefficients remain unchanged and work from 1995 light duty fleet conditions ($20,000 vehicle purchase price, 20 mpg on-road fuel economy, and $1.20/gallon retail gasoline price). The resulting trade-off curve is shown in Figure 3-5. Thus, a 50% fuel economy increase (for a 33% reduction in fuel cost per mile) would appear to be worth an added 15% in purchase price ($3,000 for a $20,000 vehicle). Assuming 10,000 miles per year of driving with current average fuel prices and vehicle characteristics, a 33% reduction in fuel consumption rate is worth about $200 per year.

Since the choice model does not suggest that all consumers would have this behavior, these results do not imply that car buyers would accept a 15-year payback (i.e., pay $3,000 more to save $200 a year). Indeed, such an outcome would be quite at odds with market experience. Rather, the model predicts market shares for various vehicle attribute combinations (in this case, price and efficiency), based on the probabilities that households would purchase vehicles with certain characteristics. Table 3-7 shows the results of choice model computations for combinations ranging up to a price increase of 50% and an efficiency increase of 200% (tripled fuel economy). In this case, the choice is posed as being between a vehicle of unchanged price and efficiency and one having a different efficiency and price. The model predicts market shares and for two choices, if the vehicles are identical, the market shares are 50% each, as indicated for the (0%,0%) location in the table. For the example of a 50% fuel economy increase at a 15% price increase, the implication is that such vehicles would be chosen by half of vehicle buyers. If this efficiency improvement came at no added cost (the 0% price increase row of the table), the market share

Table 3-7. Simplified Vehicle Choice Model Outcomes, considering only Efficiency Improvements and Vehicle Price Increases

Predicted Market Shares for Improved Vehicles

Price Increase	Efficiency Improvement (above 20 mpg on-road) 0%	10%	30%	50%	100%	150%	200%
0%	50%	53%	57%	59%	64%	66%	68%
5%	47%	49%	53%	56%	61%	64%	65%
10%	44%	46%	50%	53%	58%	60%	62%
15%	40%	43%	47%	50%	54%	57%	59%
20%	37%	40%	44%	47%	51%	54%	56%
25%	34%	37%	40%	43%	48%	51%	53%
30%	31%	34%	37%	40%	45%	48%	50%
35%	29%	31%	34%	37%	42%	44%	46%
40%	26%	28%	31%	34%	38%	41%	43%
45%	24%	26%	29%	31%	35%	38%	40%
50%	21%	23%	26%	28%	33%	35%	37%

Source: Author's derivations from a reduced-form qualitative choice model based on stated preference results of Bunch et al. (1993).

would go up to 59%. Tripled fuel economy vehicles available at no added cost over a comparable base vehicle are predicted to achieve a 68% market share. Thus, the curve in Figure 3-5 can be interpreted as showing the price-efficiency combinations for which half the market would choose the more efficient vehicle at the higher price.

The vehicle choice modeling results seems to suggest a fair amount of optimism about participation in a market creation program for efficient vehicles. Several factors, however, suggest caution. One is the liability of stated preference results to poorly match preferences actually revealed in the marketplace. Another is the knowledge, based on more sophisticated choice models, that the preference for fuel economy greatly depends on market segment (relating to both vehicle type and household characteristics). Results may not be reliable short of a more disaggregate analysis. (Ongoing vehicle choice modeling has been conducted by DOE.) Furthermore, as is the case when interpreting vehicle choice model results for alternatively fueled vehicles, such predictions ignore transition issues that would have to be faced before such vehicles could achieve such substantial market shares. A market creation program is, in fact, a way to address such issues, but it may be difficult to predict how successful it would be in achieving projected "equilibrium" choice outcomes premised on transitional issues having been overcome. Most recent market survey indicate that fuel efficiency is low on the list of attributes considered important in vehicle purchase decisions, even though the "green buyer" surveys indicate that a greater potential may exist, particularly if efficiency could be better linked to environmental protection in car-buyers' minds.

Potential Participation Rates

It is difficult to estimate likely general market participation rates in an efficient vehicle market creation program. The large market shares estimated as equilibrium outcomes of choice modeling would be inappropriate. The roughly 15% share suggested by green buyer surveys might be appropriate for an optimistic level reachable in the latter stages of a program, after widespread promotions, several years of consumer experience with the improved vehicles, and a very low price differential for the "greener" product. Assuming that fleet sales are 20% of the overall market, 15% of the remaining 80% gives a 12% share that might be the ultimate goal of a program. Given that a program will target only certain vehicle classes, accounting for say half of the fleet, the implication is a participation rate amounting to a 6% share of the overall light vehicle market. Taking this as an optimistic case, we arbitrarily halve it for a moderate case, assumed to reach a 3% share. Given 2010 new light vehicle sales projection of 17.2 million (Table 3-3), 3% and 6% of the market correspond to roughly 500,000 and 1 million vehicles, respectively. These estimates are still quite large numbers, and working toward them would be an ambitious objective for a market creation program. If a program ramped up linearly over five years, it would involve organizing as many as 200,000 "green buyers" in its first year.

The question remains of what would these buyers be asked to buy. If it is an advanced technology vehicle substantially different from the rest of the vehicles on the market, many of the issues noted in Table 3-6 could act as barriers, both to buyers and to automakers who might consider offering the vehicles. (Recall that the vehicle choice probabilities rest on an assumption of all other attributes being unchanged, and this would mean that perceptions of such attributes are unchanged from those regarding conventional vehicles.) Thus, a program may not be able to tap the potentially large interest in more efficient vehicles until after a yet earlier phase of more limited introductions and test marketing. Such a phase would be needed to introduce new designs (with nominally similar attributes other than efficiency, but very different technologies) to the public. It would also be valuable for automakers in helping to prove and refine the new designs based on in-use experience. Thus, some type of demonstration or test fleet program would be warranted. Example of this type of prior step are the limited market introductions of electric vehicles recently being pursued in California in advance of the broader sales that will be needed to meet the ZEV mandate.

Section Summary

Fleets can form an important core of a market creation program for efficient vehicles. Yet, unlike alternative fuel vehicle programs, efforts need not be restricted to fleets. Fleet vehicle purchase characteristics are different than those of the overall market. The share of fleet purchases in the compact, mid-size, and large car classes is greater than shares of these classes in the general market. The same is true for vans. On the other hand, fleets tend to purchase a lower share of pickup trucks and utility vehicles than in the general market. Thus, considering those classes identified earlier as important by virtue of their fuel use shares, a program focusing on sedans and vans would have good compatibility between the fleet efforts and outreach to the general market. Although alternative fuel vehicle programs are expected to significantly impact fleet markets, the AFV program restrictions—to certain metropolitan areas and to larger fleets capable of central refueling—leave substantial numbers of fleet vehicles as being potentially available for inclusion in a program promoting efficient vehicles regardless of their fuel type. In the post-2000 time frame, among government fleets, roughly 25,000 federal, 40,000 state, and over 100,000 local government annual fleet purchases would remain after AFV (EPACT) commitments are met. Private (excluding rental) fleet purchases not committed for AFV programs would number over one million.

Regarding the general market, introducing advanced technology efficient vehicles would face a number of issues similar to those encountered by alternatively fueled vehicles (refer back to Table 3-6). Thus, addressing these issues through demonstrations and test fleets (in order to build confidence on the part of both consumers and automakers) is likely to be an important prelude for a widespread market creation program. Based on general consumer surveys regarding environmentally improved products, a significant potential appears to exist for cultivating interest in "greener" vehicles. Thus, if higher efficiency is well associated with "greeness," this interest could be tapped for a market creation program. However, available surveys are only suggestive, indicating potential interest by roughly 15% of buyers. Simplified, aggregate vehicle choice predictions based on stated preference surveys indicate a higher than plausible interest in vehicles of improved efficiency. Further analysis, using more sophisticated models, might be useful for gauging interest among various market segments. Extrapolating from general green consumer interest surveys indicates a potential general market of one-half to one million vehicles. However, initial market barriers would need to be addressed and a substantial organizing effort would be needed to reach such numbers. In any case, market research is needed, not only to better estimate likely response, but also to determine how to obtain decent participation by potential "green" buyers.

4. STATUS OF TECHNOLOGY DEVELOPMENT

A key issue in designing a market creation program is the likely commercial status of technologies for efficiency improvement within the time frame over which the program operates. Many of the technologies needed for the PNGV's tripled fuel economy goal are in early stages of development. It is not possible to project when they would become available for incorporation into initial production runs as might be used to fulfill a market creation program. This issue is particularly relevant to specifying targets over the initial years of a program, when only very near-commercial technologies might be feasible. In all likelihood, program targets would need to evolve over time. Examining a range of technologies suggests a corresponding range of efficiency improvements attainable if the technologies were incorporated into vehicles. The efficiency improvement achievable in a given time frame is also related to the lead time available for incorporating technology advances into a vehicle design, including time to tool up for production.

Lead-Time Issues

The time needed for product development is relevant for designing a market creation program because it sets a lower bound on how soon the program can specify an efficiency level requiring major design changes. Product development entails not only creating the design but also building the tooling for manufacture and components, many of which can depend on outside suppliers. A related question is that of product cycle, since it could be costly for an automaker to prematurely terminate production of a model to be replaced with a comparable but more technologically advanced model. Product cycles depend partly on the time it takes for product development but are also a function of competitive forces (Clark and Fujimoto 1991). Longer development times can permit a greater degree of product refinement and testing, but longer development times also mean higher development costs. Market considerations are relevant as well, since on one hand, a longer product cycle allows a greater number of cumulative sales, enabling a greater return on the tooling investments associated with a vehicle. On the other hand, if a vehicle's design becomes "stale" or dated, competition can cause sales to drop off to the point where profitability suffers.

The current state-of-the-art for product development is roughly four years, which is typical for most Japanese automakers. U.S. domestic automakers have had an average product development time of about 5 years (NRC 1992). Some domestic models (e.g., Chrsyler's Neon) have been developed in less than 4 years. Thus, approximately 4 years of lead time should suffice for introducing a new vehicle design based on technologies ready for commercialization. However, if a more efficient model—perhaps designed in response to a market creation program—is to replace a model having a product cycle that extends beyond the development time, additional time would be needed to avoid premature termination of current production.

Product cycles vary among vehicle class and among automaker. Competitive pressures caused cycles to shorten through the 1980s and early 1990s, but this trend appears to have stabilized recently. In particular, Japanese automakers, who had been leading the trend to shorter product development times, no longer appear to be shortening their cycles, which had dropped to 4 years

Table 4-1 Automotive Product Cycles (Time between Major Redesign) by Vehicle Class

Vehicle Class	Product Cycle (years) Faster	Slower
Subcompact	4	5
Compact	4	5
Mid-size	4	10
Large car	4	10
Small Van/Utility	6	7
Large Van/Utility	8	12
Small Pickup	8	12
Large Pickup	8	12
AVERAGE (sales-weighted)	5	8

Source: Various *Automotive News* articles from 1991.

in the most competitive classes. *Automotive News* periodically reviews product plans by major automakers; Table 4-1 summarizes the range of recent cycles reported. The best cycles are consistent with the competitive product development times reported by Clark and Fujimoto (1991).

The product cycles listed here refer to vehicle platforms, focusing largely on the body and chassis, incorporating major styling and structural components of the vehicle other than the driveline. The driveline—engine, transmission, and related mechanical components—can follow a different, often longer, product cycle. Engine blocks, for example, require very large tooling investments; some engines lines have remained in production for many years. As with vehicle models, however, competitive pressures have resulted in reduced development costs and lead times in recent years. Doi (1992) showed that the best performing firms had engine development programs compatible with short product cycles. Moreover, engine development times reflect a hierarchy of refinements pertaining to major engine design elements: cylinder bore (displacement) changes, fuel system changes, new cylinder heads (valves and camshafts), and new blocks. An example is also provided by the Chrylser Neon project, for which new engine development proceeded on the same rapid schedule as the vehicle project (Woodruff and Miller 1993).

In examining technologies that might be applied for vehicles meeting a Green Machine Challenge, we categorize potential improvements as either "near-term" or "advanced." The line between these categories is not always sharp. For our purposes, near-term improvements are those that could be introduced within an immediate product cycle. We also restrict "near-term" to conventional technology improvements considered in published reports on fleetwide fuel economy potential (discussed below). Based on the review here, the minimum lead-time needed for a challenge to automakers to put a design of significantly improved efficiency into production would be 4 years. If the design is to replace a model having longer product cycle, then a longer time could be needed. For example, the time between major redesigns of the Ford Taurus has been 10 years (after its introduction in 1986, the first major redesign was in 1996, although minor changes were made model over the intervening years). If, on the other hand, a design made in response to a challenge is new, it could be put into limited production given enough time for product development, with less regard for existing production. For an advanced design, this time could be longer than 4 years. For example, GM unveiled its prototype electric vehicle, the Impact, in early 1990. Initial production of the model based on this design, the EV1, did not start until recently, in 1996.

Most near-term fuel economy assessments address the question of fleetwide improvements rather than improvements to an individual model, and so account for the time needed to make improvements throughout the fleet, since not all platforms can be redesigned at once. NRC (1992) assumed a 15-year horizon for achieving near-term efficiency improvements. However, NRC did not appear to use up-to-date product cycle information and underestimated the capacity for many technology improvements to be made without complete retooling, as is the case for many engine refinements documented by Doi (1992). DeCicco and Ross (1993) estimated a time requirements of 8-11 years for incorporating near-term efficiency improvements throughout the automobile fleet. Thus, a 10-year horizon is generally appropriate for fleetwide attainment of "near-term" technology improvements, which would rely in efficiency-optimized application (or re-application) of technologies already in use and of near-commercial refinements to conventional gasoline-powered vehicles. In response to a Green Machine Challenge, however, initial introductions of such efficiency improvements in a few vehicle lines could happen much sooner, e.g., in 4-5 years.

Near-Term Vehicle Refinements

Estimating the degree of vehicle efficiency improvement possible using conventional technologies that can be phased into the fleet has been a controversial subject. Disagreements are rooted in differing assumptions about the benefits, costs, applicability, and marketability of the technologies considered. Also, a number of different methodologies can be used to make the estimates (NRC 1992; Heavenrich and Hellman 1996). Approaches include:

- "Best-in-Class" (BIC) analysis;
- "Menu" ("shopping cart") methods based on characteristics of discrete technologies.
- Engineering modeling, based on physical models of the vehicle and its drivetrain;
- Comparisons to high-efficiency prototypes or concept vehicles;
- Regression analysis of fuel economy with other observed vehicle attributes;
- Delphi studies, based on expert opinions.

The menu approach has been used for many major studies because of its convenience for making integrated cost and fuel economy estimates. Engineering modeling and comparison to prototypes (which can be used to help calibrate an engineering model) are valuable because they can better reflect an optimization of designs for higher efficiency. In this report, we draw on best-in-class analyses and menu-based assessments for suggesting targets based on the improved conventional technology and we draw on published engineering assessments of advanced technologies.

Best-in-class results depend on the attributes used to define the classes for purposes of analysis. The classes might be based on EPA size classes (as used in the *Gas Mileage Guide*, for example), or similarly defined market segments, which might separate luxury or performance vehicles from other vehicles in the same size category. NRC (1992) reported a best-in-class analysis using 1990 light vehicles classified by size or function. Their results range from a 3% improvement for large cars (a class with few models) to a 50% improvement for subcompacts (a class with a wide variety of models, including luxury sedans and sports cars as well as low-cost "econoboxes"). This case points out a shortcomings of a best-in-class analysis if the choice of attribute defining the classes results in combining vehicles differing in other attributes that have a strong bearing on efficiency potential. Size-based classes might be confounded, for example, if luxury sports coupes fall into the same size class as inexpensive small cars in spite of the great differences in other characteristics.

A sample size-based best-in-class analysis for major classes is summarized in Table 4-2. Based on exploratory data analysis of all model year 1993 offerings (i.e., not sales weighted but ignoring models with trivial sales), a fuel economy level close to the 80^{th} percentile appears to give reasonable results, in terms of leaving a variety of models from which to choose. Such best-in-class purchasing would result in fuel economies 4%–33% better than class averages. The low end of potential improvement is for large cars, with few models and a relatively narrow distribution. Small utility vehicles show a wide dispersion, with models ranging from a 4-wheel drive Toyota 4-Runner (16.9 mpg) to a Suzuki Samurai (33.5 mpg). Thus, more sophisticated classifications might be warranted and different percentile targets might be used for different classes. Further analysis would be needed to control for other attributes. For general comparison, Heavenrich and Murrell (1996) applied a best-in-class analysis using weight classes. Their results (also listed in Table 4-2) were potential improvements of 10% for cars and 14% for light trucks, similar to the middle-range increases reflected in our size-class based analysis.

Refinements of the best-in-class approach can control for particular vehicle attributes, such as transmission type. However, because best-in-class analysis is based only on technologies and designs already in production, it cannot account for new and emerging technologies, let alone those under development. Thus, it is not really useful for developing targets for a challenge intended to pull technology advances into the market. It would be useful to a program element the encourage buyers to select the most efficient available vehicles that meet their needs. Thus, size class or market segment based analyses can be used to guide a "best-in-class" procurement element of a market creation program. While results as given here in Table 4-2 can be used illustratively, as we do below, consultation with potential participants (such as fleet managers) and further analysis would be needed to develop workable best-in-class specifications for program participants.

Table 4-2 Best-in-Class Fuel Economy Levels for Major Light Vehicle Classes

Vehicle Classification	Average MPG	No. of models	No. of BIC	BIC MPG	BIC/ Average
By EPA Size Class					
Compact Car	29.5	174	30	33	12%
Mid-size Car	26.0	104	21	27	4%
Large Car	24.3	45	14	26	7%
Small Van	22.9	115	16	26	14%
Small Utility	21.0	90	10	28	33%
Large Pickup	19.9	351	49	22	11%
By Inertia Weight Class					
All Passenger Cars	28.5			31.4	10%
All Light Trucks	20.4			23.2	14%

Source: Best-in-class (BIC) analysis by author of EPA data for major classes in model year 1993, not sales weighted but excluding very low (< 10) sales models, picking 1-mpg bin closest to 80th percentile.
Results for all cars and all trucks are based on best 12 by weight class from Heavenrich and Hellman (1996).
Fuel economy values are unadjusted composite (55% city, 45% highway) miles per gallon (MPG).

Fleetwide Fuel Economy Assessments

Recent studies applying a menu approach to estimate potential near-term fuel economy levels have identified new passenger car fleet averages ranging from little improvement over recent levels of 28 mpg up to an 80% improvement, or 51 mpg (OTA 1991; NRC 1992; DeCicco and Ross 1993). Results from key analyses are summarized in Table 4-3. Assessments include federally-sponsored studies based on work by K.G. Duleep at Energy and Environmental Analysis (EEA), such as Greene and Duleep (1993), and studies by auto industry consultants, such as SRI (1991). The National Research Council study (NRC 1992) was derived mainly from prior federal and industry analyses; it concluded that average new car fuel economy could be improved 21%–32%, from 28 mpg to 34 mpg–37 mpg, by 2006, at costs ranging up to $2500 per car. NRC gave a range of $1,000–$2,500 for their higher ("lower confidence") fuel economy estimate; the mid-range is shown in Table 4-3. Greene and Duleep (1993) estimated a new car fleet average fuel economy level similar to the higher NRC value but at somewhat lower cost.

DeCicco and Ross (1993) study drew on the EEA work, but re-analyzed the potential efficiency benefits of many technology options based on their own engineering estimates, updated the cost estimates, and included some additional options. Their menu-based approach was also confirmed by comparison to an efficiency-optimized production vehicle, the Honda Civic VX (discussed below), and engineering modeling. The potential for fleetwide fuel economy improvement was estimated by considering refinements added to a base new car fleet status (base year 1990) for

Table 4-3 Estimates of Potential Improvements in New Fleet Average Passenger Car Fuel Economy using Conventional Technologies

	Average MPG	Percent increase	Incremental cost (1995$)	Cost increase	Payback (years)
Base (1990 technology)	27.8	--	--	--	--
[average new car price]			[19,000]		
SRI (auto-industry sponsored)	29	4%	2,200	12%	93
NRC (mid-ranges of costs)					
Low	34	21%	1,000	5%	10
High	37	32%	2,000	11%	14
Greene & Duleep (EEA)	37	32%	1,200	6%	8.4
DeCicco & Ross (ACEEE)					
Level 1	39	41%	570	3%	3.5
Level 2	46	65%	810	4%	3.6
Level 3	51	82%	830	4%	3.2

Source: SRI (1991); NRC (1992); Greene & Duleep (1993); DeCicco & Ross (1993); OTA (1995); inflated as needed to 1995$ using CPI-U.
The simple payback estimates were calculated assuming $1.35/gallon gasoline price, 10,000 miles/year of driving, and 15% fuel economy shortfall.

which average vehicle size and performance were maintained. The analysis was developed at three levels of technical certainty, reflecting the uncertainties surrounding new applications of technology:

- Level 1 technologies are already in production in at least one mass market vehicle worldwide and face no technical risk in that they are fully demonstrated and available.

- Level 2 technologies are ready for commercialization and face no technical constraints which might inhibit their use in production vehicles, but entail some risk because of limited production experience.

- Level 3 technologies are in advanced stages of development but may face some technical constraints (such as emissions control considerations) before widespread application.

In this context, technical risk is interpreted as the risk that a technology cannot be put into widespread use within a given time horizon at acceptably low cost (full production scale average cost). For options better characterized by degree of design refinement, such as aerodynamic improvements or weight reduction, the certainty levels are interpreted as being successively less conservative regarding the degree of improvement. As summarized in Table 4-3, the ACEEE

(DeCicco and Ross 1993) estimates are for cost-effective new car fleet averages of 39 mpg, 46 mpg, and 51 mpg (41%, 65%, and 82% higher than the 1990 average), at certainty Levels 1, 2, and 3, respectively.

Accurately estimating the cost of improving fuel economy is difficult because of limitations in publicly available data and costing methodologies. The EEA estimates have been used for several government sponsored studies and are based largely on comparisons of technology among production vehicles. The resulting estimates represent the incremental retail costs of improved, mature technology averaged over a total period of production. DeCicco and Ross drew on the EEA work but adjusted some estimates based on other published information. Their fuel economy estimates assume use of technologies that are cost-effective in terms of fuel saved over the life of a car. Another index of cost-effectiveness is simple payback time, namely, how long it takes to recoup the incremental cost of a more efficient vehicle through fuel savings. The last column of Table 4-3 lists simple payback estimates derived from the reported analyses using assumptions of a fixed $1.35/gallon gasoline price, 10,000 miles/year of driving, and 15% fuel economy shortfall. Since vehicles now last 12 or more years on average, paybacks of this length or less could be considered cost-effective to vehicle owners in aggregate, although first owners may not recoup all costs. New car buyers typically keep their vehicles for about 4½ years, so paybacks of this length or less can be considered cost-effective to first owners.

Following the assumptions of the SRI (1991) or NRC (1992) analyses would indicate that no or relatively little fuel economy improvement is cost-effective. However, the assumptions and approach taken by these studies beg the question of improvement potential by assuming that current market outcomes are optimal and disregarding demonstrated design options offering higher efficiency (DeCicco 1992). The assumptions used to develop the ACEEE analysis are more appropriate for guiding policy development, and those results suggest program targets 40%–80% higher than current fuel economy levels.

Figure 4-1 summarizes the EEA and ACEEE estimates of the costs of new car fuel economy improvement through use of conventional technologies. For ease of analysis, and with little loss of accuracy in light of the uncertainties inherent in such estimates, the empirically-based sets of discrete technology cost and benefit estimates were fit to quadratic forms, which are shown in the figure. EEA represents its results with a two-parameter quadratic, with the linear term dominating (meaning relatively higher costs) for smaller levels of efficiency improvement (Duleep 1997b); shown in the figure are estimates for 2005 similar to those reported by Greene and Duleep (1993). The ACEEE estimates fit a pure quadratic quite well, with curves corresponding to the DeCicco and Ross (1993) certainty Levels 1–3 labeled as L1–L3 in the figure. The square point plotted on each curve is the limit of the empirically-based estimation; points to the right of this square are extrapolations beyond the range of the technology assumptions behind each set of estimates. In each case, the limit of technology costs is about $1000. Thus, the differing assumptions for each curve can be viewed as representing different degrees of technological progress (optimized for efficiency), yielding progressively higher estimates for how much fuel economy improvement can be obtained for $1000 of incremental technology investment (at the retail price level). In all cases, the levels calculated to be cost-effective are lower than the technical potential levels marked by the square points on each curve (refer back to Table 4-3).

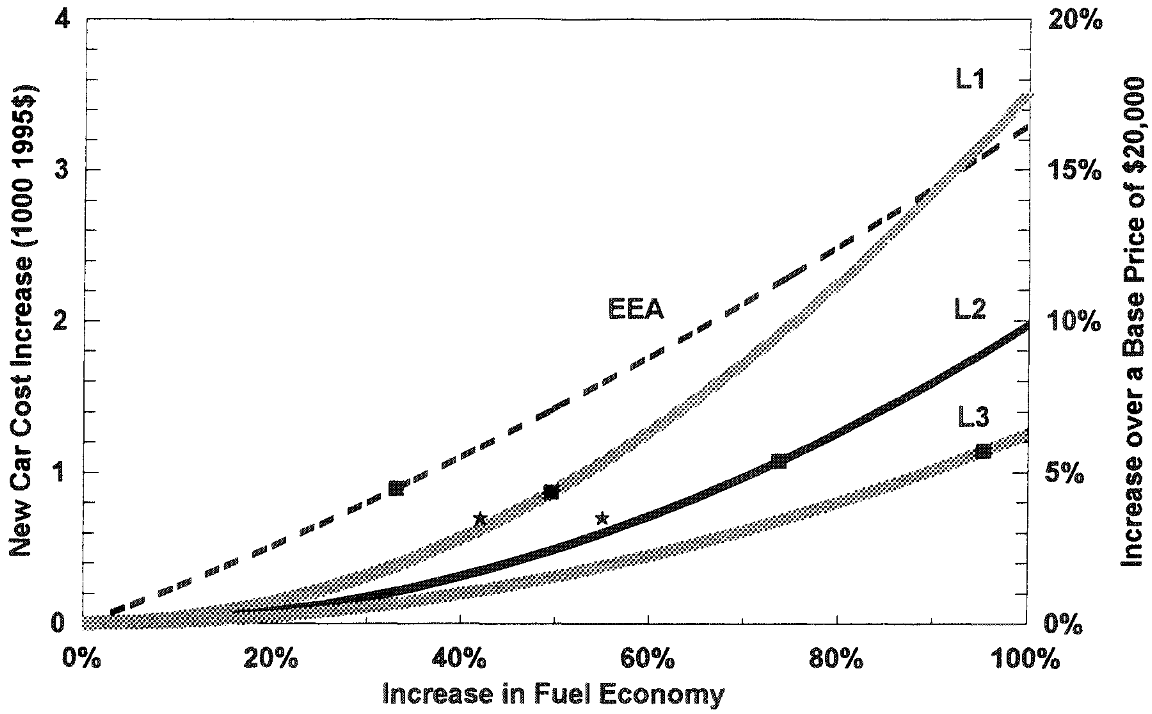

Figure 4-1. Costs of New Car Fuel Economy Improvement using Conventional Technologies, given as Curve Fits to Estimates by EEA and ACEEE

The EEA curve is from Duleep (1997b) estimates for 2005, given as Cost = $2400*Pct+$900*Pct^2 where Pct is percent MPG improvement over 28 mpg. Curves L1–L3 are fits of Cost = a*Pct^2 to the certainty Level 1–3 estimates of DeCicco and Ross (1993), with parameter estimates (â) of $3516 for L1, $1973 for L2, and $1255 for L3 (all in 1995$). The square points mark the limits of the empirically-based portions of each curve. The asterisks mark the relative MPG improvements demonstrated by the two versions of the 1992–95 Honda Civic VX, 55% for the 49-state lean-burn version and 42% for the California version.

The only good example of a production vehicle optimized for fuel economy is the 1992–95 Honda Civic VX, a subcompact coupe. It was priced $700 higher than the comparably equipped Civic DX hatchback simultaneously offered, and $2000 more than the "bottom of the line" Civic CX hatchback. VX sales were lower than hoped for, amounting to about 11% of total Civic hatchback sales and 25% of DX sales (Knight 1995). Honda did not continue the VX in their subsequent redesign of the Civic line for model years 1996–99. They did offer a Civic version (the HX) using a continuously variable transmission (CVT), but that model is less optimized for efficiency than was the VX relative to similar models. A comparable base version of an earlier model (a 1991 Civic DX) had a composite unadjusted test fuel economy of 38 mpg. Two versions of the VX were produced, both using Honda's "VTEC" variable valve control technology along with transmission improvements and load-reduction measures. The federally certified version used lean-burn and achieved 60 mpg, a 55% improvement over the 1991 DX (Honda 1991). The California version did not use lean burn, because of the state's tighter tailpipe standards, and achieved 55 mpg, a 42% fuel economy improvement. These relative improvement levels are plotted as the asterisks in Figure 4-1. Note that the Civic VX is a compact car whereas the curves in the figure apply to the car fleet as a whole, which has average characteristics closer to those of a mid-size car. Also, the $700 price difference for the VX is that of an individual model demonstrating new technologies in 1992–95, while the pricing assumptions for the Figure 4-1 curves are for mature technologies in widespread use in 2005.

The DeCicco and Ross (1993) analysis was done only for passenger cars, not for light trucks, which now account for 40% of new light vehicle sales. NRC (1992) estimated potential light truck fuel economy increases slightly more than proportionate to those for cars. Greene and Duleep (1993) estimated potential light truck fuel economy increases slightly less than proportionate to those for cars. At least 80% of light truck usage is strictly for personal transportation (Bureau of the Census 1990). Light truck fuel economy has been more leniently regulated than that of cars; the main sources of inefficiency are the same as in cars; and the new light truck fleet has lower utilization rates for efficient technologies. Therefore, in projecting potential future overall efficiency potential, it is reasonable to assume that light truck fuel economy can be increased proportionately to that of cars at similar incremental cost. Thus, for cost estimation purposes, one can apply the curves of Figure 4-1 on a percentage basis to the base fuel economy levels of light trucks.

A Role for Diesels?

Diesel engines were not considered in any of the menu-based fuel economy estimation studies discussed above, even though diesel—that is, compression-ignition (CI)—engines are generally more efficient than comparably powered gasoline, spark-ignition (SI) engines. Diesel engines are among the technologies being pursued by the PNGV, for use with either conventional drivetrains or hybrid drivetrains.

Many high-efficiency prototypes have used diesel engines. Such was the case for the Volvo LCP, for example, a compact car prototype of relatively light weight (1560 lbs vs. the 1990 U.S. compact car average of 2760 lbs) which was rated at a 62 mpg U.S. city/highway composite average, based on conversions from European test cycle values (Bleviss 1988; EEA 1991). Generally, European efforts at efficiency improvement have centered around use of improved direct-injection (DI) diesel engines and conversion of gasoline segments of their fleet to diesels. For example, German R&D work has been focusing on using advanced diesel technology with a lightweight steel or aluminum body aiming to develop a 3 l/100km (approximately 78 mpg) car. Their target car class is comparable in size to a subcompact in the U.S. market. Compression ignition has historically been considered to offer substantial (20%-30%) efficiency benefits over gasoline SI engines in comparable automotive applications provided that criteria emissions constraints could be met. However, a variety of factors make it appear unclear whether diesels will find more widespread use in U.S. light duty vehicles, unless they find use in a hybrid drivetrain.

The primary issue inhibiting passenger vehicle diesel use in the United States is emissions standards. Greater use of diesels has been possible in Europe because of less stringent standards, less robust test cycles, and the flexibility to trade-off NO_x and HC emissions. Europe has been moving towards more stringent standards, but at effective stringency levels still weaker than those in the United States and in a way that will accommodate diesel use (Walsh 1996). In contrast, the U.S. market faces a continuing tightening of permitted criteria emissions levels, including the possibility of national Tier 2 standards (which might cut permitted emissions of CO, HC, and NO_x to half of the Tier 1 levels that were phased-in during 1994–96).

Currently, very few new U.S. passenger cars have diesel engines. Volkswagen offers a 90 hp turbocharged DI diesel in Passat models (sedan and wagon); the good low-end torque characteristics and turbocharging provide good performance at this power level in the compact class. However, it meets current standards only because of a NO_x exemption, which permits diesels to emit 1 g/mi, compared to the Tier 1 NO_x standard of 0.4 g/mi for gasoline vehicles. It is unclear whether more powerful DI diesels meeting gasoline-equivalent Tier 1 emissions standards could be developed and find wider application in the U.S. market. Diesels are used in some models at the heavy end of the light truck segment, which is also subject to much weaker emissions standards.

Further constraints on diesel applications could result from extensions of California's low emission vehicle (LEV) program to other states or a "national low emissions vehicle" (NLEV) program, as well as reforms of emissions test procedures to make any prevailing standard more robustly control real-world emissions. The California ultra-low emissions vehicle (ULEV) standard and possibly the Tier 2 federal standard would limit NO_x emissions to 0.2 g/mi. Barring a breakthrough in lean NO_x-reducing catalyst technology, such emissions control requirements would inhibit the use of even the most sophisticated direct-injection diesels with low-sulfur fuels.

Compression ignition engines using diesel fuel have also tended to produce much greater emissions of particulate matter (PM) than gasoline engines. Diesel emissions control strategies confront a NO_x-PM trade-off, which is helped but not eliminated by advanced catalytic converters and particle traps. Recently, the case has been building for greater attention to fine particulate control (Shprentz 1996), which could confront diesels with a yet higher hurdle for meeting emissions control requirements. Lean-burn gasoline engines still face emissions control hurdles, particularly for NO_x reduction under lean conditions. But these hurdles may be less challenging than those faced by diesels. Promising technologies such as Toyota's storage/reduction 3-way catalyst have been developed, although these control approaches would also require use of a very low-sulfur fuel, such as California Phase-2 reformulated gasoline.

Finally, the advent of four-stroke direct-injection spark-ignition (DISI, also known as direct-injection stratified-charge, DISC) engines vitiates some of the efficiency advantage of diesels. DISI engines can operate on gasoline with very lean mixtures at part load and when used with optimized variable induction (valve control) mechanisms would nearly eliminate pumping losses, greatly improve volumetric efficiency, and enhance low-end torque. Diesels would have a smaller efficiency advantage over such advanced gasoline engines. ACEEE's Level 3 fuel efficiency analysis did not assume DISI technology, but did assume the use of a lean-burn port-injected engine or a DI two-stroke engine, with efficiency levels similar to or slightly less than those of DISI engines. OTA (1995) estimated that a DISI-equipped vehicle with an optimized aluminum body (achieving a weight reduction similar to that assumed at ACEEE Level 3) could achieve 53 mpg, a 90% improvement over the 1990 new car average. If advances in diesel technology and emissions control do occur at costs competitive with advanced lean-burn spark-ignition emissions, the additional efficiency benefits may not be very large. Thus, we assume that the 51 mpg ACEEE Level 3 estimate for an average passenger car essentially incorporates the impacts of any likely internal combustion direct-injection (CI or SI) engine designs as among the options usable for reaching that level, which again is contingent on an ability to meet Tier 1 or tighter NO_x standards under lean conditions.

Potential Near-Term Efficiency Targets

Menu-based studies published to date have been limited to examining refinements of conventional vehicle technologies, to which the method is well suited. Although not as limited as best-in-class assessments, menu-based estimates still do not cover advanced technologies, such as those being considered for next-generation vehicle designs. However, one can look at the results of a menu-based analysis as an "existence proof" of the attainability of a certain fuel economy level and not necessarily as the best recipe for achieving it. An efficiency level estimated based on optimal use of conventional technologies might in fact be better achieved by more advanced technologies, for which the potential application has not yet been publicly reported enough to have been included in the technology menu. Conversely, some higher efficiency levels, premised on the use of advanced non-conventional technologies, might well be attained with engineering creativity that pushes "conventional" technologies to levels not anticipated in published assessments. Therefore, a relatively high degree of assumed technological optimism seems appropriate for targets designed to pull new efficient new designs into the market. Such optimism is appropriate when setting targets for a market creation program, in contrast to the caution in technological assumptions that is commonly appropriate for a regulatory program applying to all vehicles.

The menu approach provides guidance about what to expect by way of an average improvement to the fleet as a whole. For a challenge program, however, it would be more appropriate to examine potential fuel economy improvements for a particular model or type of vehicle as would be targeted by the program. Following the evolution of particular model lines does provide examples of improvements to particular vehicles. In fact, comparisons of such improvements provides much of the basis for the individual technology benefit estimates that underlie analyses of fleetwide improvement potential. However, few examples exist of production vehicles having greatly increased fuel economy over the course of redesign. Under current market conditions and lacking policy pressure for higher fuel economy, when "efficient" technologies are incorporated during redesign, they are usually applied to increase other vehicle amenities while maintaining or only slightly increasing fuel economy.

As noted earlier, the Honda Civic VX validates ACEEE's estimates of the technical potential for fuel economy improvement, with the California and lean-burn versions corresponding to certainty Levels 2 and 3, respectively. It also can be taken to conservatively indicate the potential level of improvement that might be expected for a single model redesigned to meet the "step-forward" efficiency of a market creation program. More recently, Honda has marketed other efficient technologies, such as the CVT in the 1996–99 Civic HX coupe, and achieved California's ultra-low emissions vehicle (ULEV) emission standard in a version of the Accord, using its VTEC valve train along with improved microprocessor-controlled fuel injection and catalyst technologies. The Honda Civic VX, and the technologies subsequently demonstrated in the more recent Civic HX and ULEV-certified Accord, are still strictly refinements of conventional gasoline vehicle designs. However, targeting such improvement levels may still be appropriate for the first stage of a Green Machine Challenge. If it were clear that further stages would aim higher, it could be in an automaker's interest to meet a 40%–80% MPG improvement challenge using "first generation" versions of a next-generation technology. Yet setting the target based on a level thought to be achievable by conventional means would lower the risk that the target could not be achieved at all within the near-term time frame used for an initial stage of a market creation program.

Advanced Technologies

A number of studies have examined the potential for more advanced technologies, typically involving a radically new drivetrain technology, to improve fuel economy beyond the limits of drivetrains restricted to piston engine technologies. Bleviss (1988) identified a number of options that had been investigated in the years following the energy crises, including advanced diesels, hybrid electric vehicles, gas turbines, and the potential for lower mass body structures. EEA (1991) estimated potential efficiency levels for a 2010 time horizon at three "risk" levels, projecting potential passenger car fleet average efficiency levels of (1) 45 mpg, (2) 55 mpg, and (3) 74 mpg, respectively. The Risk Level 1 estimate is for an improved efficiency conventional vehicle. EEA's Risk Level 3 estimate goes beyond conventional gasoline vehicle technologies, requiring use of either hybrid drivetrains permitting energy storage or advanced, turbocharged diesels—technologies which clearly fall in the "advanced" category.

A number of analysts have projected that fuel cell vehicles could become competitive on a lifecycle-cost basis. DeLuchi (1992) estimated that hydrogen fuel cell vehicles attaining an equivalent of roughly 75 mpg would cost about $7,000 more than a comparable gasoline vehicle (a mid-size 1990 model costing about $17,000 and attaining 26 mpg on-road). Based on analyses by GM/Allison (1993) and Ogden et al. (1994), Mark (1996) estimates that mass-produced fuel cell vehicles attaining 70–80 mpg might cost $1,000–$3,000 more than a comparable conventional vehicle.

Very high fuel economy levels have also been identified as research goals by the Partnership for a New Generation of Vehicles. PNGV "Goal 3" targets the development of production prototypes of vehicles achieving three times the fuel economy of today's typical cars while maintaining size, utility, and performance, meeting safety and emissions requirements, and costing no more to own and operate than comparable 1994 mid-size sedans (PNGV 1995). The technologies identified for PNGV R&D efforts run the gamut of options having potential for efficiency improvement. The PNGV Program Plan identifies efforts in lightweight materials and structures; more efficient energy conversion devices, including lean-burn piston engines (both SI and CI), gas turbines, fuel cells, and hybrid drivetrains; energy storage devices, including batteries, ultracapacitors, and flywheels; energy-efficient electrical systems, including power conversion devices and controllers as well as vehicle accessories; and methods for waste heat recovery. At this point in time, many options are being simultaneously pursued, and so it is premature to select particular advanced technology designs as most likely to become viable as a next step beyond conventional designs.

More radical automotive technology advances have been analyzed by Lovins (1995), who envisions "hypercars" based on ultralight bodies combined with hybrid electric drivetrains attaining manyfold improvements in fuel economy. His concepts exploit the synergies of tractive load reduction with hybrid drive, which becomes more feasible as power needs decrease. Extending the approaches used in GM's *Ultralite* concept car, Lovins estimates potential reductions by factors of 2–4 for vehicle mass, 2–6 for aerodynamic drag, and up to 2 for tire resistance (which compounds with mass reduction to yield up to a factor of 6 reduction in net rolling resistance). Even without changing the drivetrain, achieving such load reductions would at least double fuel economy. Combining this ultralight design approach with highly efficient hybrid drivetrains, Lovins projected fuel economy increases by factors of 4 to 25 (roughly 100 mpg to 600 mpg). GM's *Ultralite* concept car was powered with a 245 hp (183 kW) DI 2-stroke engine—one might say very overpowered, with a power-to-mass ratio of 280 W/kg compared to 90 W/kg for today's average car—yet attained 62 mpg, or about 2.5 times today's average cars of similar interior volume. Thus, if ultralight designs become cost effective, as Lovins predicts to be highly probable, tripled or better fuel economy would be attainable even without major changes in the drivetrain.

A recent comprehensive review of advanced vehicle technologies is the OTA (1995) *Advanced Automotive Technology* report. Much of the analysis for this study was done for OTA by K.G. Duleep and colleagues at EEA; key results are also reported in Duleep (1997a). The conclusions are less optimistic than both the PNGV research goals and a number of other advanced automotive technology assessments (especially compared to Lovins, for example). Nevertheless, OTA (1995) identifies potential advanced technology fuel economy levels exceeding those outlined earlier for conventional vehicle technologies. Most of the designs analyzed by OTA entail significant mass reduction, e.g., using aluminum bodies, and an advantage of their analysis is that it assumes similar levels of tractive load reduction for competing drivetrain technologies and controls for other vehicle attributes (such as size, performance and range). The OTA report covers battery electric vehicles, but we exclude these from discussion here because of their inherently different attributes regarding range and refueling characteristics.

Table 4-4 summarizes the OTA (1995) estimates with our calculations of simple payback based on their cost estimates and the noted usage and fuel price assumptions. The estimates are also plotted in Figure 4-2 along with our quadratic fits to the estimates by projection year (2005, 2015). The first part of the table covers advanced conventional gasoline technologies. The 2005 estimates, made for a typical individual mid-size car having a base efficiency of 28 mpg, can be compared to the Table 4-3 estimates of potential near-term fleetwide improvement from a roughly 28 mpg base. OTA foresees that significantly higher conventional drivetrain efficiencies can be had by 2015. The "optimistic" 2015 design is for a vehicle having a 37% mass reduction compared to current designs (e.g., using an optimized aluminum body and other load reduction refinements) as well as a direct injection stratified charge gasoline engine with variable valve control. OTA also examined diesel engine options, which have only very slightly higher efficiencies than the optimized gasoline engine designs (the diesel estimates are not shown here).

Toyota (1997) recently announced an electric hybrid, compact-sized passenger car, achieving 66 mpg on a Japanese urban driving cycle, which it plans to begin marketing in Japan this year. The hybrid drivetrain yields an 80% fuel economy benefit, essentially matching the "2005" hybrid technology level estimated by OTA. The hybrid design incorporates an automatic transmission

Table 4-4 Estimates of Potential Improvements in Mid-size Passenger Car Fuel Economy using Advanced Technologies

	MPG	Percent increase	Inc. Cost (1995$)	Cost increase	Payback (years)
Base (1995 technology)	28	--	--	--	--
[average price]			[19,500]		
1. Conventional Drivetrain					
2005 advanced	39	39%	400	2%	2.5
2005 optimistic	42	50%	1,600	8%	8
2015 advanced	53	90%	2,550	13%	9
2015 optimistic	64	127%	6,250	32%	20
2. Hybrid Drivetrain					
2005 lead-acid battery	49	75%	4,900	25%	20
2015 lead-acid battery	65	133%	5,700	29%	18
2015 ultracapacitor	71	154%	10,850	56%	32
2015 flywheel	73	160%	8,650	44%	25

Source: based on OTA (1995) and Duleep (1997a). The simple payback estimates were calculated assuming $1.35/gallon gasoline price, 10,000 miles/year of driving, and 15% fuel economy shortfall.

that houses two motor-generators and gearing plus a control system that optimally blends power from the combustion engine and electric motors. The system provides regenerative braking and idle-off (whereby the combustion engine shuts off when its power is not needed). If applied to an average U.S. car (now at 28 mpg), the Toyota design would achieve roughly 50 mpg. Because of the idle-off and power-peaking capabilities of the hybrid drivetrain, the combustion engine can operate over a restricted power range, allowing significant optimizations for both efficiency and low emissions. Although the vehicle has not been certified to U.S. emissions standards, the engine's stoichiometric operation will enable it to use a 3-way catalyst very effectively, so that attainment of ULEV or lower emissions should be straightforward (German 1997). The hybrid vehicle will be initially priced at $4300 more than a comparable (Corolla-sized) conventional vehicle (Dow Jones Newswires 1997). The point estimate represented by this vehicle is plotted as the asterisk in Figure 4-2. It falls quite close to the OTA "2005" curve, although the Toyota is a compact car in the Japanese market and so is not fully comparable to the mid-size cars for which the OTA estimates were made.

For hybrid designs in a 2015 time frame having ranges comparable to conventional vehicles (i.e., excluding battery-only electrics), Duleep (1997a) estimated fuel economy levels of 65 mpg to 73 mpg, or improvements of 133% to 160% over the base, which was chosen to represent a typical 1995 mid-size car (e.g., Ford Taurus) rated at 28 mpg. The estimated cost increases range from $5,700 to $10,850, or 30% to 57% higher than the base price of $19,500 (1995$). (The most expensive hybrid configuration assumed ultracapacitors for energy storage.) Duleep and OTA also examined fuel cell vehicles and estimated that they might attain 80 mpg, but were much

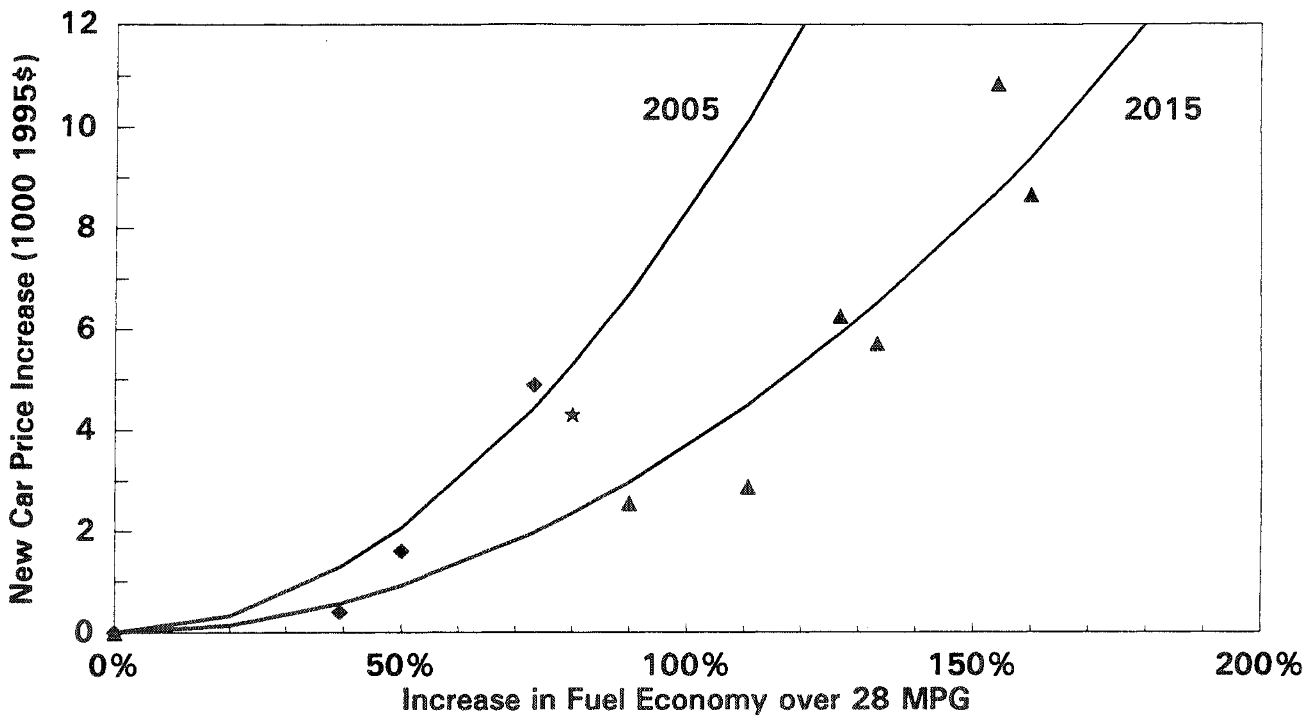

Figure 4-2. Costs of New Car Fuel Economy Improvement using Advanced Technologies, Quadratic Fits to OTA Estimates

Estimates are given in 1995$ based on the OTA (1995) study, as reported by Duleep (1997a); the diamonds are estimates for 2005 and the triangles are estimates for 2015. Curves are the author's fits of Cost = a*Pct², where Pct is percent MPG improvement; the parameter estimates (â) are $8265 (±1037) for 2005 and $3665 (±293) for 2015. The Toyota hybrid vehicle is plotted as the asterisk.

less optimistic regarding the ability to bring down fuel cell costs over the next 20 years. Their *incremental* price estimate for a fuel cell vehicle is $40,000, for a projected vehicle price more than triple that of today's cars. However, OTA acknowledged the far more optimistic fuel cell cost projections noted above. In any case, the conclusion of the OTA (1995) analysis is that advanced conventional gasoline designs can potentially double fuel economy and the added benefits of electric drivetrain benefits are relatively small compared to their added costs.

A fundamental determinant of fuel economy with any drivetrain type is a vehicle's tractive load, which depends largely on its mass. Assumptions of extensive mass reduction underpin Lovins' estimates of multifold increases in fuel economy. His analysis foresees a revolution in vehicle materials use and assembly, moving away from structures based on metals (now mainly stamped steel) to structures based on advanced composites, such as the carbon fiber composite monocoque body used for GM *Ultralite* concept car. Working with Lovins, Mascarin et al. (1995) estimated that composites would have lower vehicle lifecycle costs than steel at low (under 75,000 units per year) production volumes. At 100,000 units per year, they found manufacturing cost premiums of $700 to $1300, depending on the type of tooling used for the composites, for a roughly 50% cut in body mass in a compact car. The cost advantage of steel grows with production scale. Thus, arguments for composites at least partly rest on lower production scales becoming viable, for example, due to competitive advantages in a more differentiated market. Since a market creation program would involve small volumes (e.g., less than 50,000 units per year for a given model), it would possibly be attractive for an automaker—or a new start-up company—with a composite-based design. However, few other analysts see such materials becoming cost-competitive with steel over the next decade or so. Also, a program introducing such vehicles might fail to lead to a more extensive market transformation if such designs are not competitive at larger volumes.

Without moving to composites, the potential for mass reduction without downsizing appears to be well under 50%. Improved steel-based designs do not appear to cut weight beyond the range discussed above under near-term vehicle refinements. The Porsche (1995) study prepared for the steel industry estimated a 24% mass reduction for a sedan body-in-white[3] at a cost similar to or lower than current designs. The body-in-white now accounts for about 20% of curb weight, so of itself, this improvement would yield about a 7% overall mass reduction (counting secondary weight savings). Stodolosky et al. (1995) analyzed several advanced materials substitution options for vehicles. They estimated that aluminum-based designs could become competitive, achieving a 30% curb weight reduction at an incremental cost of roughly $1200. Stodolosky et al. concluded that composites appear too costly for the 2005-2010 time frame. OTA (1995) identified several mass reduction scenarios, including a 15% curb weight reduction from an advanced steel design and up to a 30% reduction for an aluminum-intensive design. OTA agreed with Stodolosky et al. that composites will remain too expensive for the foreseeable future.

Section Summary

A number of approaches can be used to assess the potential for technology-based efficiency improvements to cars and light trucks. Here we drew on three approaches, best-in-class analysis, fleetwide technology menu-based analysis, and engineering analysis, relying mainly on previously published results.

Best-in-class analyses indicate that modest levels of efficiency improvement (10%–15%) can be readily tapped, but may involve trade-offs of other vehicle attributes. Best-in-class vehicles involve little added cost; some vehicles may have improved technology, but in many cases, the more fuel-efficient vehicles can be less expensive than the class average because of trade-offs in performance or other amenities. Best-in-class purchases could form the basis for a widespread, low-risk promotional effort for efficient vehicles. However, of themselves, market creation efforts based on best-in-class specifications would be unlikely to pull advanced technologies into the market.

Near-term conventional vehicle technology assessments suggest potential fuel economy improvements of 30%–80% depending on assumptions and timing. Costs of such improvements appear to be relatively modest, for example, with payback times well under vehicle lifetimes. ACEEE's previously published estimates indicate the potential for a 40%–80% fleet average fuel

[3] The term body-in-white (BIW) refers to the basic structure of a vehicle, without doors and windows, interior components, wheels, and drivetrain.

economy improvement achievable at an average retail cost increase of 3%–4%. Such assessments examine fleetwide potential, but also suggest the improvement feasible within one product redesign cycle for a specific model, such as might be the target of a market creation program. A market creation program specification premised on such levels of improvement would entail relatively low risk. The risk for a program attempting to pull a few vehicles into the market is much lower than that for a regulatory program seeking to influence the entire market.

Advanced technologies, including drivetrain types and body structures not yet in production, offer efficiency levels that are double or more than those of current vehicles. However, costs presently appear to be much higher, with payback times approaching or exceeding vehicle lifetimes. The OTA (1995) analysis suggests that a doubling of fuel economy could entail a 20%–30% retail price increase. However, the results of OTA's assessment fall short of estimating the tripling of fuel economy which is a key goal of the PNGV. Given the targets of this program, as well as the results of other assessments, particularly for fuel cell vehicles, mature costs of advanced technology vehicles having doubled or tripled fuel economy could be less than suggested by OTA. OTA's hybrid vehicle assessments also seem overly cautious in light of the Toyota (1997) announcement. Finally, the degree of tractive load reduction (mainly mass reduction) achievable through new materials use and designs is a key factor determining advanced vehicle efficiency levels. Most studies assume use of metals for the foreseeable future; however, if the costs of composite-based designs were to fall, a higher horizon of potential efficiency improvements could open up.

5. PROGRAM OPTIONS AND IMPACTS

Earlier sections of this report examined the light duty market, its scale, and the sizes of various sub-markets (fleets, etc.) which could be organized for an efficient vehicle promotional program. Fairly large numbers of purchases would be needed to enable automakers to offer advanced vehicles without incurring high costs; the minimum for a single vehicle type and one automaker is on the order of 30,000 or more vehicles per year. If more than one automaker or vehicle type were pursued, the requisite numbers would multiply accordingly. Aggregating such numbers appears possible with fleet purchases not otherwise committed to AFVs. Post-2000, approximately 25,000 federal, 140,000 state and local, and over one million private (excluding rental) fleet purchases would be available annually after AFV (EPACT) commitments are met. Greater numbers of vehicles would be potentially available in the general market, which could be tapped for a market creation program not restricted to AFVs. Based on surveys of consumer interest in "greener" products generally, a program might ultimately be able to reach 3%–6% of the overall light duty market, or ½–1 million vehicles.

Based on the previous section's review of technologies applicable for efficiency improvement, best-in-class purchases could from the basis for a widespread, low-risk promotional effort with per-vehicle fuel economy improvements in the 10%–15% range. Best-in-class purchases need not involve new technology, and so would incur little or no cost premium. New technologies involving near-term refinements conventional vehicle designs have the potential to improve fuel economy by 40%–80% over the course of a product cycle for a single model. Costs of such improvements would be modest, probably no more than $1,200 per vehicle. Advanced technologies—involving drivetrain types (such as electric hybrid) and body structures not yet in mass production—can yield efficiency improvements in the range of 100% or more. However, costs appear to be significantly higher, with estimates ranging upwards of several thousand dollars per vehicle. Breakthroughs in technology and design could cause costs to fall once production reaches a large scale. Nevertheless, a market creation program that attempts to pave the way for advanced technologies could face cost premiums of several thousand dollars per vehicle.

This final section of the report reviews the options available for an efficient vehicle market creation initiative. Then, based on the findings of the previous sections, it highlights what appear to the more promising options for structuring a program. Finally, it examines the expected impacts of hypothetical program designs based on these options.

Potential Program Elements and Design

Potential elements of a Green Machine Challenge can be examined within the framework of the generic market transformation tools outlined by DeCicco and deLaski (1995). Research and development, such as PNGV, is a key "market push" policy. The set of mechanisms that might be considered for a market creation program is summarized in Table 5-1. An efficient technologies commercialization program could also involve market push in the form of manufacturer incentives, perhaps including lump-sum cash awards. Market pull elements could involve coordinated procurement, consumer incentives, consumer information, advertising, and other forms of

Table 5-1 Possible Elements of a Market Creation Program for Efficient Vehicles

Strategic Procurement (voluntary or mandatory)
Government Fleet Purchases
Private Fleet Purchases
Rental Fleets
General Market (individual buyers)
Involving guidelines for purchasing efficient (best-in-class) vehicles and up-front commitments (letters of intent) for step-forward vehicles.

Manufacturer Incentives
Competition
Per-Vehicle Subsidies or Tax Credits
Regulatory Incentives (e.g., fuel economy or emissions credits)

Consumer Incentives
Rebates
Tax or Fee Incentives (federal or state)
Special Privileges (e.g., parking)

Marketing and Consumer Information
Government or Business Sponsored Promotions
Green Vehicle Labeling
Green Vehicle Consumer Guide

publicity. Coordinated bulk purchases of vehicles would help to assure large enough initial markets to bring down per unit costs and to encourage manufacturers to commercialize market ready technologies. Manufacturer incentives or consumer rebates would strengthen this incentive.

Policies involving tangible financial incentives, whether payments or tax credits to manufacturers or rebates to consumers, would clearly be beneficial for spurring a market for more efficient vehicles. Extensive incentives could be similar to a "feebate" program, with guzzler taxes being an obvious source of revenues for rebates or other price incentives for the more efficient vehicles. Such programs have been covered elsewhere (DeCicco et al. 1993; Davis et al. 1995). Other revenue sources might be viable for a more limited program. Consider, for example, price incentives for 150,000 vehicles per year. Assuming an incentive amounting to 10% of price (like the electric vehicle tax credit provided by EPACT) for a vehicle priced at $25,000 amounts to $2500 per vehicle. The national cost would then be $375 million per year. Given near-term expectations of U.S. oil imports reaching 10 million barrels per day (EIA 1996), such a sum could be raised with an oil import fee of just under 11¢ per barrel (which would impact the retail prices of gasoline and heating oil by no more than 0.1¢ and 0.2¢ per gallon, respectively).

In any case, the cost of substantial incentives (that is, of a scope beyond demonstration programs), especially in terms of obtaining the political commitments (either federal or state) needed to offer them, is clearly a challenging issue. Political challenges also exist for mandatory procurement policies. For these reasons, we frame a program on the basis of voluntary procurement, while noting that complementing it with incentives or mandatory aspects could greatly enhance its impact.

Best-in-Class Purchasing

At the inception of a program, fleets and individuals willing to make immediate "green vehicle" purchases can choose only from what is already on the market. For widespread participation, most buyers could not be expected to pay significant cost premiums for the efficient vehicles. These constraints suggest a role for a best-in-class element (see Table 4-2 for illustrative best-in-class levels and the related discussion). No minimum scale threshold would constrain the viability of a best-in-class effort, since buyer participation is not contingent on automakers offering new vehicle designs. Therefore, even though it may not involve advanced technologies, a best-in-class initiative can offer small but immediate energy and emissions reduction benefits. It could also serve as an organizing framework, since it allows fleets and individuals who might be motivated to act on a environmental or energy conservation values with relatively low costs and risks. Some of these participants might later be willing to join in a more ambitious effort for procuring advanced technologies offering a greater degree of efficiency improvement. Thus, a "best-in-class" purchase commitment program is one practical element of a broader market creation initiative.

Pilot Marketing of Advanced Designs

As noted earlier, a program element that involves demonstrating sufficient up-front demand for more advanced vehicles would have to achieve numbers of at least several tens of thousands to perhaps 150,000 vehicles to make mass production possible. Both automakers and potential buyers would require experience with the new designs before making such extensive commitments. Therefore, a second program element involving pilot marketing of advanced technology vehicles would be warranted. Such an effort would have to commence at least a year or two in advance of the larger effort.

Test market programs have been pursued for various alternative fuel vehicles. An apt example is the prelude to mass introduction of electric vehicles in California. Automakers resisted offering vehicles for the general market at the level of 2% of their California sales in 1998. Instead, they are pursuing limited marketing in targeted areas. Prior to initial marketing of its EV1, GM ran an electric vehicle preview program involving 50 vehicles loaned to several hundred test customers who were given two-week trials with the vehicle. Similar pre-market trials would be desirable for other advanced vehicle technologies and automakers might reasonably expect government coordination and support for such efforts. In turn, a government program offering to aggregate an assured demand for efficient vehicles could expect automakers to pursue such pilot efforts as part of what it would take for a vehicle to qualify for purchase through the program.

A Step-Forward Efficiency Challenge

The third, and most ambitious, element of an efficient vehicle market creation program would be the actual "challenge" of obtaining advance purchase commitments of vehicles providing a significant "step-forward" in efficiency in sufficient numbers to warrant one or more automakers tooling up for mass production. The objective would be to obtain, nationwide, up-front purchase commitments for a 4–5 year period beginning 3–4 years after the step-forward efficiency challenge is announced.

It is unclear at this point whether a step-forward challenge should have a winner-take-all structure or allow for several winners (e.g., a first prize and second prizes, or the like). On one hand, having but one winner could engage an automaker's desire for a competitive advantage that might come from unique recognition. On the other hand, automakers might be discouraged from pursuing product development for fear of an absent or delayed pay-off in a winner-take-all situation. Thus, it might be desirable to collect enough purchase commitments to allow more than one automaker to win recognition. Allowing multiple qualifying vehicles is also consistent with the PNGV, through which U.S.-owned automakers are collaborating to develop advanced technologies for vehicle efficiency.

Although the PNGV is restricted to the "Big 3," it would not be desirable to so restrict a Green Machine Challenge which seeks to engage competitive forces in the service of environmental goals. However, some fleets, which are likely to form the core of a market creation effort, might have either explicit or implicit "buy American" procurement guidelines. Allowing multiple winners would be a way to address such considerations without overly restricting the competitive aspects of the program. Further guidance on this issue will have to be obtained through discussions with various stakeholders and potential program participants.

Vehicles qualifying for the step-forward challenge would meet specifications based on efficiency and other vehicle attributes. Drawing on the technology review of Section 4, Table 5-2 summarizes efficiency improvement levels implied by recently published technology assessments (other than those of Lovins). One question is whether the initial step of a challenge should be premised on a high likelihood of requiring very advanced (non-conventional) technologies, or whether the target should be set at a level more likely to be attainable through sophisticated refinements of conventional vehicle designs. Given the many risks of moving to truly revolutionary technologies and the tangible benefits of a significant efficiency improvement attained independently of technology, it appears that a less technology-presumptive initial target would be preferred. Such a target efficiency level would not preclude a design solution using non-conventional approaches (such as hybrid drivetrains or new structural materials). Thus, a prudent target for the first phase of a market creation program might be premised on allowing "advanced" conventional vehicle technologies, to insure likelihood of automakers being able to meet the challenge. If it is accepted that the market creation efforts will have future stages requiring fuel economy levels beyond those achievable with conventional technologies, then automakers could be encouraged to offer advanced technologies sooner in order to gain experience and stake a strategic claim on a future next-generation vehicle market.

Table 5-2 Potential Fuel Economy Values for Major Vehicle Classes under Various Assumptions of Technology Advancement

Technology Level	*Effcy incr.*	*Consm decr.*	Midsize Car	Large Car	Small Van	Small Utility	Large Pickup
Base (1993-95)	*0%*	*0%*	26.5	24	23	21	19
OTA 2005 opt., ACEEE L1-2	*50%*	*33%*	40	36	35	32	29
OTA 2005 hybrid, ACEEE L2-3	*75%*	*43%*	46	42	40	37	33
Intermediate (double MPG)	*100%*	*50%*	53	48	46	42	38
OTA 2015 hybrid	*150%*	*60%*	66	60	58	53	48
PNGV Goal 3	*200%*	*67%*	80	72	69	63	57

Note: Fuel economy levels are EPA unadjusted composite (55% city, 45% highway) MPG.

All-electric (such as battery powered) vehicles also offer potentially high efficiency levels. For example, GM's EV1 has a composite consumption rating of 0.28 kWh/mile (derived from GM 1996), the energy-equivalent of 132 mpg excluding electricity generation and distribution losses. Adjusting for such losses and the analogous refining and distribution losses for gasoline, its energy use rate is comparable to a fuel economy of 48 mpg,[4] about 80% higher than current 27 mpg average for the two-seater car class. (Some of the higher efficiency is due to streamlining and weight minimization, which could also be applied to gasoline vehicles.) Allowing selected electric or other alternative vehicles to qualify for participants of a challenge will promote coordination (rather than potential conflict) with existing programs to promote these vehicles. It would also afford greater flexibility for fleet buyers and other participating consumers. It is conceivable that some first-generation advanced efficiency gasoline vehicles (e.g., electric hybrids) could share some platform elements with an automaker's sibling all-electric models, thereby helping achieve the production-viable demand levels. Further research and analysis would be needed to develop alternative vehicle specifications compatible with those used for a given stage of a step-forward efficiency challenge.

Subsequent stages of a program could pursue more advanced high-efficiency and low-emissions targets. An ultimate stage of the challenge could target the PNGV Goal 3 of tripled efficiency. An intermediate stage could offer a challenge for doubled efficiency. It may not be realistic to propose details for second and latter stages of a challenge until experience is gained with a first stage. On the other hand, a stated goal of the PNGV is to have production prototypes ready in a 2005 time frame. Allowing for test marketing within two years of that time, a limited production scale (e.g., tens of thousands per firm) would then be feasible in another 2-3 years. Thus, if the PNGV meets its goal, a tripled fuel efficiency challenge could be viable by 2010. It would probably not make economic sense for automakers to have stages less than about 4-5 years apart, since that is already close to the most rapid product cycle lengths. Indeed, new products

[4] This calculation assumes a 30% primary energy to wall plug energy efficiency for electricity and a 83% oil well to gas pump energy efficiency for gasoline.

might initially require longer cycles to minimize cost risk. Advanced technology vehicles may not truly become profitable until much larger—hundreds of thousand vehicles per year—scales are achieved.

Given these considerations, it seems reasonable to propose only one stage prior to the PNGV Goal 3 level. Table 5-2 indicates a 75% efficiency improvement as being within the upper end of levels that could be attainable with conventional vehicles. It is also the level OTA identifies for a hybrid vehicle design in 2005. A further 75% improvement would yield tripled fuel economy. Therefore, such a first stage would be midway to the PNGV Goal 3, consistent with a two-step program. We therefore adopt this 75% improvement level as a preliminary recommended Green Machine Challenge target. Further work is needed to examine the implications of such a target level and refine it. For a mid-size car, a 75% fuel economy improvement implies 46 mpg; it implies 40 mpg for a minivan (estimates for other classes are shown in the table). Given that climate concerns are an important part of the motivation for a program such as this, it might be valuable to actually specify vehicle performance goals in terms of a reduction of greenhouse gas (GHG) emissions per mile. For gasoline vehicles, a 75% efficiency improvement would correspond to a 43% reduction in fuel consumption and per-mile CO_2 emissions. Additional specifications would have to be developed to address tailpipe emissions, safety, and an acceptable price, and control for (or specify minimum values of) other characteristics such as size, comfort, and performance. Also, the specifications would need to be extended to cover electric or other alternative vehicle technologies.

Implementation Steps

Implementation would proceed differently for the best-in-class versus the pilot advanced vehicle and step-forward elements of a market creation program. No obstacles exist to pursuing a best-in-class effort; what is needed is a commitment to move forward by key federal and state officials. Some of the organizational apparatus already exists for the various federal, state, and local alternative fuel vehicle programs underway. Moreover, an independent program spearheaded by the International Council for Local Environmental Initiatives (ICLEI) has been working for several years on "buy efficiency" projects modeled after the "Green Fleets" proposal developed in Denver, Colorado (Skinner and Cohen 1994). ICLEI's U.S. affiliate, Cities for Climate Protection (based in Berkeley, California), has been coordinating a set of municipal governments who are implementing efforts to reduce both CO_2 and criteria emissions from their local fleets. Their experience can provide important guidance for developing a broad-based best-in-class program as well as other elements of a Green Machine Challenge.

Another need is the development of supportive information on vehicle "greeness." Such information can provide the basis for purchase guidelines specific to vehicle classes and market segments. ACEEE has been researching these issues and is developing a vehicle rating system that incorporate both criteria emissions and greenhouse gas (linked to fuel efficiency) impacts; a first edition "green vehicle guide" will be published for model year 1998 (DeCicco and Thomas 1997). Once supportive information becomes available, coordination would be needed with automakers and agencies (in particular, the U.S. EPA and California Air Resources Board) who would act a primary data sources. If a program is purely voluntary, and labeling of vehicles as qualifying for "best-in-class" status is optional, then there should be no legal conflicts with the federal and state government-mandated efficiency, emissions, and alternative fuel labeling requirements. Further research efforts as well as collaboration by relevant agencies would be needed to develop a practical system to guide best-in-class vehicle purchases. A parallel effort would have to be undertaken to determine how best to promote the initiative and evaluate participation.

For the step-forward part of the program, a more complex set of undertakings would be needed. A best-in-class program could be pursued within the context of existing institutions and programs. A step-forward challenge could build on this foundation. However, the need for meaningful market aggregation, so that automakers would respond positively, requires demonstration of greater level of commitment and the likely establishment of a specialized entity to implement the challenge. A network would have to be set up to obtain memoranda of understanding or letters of intent for advance purchase of vehicles yet to be mass produced. Such advance commitments go beyond the types of obligations incurred in most existing voluntary programs (such as Clean Cities), and would to be framed and tracked so as to be sufficiently convincing that automakers would meet the challenge. The appeal to automakers from firm, up-front purchase commitments would have to be balanced against the buyer-participants' need to have confidence in the attributes of the promised step-forward technology vehicles.

Given preliminary design features identified earlier, several stages are likely to be needed to establish the step-forward program element of a Green Machine Challenge:

(1) A lead organization would be identified to formalize and coordinate the challenge. The organization could be a new entity, or it could be a program within an existing agency (e.g., building on DOE's "Clean Cities" program). The organization would need an advisory board drawing on key stakeholders for the program, including representatives of public and private fleet purchasers, consumer and environmental groups, government agencies, automakers, and other interested parties.

(2) The coordinating organization would review information on the needs of likely participants and assess technology development possibilities for advanced vehicles. Under the guidance of the advisory board, this information would be used to set the requirements for the qualifying vehicles, including emissions, performance, and safety specifications, certification procedures, and a delivery time frame.

(3) A group of charter buyer-participants would be recruited. These core participants, which could be drawn from federal agencies, state and local governments (e.g., drawing on Cities for Climate Protection), corporations, or institutions wishing to show environmental leadership, would serve to lend credibility to subsequent promotional efforts.

(4) The Challenge would be formally announced to the public, followed by extensive media coverage, promotion, and marketing of Green Machine purchase commitments to likely participants. A project office would be set up for the Green Machine Challenge, to mount the outreach, promotional, and communications efforts, coordinate purchase commitments, provide for communication among participants, and report on progress towards meeting the goals.

(5) In collaboration with automakers who have expressed a willingness to pursue the challenge, plans would then be developed to support the pilot (test marketing) phase for advanced vehicles. This effort would be expected to commence within roughly two years of formal announcement of target vehicle specifications.

Contingent on a favorable industry response to the Challenge, delivery of the winning vehicles would mark a turning point, at which the fulfillment of the challenge would be largely turned over to industry. Delivery of the initial "Green Machines" would involve major publicity, including auto shows, tours, and major media coverage of the vehicles, their performance, and their production. The Green Machine Challenge project would provide informational assistance to help insure that a large, sustainable market is established, providing the ultimate reward to manufacturers for their efforts. As noted earlier, special financing and other market incentives could enhance widespread acceptance of the Green Machines.

Expected Impacts

A Green Machine Challenge would be but one part of a broader market transformation effort leading to more efficient vehicles. As for R&D efforts like the PNGV, it is difficult, and not fully meaningful, to estimate energy savings and emissions reductions specifically attributable to such a program, since it creates no compelling market constraints. If price incentives were part of the program, an econometric response could be estimated. In that case, the impacts are likely to be similar to those of feebates (e.g., see Davis et al. 1995); the extent of impact would depend on the magnitude and market scope of the incentives. Since our focus is on a voluntary program, we do not assume the availability of incentives to help induce a market response. Since incentives could be valuable for increasing program impact, examining the design and likely impacts of Green Machine Challenge incentives is a worth subject for future analysis.

A Green Machine Challenge proposal was discussed during "Car Talk" (see Majority Report 1995, included in NEC 1996). The example policy outlined there involved two steps, first for a 100% improvement (doubled fuel economy) and second for a 200% improvement (tripled fuel economy), and an example procurement level of 50,000 vehicles per year. The Interagency Analysis Team supporting "Car Talk" did not score the program separately from PNGV, for which they developed three hypothetical scenarios for market penetrations of PNGV Goal 3 vehicles (averaging 80 mpg for cars and 60 mpg for light trucks). The most ambitious scenario involved Goal 3 vehicles attaining a 1% market share by 2006, 11% by 2010, 58% by 2015, and ongoing increases thereafter. The least ambitious scenario showed no significant penetration until 2015, when a 5% share was reached, followed by very rapid market share increases thereafter.

To estimate effects of the preliminary Green Machine Challenge design presented here, we separately treat the best-in-class and step-forward parts of the program. The intermediate step of a pilot marketing program for advanced technology vehicles would not be expected to have impacts at the level of national energy use and emissions statistics.

Best-in-Class Program

For estimating best-in-class impacts, we assume improvements over the class average as given in Table 4-2 applied to the six major classes that cover 75% of the market. The exception is for small utilities, where we replace the unreasonably high 33% improvement with a 14% improvement (the same as for all light trucks based on best 12 by weight class). The resulting sales-weighted MPG improvement would average 7.4% over all light vehicle classes; this value represents the average fuel economy improvement realized by buyers who make best-in-class purchases.

Because of better organizing abilities, fleets are likely to have higher best-in-class purchase commitment rates than the general market. For simplicity, we assume that the fleet commitment rate is double that of the general market. Then, using as an optimistic estimate that 15% of the general market eventually agrees to best-in-class purchasing, incorporating a doubled (i.e., 30%) commitment rate by fleets comprising 20% of the market, we obtain an 18% share. In other words, we are assuming that when the best-in-class initiative is fully operative, 30% of fleet purchases and 15% of remaining general market purchases will be best-in-class vehicles. A 7.4% fuel economy improvement in 18% of the market yields a 1.3% improvement overall. For a less optimistic scenario, we assume commitment rates half as large, implying a 0.7% fuel economy improvement.

If promotional efforts for best-in-class commitments first affect model year 1999 (e.g., starting fall 1998) and we assume that it takes five years for widespread participation, this 0.7% to 1.3% impact would be seen by roughly 2004. Given a total light vehicle market of about 16 million, 1.4–2.9 million vehicle purchases would have to be influenced. The implied annual new fleet average fuel economy improvements are 0.13%/yr to 0.26%/yr (barring the effect of the CAFE standards constraint—see below). We might further assume that the establishment of such best-in-class purchasing results in an ongoing response based on some combination of spreading buyer participation and manufacturers responding with more efficient offerings (though still short of significant new technology deployment). On that basis, we continue the annual improvement rates into the future. The resulting new fleet fuel economy improvements and light vehicle stock GHG emissions reductions are given in Table 5-3, relative to a frozen fuel economy baseline. Calculations were made using a light vehicle stock model account for vehicle stock turnover and compute fuel consumption, with GHG emissions estimated By 2010, for example, if the program yields new fleet average MPG improvements of 1.4% to 2.9%, then fuel savings would be 63,000 to 126,000 barrels per day (not shown) and GHG emissions reductions would be 4 to 7 MTc (million metric tons) per year, for lower and higher best-in-class participation rates, respectively. Under the stated assumptions of continuing improvements, the emissions reductions would reach 21 to 42 MTc by 2030.

Table 5-3 Summary of Estimated Green Machine Challenge Impacts on Light Duty Vehicle Fleet Efficiency and Greenhouse Gas Emissions

	Best-in-Class Program		Step-Forward Program	
	Low	High	Low	High
New fleet MPG improvement				
2005	0.8%	1.6%	0.4%	0.4%
2010	1.4%	2.9%	1.7%	1.7%
2015	2.1%	4.2%	4.0%	16.3%
2020	2.8%	5.6%	10.0%	50.0%
2025	3.4%	7.0%	19.5%	57.9%
2030	4.1%	8.4%	35.3%	66.7%
GHG reduction (MTc/yr)				
2005	1.2	2.4	0.3	0.3
2010	3.6	7.2	2.2	2.2
2015	7	14	9	23
2020	11	22	26	90
2025	16	31	57	166
2030	21	42	108	227

Assumptions: The best-in-class and step-forward programs are analyzed separately as described in the text, without accounting for the potential interactions of one program with the other or with other policies.

The baseline assumes a frozen new fleet average of 24.5 mpg, VMT growth averaging 1.8%/yr through 2010 (as in EIA 1996) and 1.6%/yr 2010-2030, and new vehicle sales increasing at 1%/yr 1990-2030.

MPG improvements are for the new fleet only; GHG reductions are for the light vehicle stock, in million metric tonnes of carbon-equivalent (MTc) based on a full fuel cycle emissions factor of 3.73 kg_C/gal.

Step-Forward Challenge

For estimating the impacts of a step-forward challenge, we also present low and high scenarios. The resulting impacts on overall new light duty fleet fuel economy and GHG emissions are shown in the last two columns of Table 5-3.

The low scenario envisions a staggered, two-stage program, with introductions of "Stage 1" vehicles (75% higher fuel economy) starting in 2003 and of "Stage 2" vehicles (tripled higher fuel economy) starting in 2010. Figure 5-1 illustrates hypothetical market evolution under this 2-stage step-forward efficient vehicle challenge scenario. The program starts with sales of 30,000 Stage 1 (46 mpg) mid-size vehicles in 2003, ramping up to 150,000 by 2008. Purchases of Stage 1 vehicles in other classes are assumed to start a year later and ramp up to 100,000 by 2008. We assume targeting of light truck classes for other step-forward challenge vehicles, which serves to increase the impact of the program since they have lower than overall average base fuel economy levels. We then assume that vehicles of 75% improved fuel economy spread throughout the market as time goes on, with market share doubling every 5 years in classes other than mid-size vehicles (which we cap at 1.5 million to allow room for the Stage 2 vehicles). This scenario results in Stage 1 vehicles attaining roughly 39% of the market by 2030.

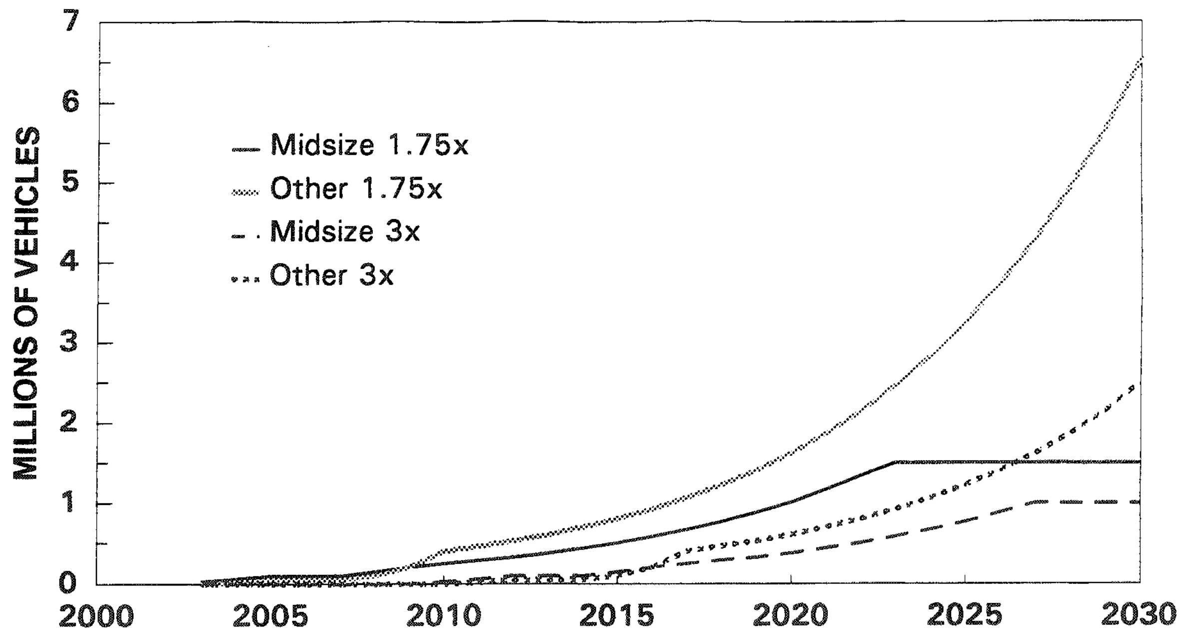

Figure 5-1. Sales Scenarios for Light Vehicles with Step-Forward Efficiency Improvements

As might be induced by a two-stage step-forward challenge; Stage 1 vehicles would have fuel economies 1.75 times the base and Stage 2 vehicles would have tripled fuel economies (see Table 5-2).

The second stage is assumed to start in 2010 and follow a pattern identical to that of the first stage, except that tripled fuel economy vehicles are introduced, while Stage 1 vehicles continue to more broadly permeate the market. The Stage 2 (tripled fuel economy) vehicle sales trajectories are shown as the dashed curves in Figure 5-1. Referring to Table 5-3, we see that through 2010, the fleetwide impacts of the step-forward program are lower than those assumed for the high case of the best-in-class program. However, impacts then accelerate. The step-forward low case would yield a 10% fleetwide fuel economy improvement by 2020 along with 26 MTc/yr of GHG emissions reductions.

For the high scenario of a step-forward challenge, we follow the low scenario through 2010 but then assume a much more rapid introduction of Stage 2 vehicles, drawing on PNGV Scenario 2 of Majority Report (1995, p. 36), without further promotion of Stage 1 vehicles once the tripled fuel efficiency vehicles are introduced. As shown in Table 5-3, these assumptions yield substantially higher fleetwide efficiency increases in 2015 and later. Thus, by 2030, the range of hypothetical impacts for a step-forward challenge would be new fleet average MPG improvements of 35% to 67% and GHG emissions reductions of 108 to 227 MTc/yr, for the low and high scenario assumptions, respectively.

The results presented here do not consider interactions, either of a best-in-class program with a step-forward program or of these Green Machine Challenge elements with other policies affecting the light duty sector. Given the uncertainties in response discussed earlier, it would be difficult to justify assuming that impacts as extensive as the larger values shown in Table 5-3 could follow from voluntary programs alone. Such initiatives are best viewed as complements to policies involving a binding impact on the market, such as stronger fuel economy standards (which have a track record of effectiveness) or feebates (for which supportive econometric estimates can be made).

Moreover, CAFE standards are already constraining the market to fuel economy levels higher that those likely to be observed in their absence (Greene 1990; DeCicco and Gordon 1995). As Sweeney (1979) pointed out in reference to gasoline taxes, gas guzzler taxes, and efficient vehicle procurement measures, "no policy option will increase mean efficiency unless that option provides strong enough incentives to increase mean efficiency above the standards even in their absence." (This result is due to the fleet-average, sales-weighted nature of CAFE standards; it would not apply, for example, to tailpipe emissions standards which specify uniform per-vehicle emission levels.) Even if standards are not raised, sales of either best-in-class vehicles or relatively modest numbers of step-forward vehicles could well be offset by increased sales of less efficient vehicles.

Costs

In general, the costs of a market creation program would be borne by three parties: vehicle purchasers, automakers, and government agencies. In this preliminary analysis, we examine only direct costs, not attempting to estimate external, hedonic, or induced costs other than those of changes in vehicle technology or program administration.

Of itself, the best-in-class purchasing aspect of a Green Machine Challenge would probably not be technology forcing. It is expected to involve only changing purchase choices among the range of models already on the market. Generally, the more fuel efficient models within a vehicle class are those with less powerful engines or fewer amenities. Thus, best-in-class purchasing would entail trading some of these other attributes for higher fuel economy, typically resulting in a lower cost to purchasers. To estimate this effect, we examined the relationship between fuel economy and vehicle price (Manufacturer's Suggested Retail Price—MSRP) for 1997 vehicles. Figure 5-2 shows log-log plots of vehicle price versus fuel economy for four major vehicle classes. The data set consists of top selling models obtained by matching fuel economy records from the *Gas Mileage Guide* (EPA 1997) and the *Automotive News Market Data Book* (1997). Table 5-4 shows the results of a simple set of regression analyses, which yield estimates of an elasticity of price with respect to fuel economy.

In general, the elasticity estimates straddle -1, suggesting that on average, a 10% increase in MPG is associated with a 10% decrease in price. However, considerable variation exists among classes. The EPA compact class and the combination of compact through large car classes display the strongest correlations (r^2) and highest magnitude elasticities. These size classes, particularly the compact, include cars from quite a range of market segments. The EPA compact class is based on cars having similar interior volumes and incorporates economy cars, designed for low price and good fuel economy, as well as sports cars and luxury coupes, targeted to buyers for

Table 5-4 Regression Results for New Vehicle Price versus Fuel Economy

Vehicle Class	Sample Means MPG	Sample Means Price	Estimated Elasticity	Standard Error	r^2
Compact	26.6	$16,800	-1.21	0.21	0.56
Mid-size	24.0	$19,900	-0.83	0.23	0.42
Large	21.2	$27,700	-0.97	1.04	0.08
Compact–Large	24.6	$20,000	-1.48	0.16	0.60
Minivans	18.8	$23,400	-0.23	0.53	0.01
Midsize Sport Utilities	17.7	$25,800	-1.31	0.23	0.51

Based on regressions of data from *Automotive News* (1997) and the *Gas Mileage Guide* (EPA 1997).

whom fuel economy is generally of little concern. The variation in fuel economy among compacts is about ±37%, and among the top-selling models analyzed, prices vary by a factor of two. In contrast, minivans are a relatively homogeneous class, with a ±17% variation in fuel economy and ±38% variation in price, and show a poor association of price with fuel economy. Sport utility vehicles (SUVs) show a relatively strong association although the variations in price and fuel economy within the class are not as large as for cars. Clearly, a more sophisticated analysis could be done by separating data into more carefully defined market segments, but falls beyond the scope of this study. For preliminary estimates of the price versus fuel economy relation likely to be seen in a best-in-class program, we adopt an elasticity of -1 as an reasonable approximation.

Figure 5-3 illustrates this favorable price versus fuel economy relationship as might be experienced by the buyer-participants in a best-in-class program. Among the model offerings in a given year (a static set of technology choices), higher fuel economy is obtained by trading-off other features, resulting in a lower price (curve BIC in the figure). For example, choosing vehicles with a 5% higher fuel economy is predicted to yield a purchase price savings of about $950. Also shown on the graph is the EEA cost curve for fuel economy increases obtained through technology improvements; this relationship is the most conservative of those presented earlier in Figure 4-1. For the range of fuel economy improvements shown, the downward price effect of the "best-in-class" (BIC) trade-off is much steeper than the upward incremental price due to technology improvements. So, even if we allow for manufacturers making some technology-based efficiency improvements, participating consumers would still save money on initial purchase price (curve BIC+EEA). The savings for a 5% fuel economy improvement then falls from $950 along the BIC curve to $830 along the BIC+EEA curve.

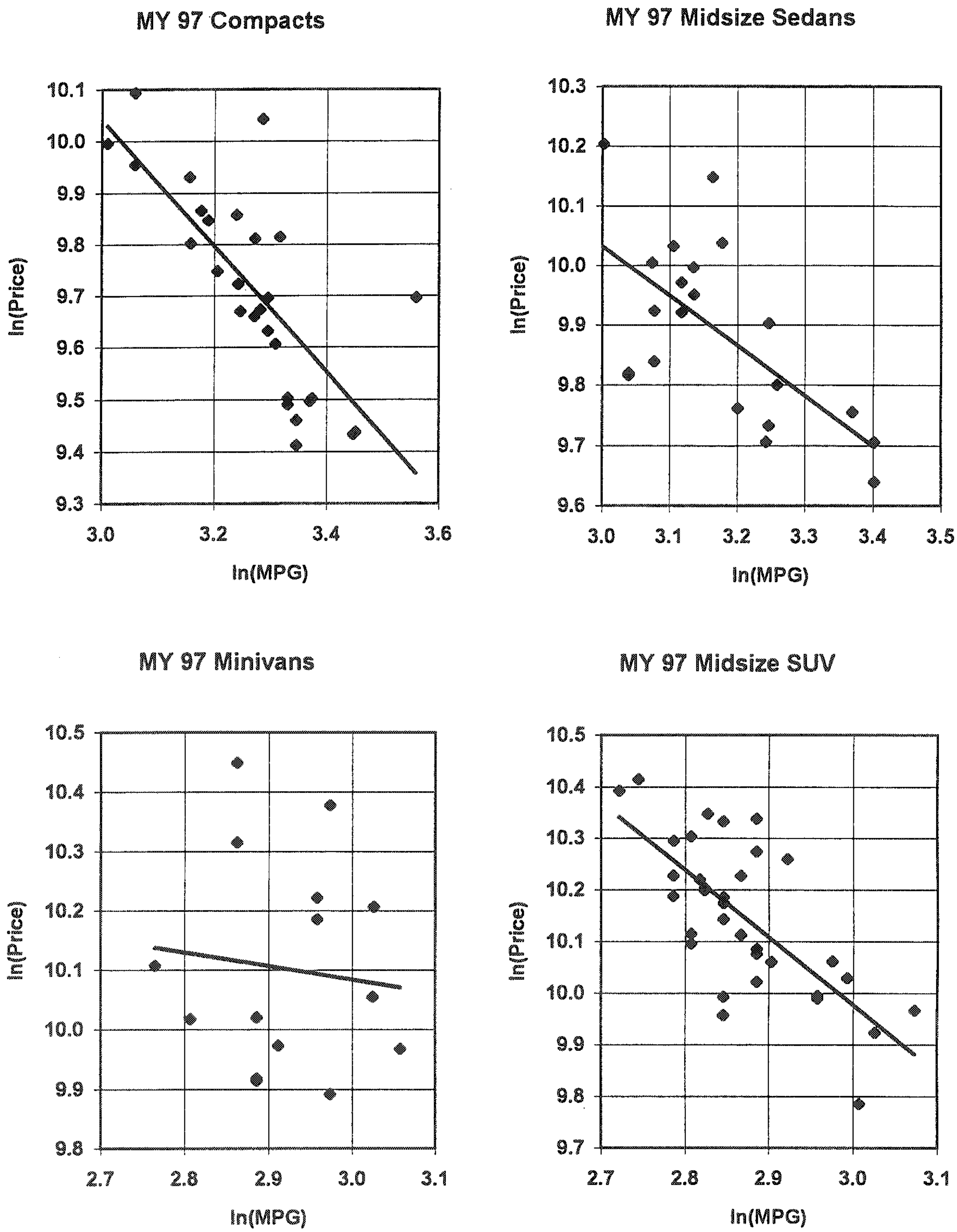

Figure 5.2 Price vs. Fuel Economy for Top-Selling Models within Major Vehicle Classes (Log-Log Plot)

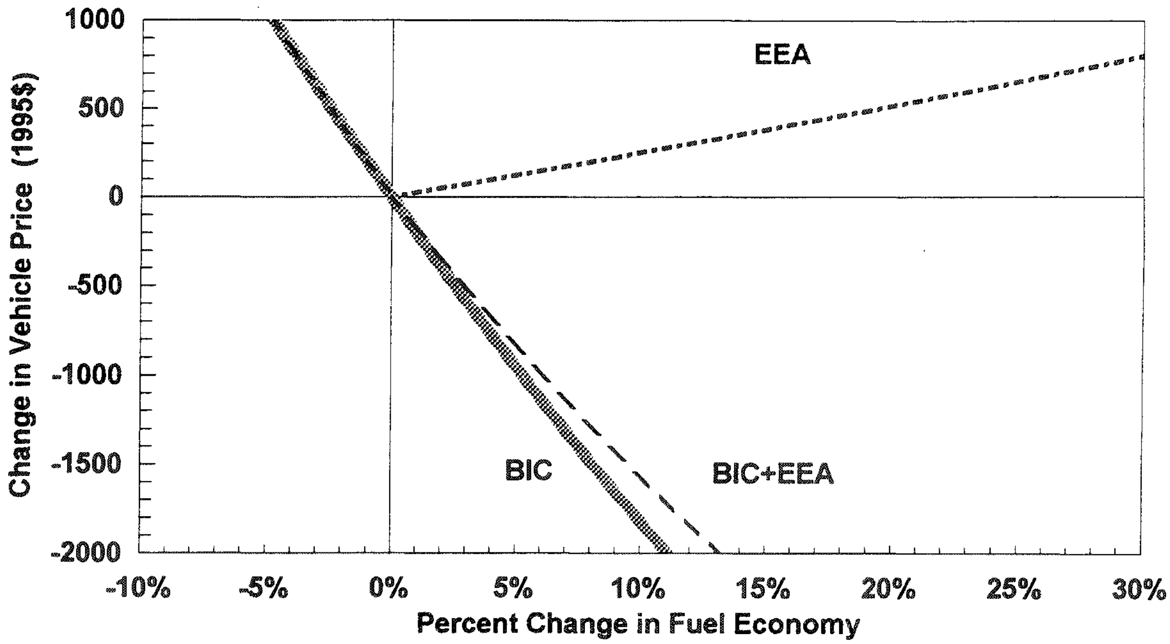

Figure 5-3. Price vs. Fuel Economy Relationships that might be seen in a Best-in-Class Vehicle Efficiency Program

Curve BIC represents a vehicle price vs. fuel economy elasticity of -1; the EEA curve is a portion of the same in Figure 4-1; BIC+EEA is the sum of the two curves.

Manufacturers could, however, respond with limited, special-edition "green" models targeted to a best-in-class program and incorporating more significant technology improvements (though still short of advanced, step-forward technologies). In this case, the response might entail a lesser trade-off of other vehicle features and allow manufacturers to retain revenues that might otherwise be forgone due to best-in-class program participants "buying down" for higher efficiency. Savings to participants might then be zero. The favorable cost impacts shown in Figure 5-3 could be interpreted as an upper bound on the savings to consumers, and actual savings could be less or even zero. As for manufacturers, costs they might incur depend on how they would respond to a best-in-class program. Special "green" models might be designed largely by low-cost re-calibrations of existing models, either technically (e.g., more fuel efficient calibration of an existing engine and transmission) or by re-packaging various features to better meet a "green" demand. If manufacturers make modest technology improvements, then an added cost would be incurred, but it could recouped from consumers. If manufacturers make no changes, then they would loose revenues equal to the consumer savings noted above, but presumably, they would also incur lower manufacturing costs. Automakers would experience the difference in profitability between best-in-class vehicles and the average vehicles whose sales are displaced, but we are not in a position to estimate this effect.

As noted previously, the CAFE constraint may imply no net change in fleet fuel economy. A best-in-class program might thus serve to bolster sales of vehicles that are more efficient than average, avoiding the need for some manufacturers to price these vehicles lower (i.e., cross subsidizing them through higher prices on vehicles less efficient than the CAFE standard). The result could then be no net cost to manufacturers. Nevertheless, if some firms have models better positioned than others to take advantage of best-in-class buying, a situation of no net cost to the industry could still entail some firms bearing costs of lost sales that are a gain to other firms. We cannot attempt to quantify such effects here, but they may merit investigation in future analysis of best-in-class program designs.

Granting such uncertainties, we estimate the cost impacts to vehicle purchasers as a range, from zero up to the savings suggested by the BIC+EEA trade-off curve in Figure 5-3. As described in Section 4, a well-promoted best-in-class program might influence 18% of the market to choose vehicles averaging 7.4% higher in fuel economy. This impact was judged to be feasible by 2004, when annual new light vehicle sales are projected to number about 16 million (Table 3-3). Applying the BIC+EEA curve for an 7.4% MPG improvement yields an estimate of $1200 for the average savings per vehicle. Summed over 18% of 16 million new vehicles yields aggregate savings of $3.5 billion. This estimate would be the upper bound of the direct vehicle cost savings to best-in-class participants; the lower bound is assumed to be zero. In short, we expect that participating in the best-in-class program of a Green Machine Challenge would impose no added vehicle acquisition costs on participants and may offer a significant savings. Participants will, of course, realize an operating cost savings. The 6.9% fuel consumption reduction corresponding to the average 7.4% MPG improvement would result in annual fuel cost savings of $52 per vehicle (assuming annual usage of 12,000 miles and a retail gasoline price of $1.25 per gallon); the annual aggregate fuel cost savings would $148 million for an initial program of the scale assumed here. If a best-in-class program induces small ongoing fleetwide MPG improvements as assumed in Table 5-3, aggregate fuel savings could reach $1.2–$2.4 billion by 2010.

For a step-forward challenge, costs of new technology would clearly be incurred. Considering an initial step, such as the 75% fuel economy improvement challenge suggested above, incremental costs might range from those expected if meeting the challenge through conventional technologies (as in Figure 4-1) to those estimated for advanced vehicles (as in Figure 4-2). The result is quite a range, from $700 under ACEEE Level 3 assumptions using conventional technologies to $4600 under EEA "2005" assumptions using advanced technologies. A step-forward challenge met with one limited production line of 30,000 vehicles might then cost as little as $21 million or as much as $140 million (retail price impacts). Involving several manufacturers and a total of 150,000 vehicles would imply an aggregate incremental cost range of $105 million to $690 million. A program that ramps up rapidly to attain the 1.7% fleetwide efficiency improvement by 2010 as given in Table 5-3 would involve 680,000 "step-forward" vehicles; the implied annual aggregate incremental vehicle cost would be $480 million to $3.1 billion.

How these costs are borne between manufacturers and consumers would depend on the pricing strategy adopted by manufacturers for the step-forward vehicles, which might in turn be constrained by cost limitations placed on the program by participants. The annual fuel savings for a 75% fuel economy improvement over a 28 mpg vehicle would be $270 per year (assuming 12,000 miles/year, $1.25/gallon gasoline, 15% shortfall). Participants might limit what they are willing to pay, for example, to a four-year payback, which, if undiscounted, means an incremental price of $1080. If the technology costs are only $700 per vehicle, manufacturers could meet the challenge at an additional profit (recall that all vehicle price estimates are at the retail level, so average profits are already assumed). On the other hand, technology costing $4600 could probably only be offered at a loss. Such considerations are why incentives would be valuable (and might perhaps be necessary) for a step-forward challenge; the effect of incentives, of course, is to transfer some of the added costs to the government (and ultimately taxpayers).

Administrative Costs

Program administrative costs would be a relatively small aspect of the overall cost implications of market creation programs. However, in a time of lean operations at all levels of government, it would be important to pursue programs with minimal new cost. At the federal level, Green Machine Challenge efforts could be coordinated between the Department of Energy (DOE) and the Environmental Protection Agency (EPA). At the state and local levels, efforts could involve departments dealing with environmental issues (particularly air quality) and natural resources. Private fleets involved in a program would also incur added administrative costs. Here we examine only potential federal costs, since federal efforts would be an early initial step in starting a nationwide program as outlined here. However, it is important to keep in mind that a program is only meaningful once it involves widespread participation, and so the involvement and costs to state, local, and private parties would ultimately exceed any federal costs. These parties will also receive the benefits of reduced fuel costs and reduced pollution; however, a full cost-benefit analysis is beyond the scope of this report.

DOE already has implementation-oriented (as opposed technology development or regulatory) programs as part of its Office of Transportation Technologies (OTT). The OTT Office of Technology Utilization have been recently budgeted at $10 million per year. This office now administers the alternative fuels market creation efforts authorized by EPACT, including the Clean Cities program noted in Section 3 of this report. It is possible that efficiency-oriented efforts could be built upon the existing AFV efforts. EPACT does not, in the way it specifies petroleum displacement goals, spell out specific goals for energy efficiency improvement, criteria emissions reduction, or greenhouse gas emissions reduction. However, it does have language stating that these should be considered in the programs it authorizes and energy efficiency improvement in particular is a long-standing part of DOE's overall mission (all of the relevant programs fall under the Office of Energy Efficiency and Renewable Energy). Thus, extensions of the programs now emphasizing alternative fuels deployment could be rationalized provided that they can be shown to be compatible with EPACT's petroleum displacement goals.

EPA has implementation-oriented programs in its Office of Mobile Source (OMS) and Office of Atmospheric Programs (OAP), both of which are part of the Office of Air and Radiation. OMS's traditional focus has been regulation (it administers the federal motor vehicle emissions standards) and it has also conducted technology R&D (it is one of the federal participants in the PNGV). OMS also has programs oriented to helping state and local governments pursue air quality improvement plans, e.g., through approaches to travel demand reduction. OAP is the home of EPA's "Green Programs" which have spearheaded a number of successful voluntary energy efficiency initiatives in the commercial sector as means of cost-effectively reducing pollution, largely through electricity conservation. Pollution prevention would also provide a strong rationale for a Green Machine Challenge, particularly if oriented to promoting vehicles having both higher efficiency and lower criteria emissions.

A bottom-up approach to estimating administrative costs could be based on a rough estimate of $150,000 per person-year (salary plus overhead) for staff that might be assigned to Green Machine Challenge efforts. A program might reasonably get underway with 3–5 staff, utilizing existing management and providing for some associated expenses such as travel and consultants, for under $1 million dollars. Clearly, however, a program would have wider reach with a larger commitment of resources. Developing a "business plan" for a Green Machine Challenge with more detailed administrative cost estimates would be an important early step if policy makers wish to pursue this promising concept.

Section Summary

Previous work on market creation approaches for new products designed for improved energy efficiency and environmental performance identified a range of mechanisms that can be used to generate a market pull for new technology. Coordinated procurement is one such strategy. Based on our review of the automotive market and the opportunities to improve vehicle efficiency, both near-term and long-term, we propose several elements for a "Green Machine Challenge."

One would be a best-in-class vehicle purchasing initiative to encourage both fleets and general buyers to select the cleanest and most efficient vehicles that meet their needs. Such an effort could be organized immediately and its costs would be relatively small. Best-in-class purchasing could provide an up-front purchase price savings to consumers as well as fuel savings. Alone, however, it unlikely to create a strong enough pull for advanced technologies. A best-in-class program could be pursued within the context of existing institutions and programs. The value of a best-in-class program is its potential for widespread, low-risk participation, which would create a climate for more ambitious market-creation efforts while delivering modest energy efficiency and environmental benefits in the near term.

The greater up-front costs and risks associated with advanced technologies suggests a "step-forward" vehicle efficiency challenge. This program element would assemble an advance purchase pool for vehicles that meet specifications of substantially higher efficiency and lower emissions, offering a "step-forward" from designs already on the market. The program would be announced several years in advance and automakers could compete to supply the vehicles. A new entity, either independent or a special office within an existing institution, is likely to be needed to carry it out. Implementation would involve obtaining memoranda of understanding or letters of intent for advance purchase of vehicles yet to be produced, and doing so in a way that motivates automakers to meet the challenge. A multi-stakeholder advisory board could guide the development of detailed plans and a set of core participants should be assembled to give the program credibility. An intermediate step of an advanced-technology pilot marketing program would be desirable as a prelude to the step-forward challenge.

Alone, market creation efforts are unlikely to provide benefits as large as those obtainable from regulatory programs. Financial incentives would increase the impact of any program, but incentives are not needed to get started, particularly for a best-in-class program. Any program would incur administrative costs borne by the federal government for coordinating a nationwide effort and by other levels of government and the private sector which participate. A Green Machine Challenge could be launched within existing programs at DOE and EPA with little added expenditure, perhaps a $1 million investment for a few staff and associated program expenses to get started. In general, great uncertainty is associated with estimating a national-scope impacts in the absence of market-wide policies such as stronger CAFE standards or feebates. We cannot say that a voluntary market creation effort would, with high probability and of itself, have non-zero benefits. Keeping in mind that the overall lower bound may be zero, reasonable scenarios of energy savings and emissions reductions can be constructed.

For a best-in-class program, plausible assumptions yield fleetwide fuel economy increases of 1%–3% through 2010. If fleet improvement at similar rates continues, one might see a 4%–8% fleetwide MPG improvement by 2030. Based on the lower bound of zero and the upper end of these MPG improvement ranges, GHG emissions reductions from a best-in-class program would be 0–7 MTc by 2010 and 0–42 MTc by 2030. Because a best-in-class program can involve trading off other features for higher efficiency, its costs to purchasers could be negative. On the other hand, to avoid revenue losses manufacturers might offer "green" models, involving redesign without significant new technology but reducing vehicle price savings, perhaps to zero. The implied range of average price savings is thus 0–$1200 per vehicle. Aggregated nationwide, the upper bound savings would be $3.5 billion. Thus, for 2010, the most optimistic impacts projected here are a 7 MTc GHG reduction obtained at vehicle price savings of $3.5 billion; the fuel cost savings would be $2.4 billion.

For a step-forward challenge, a two-stage scenario could have Stage 1 vehicles of 75% higher MPG introduced in 2003 and Stage 2 vehicles of tripled MPG introduced in 2010. Based on recent (1995) averages, e.g., for mid-size cars at 26.5 mpg, Stage 1 vehicles would get 46 mpg and Stage 2 vehicles would get 80 mpg. Due to the relatively small numbers of vehicles involved, fleetwide fuel economy impacts would be below 2% through 2010. Much larger impacts, perhaps a 35%–67% fleetwide MPG improvement by 2030, can be foreseen if a combination of efforts—market creation programs, successful R&D, and a major commitment to promote advanced efficiency vehicles on the part of government and industry—results in widespread acceptance of new-generation vehicles. Translating these MPG improvements to GHG emissions reductions implies that a step-forward program might yield 0–2 MTc by 2010 and 0–227 MTc by 2030. The costs of new technology for the first stage of a step-forward challenge could range from $700 per vehicle if refined conventional technologies are used to $4600 if advanced technologies, such as a hybrid drivetrain, are used. A program involving several manufacturers and a total of 150,000 vehicles would then imply an aggregate incremental cost range of $105 million to $690 million. We do not attempt to project costs beyond this already broad range of uncertainty for the first stage of a step-forward challenge. Clearly further study, ideally directed by a planning effort involving a range of interests (including the automotive industry and potential purchaser-participants), is needed regarding program design options, issues, and impacts.

REFERENCES

AAMA. 1995. Motor Vehicle Facts and Figures 1995. Detroit, MI: American Automobile Manufacturers Association.

Automotive News. 1997. Market Data Book. Detroit, MI: Crain Communications.

Bleviss, D. 1988. The New Oil Crisis and Fuel Economy Technologies: Preparing the Light Transportation Industry for the 1990s. New York: Quorum Books.

Bobit. 1994. Automotive Fleet 1994 Fact Book. Redondo Beach, CA: Bobit Publishing Company.

Bunch, D.S., M. Bradley, T.F. Golub, R. Kitamura, and G.P. Occhiuzzo. 1993. Demand for Clean-Fuel Vehicles in California: A Discrete-Choice Stated Preference Pilot Project. Transportation Research 27A: 237-253.

CCAP. 1993. Climate Change Action Plan. Issued by President W.J. Clinton and Vice-President A. Gore, The White House, Washington, DC, October.

Chew, E. 1996. New Era: Million-Unit Platforms. Automotive News, p. 1, August 19.

Clark, K.B., and T. Fujimoto. 1991. Product Development Performance: Strategy, Organization, and Management in the World Auto Industry. Boston, MA: Harvard Business School Press.

Davis, S.C. 1995. Transportation Energy Data Book: Edition 15. Report ORNL-6856. Oak Ridge, TN: Oak Ridge National Laboratory. May.

Davis, W.B., M.D. Levine, K. Train, and K.G. Duleep. 1995. Effects of Feebates on Vehicle Fuel Economy, Carbon Dioxide Emissions, and Consumer Surplus. Report DOE/PO-0031, Office of Policy. Washington, DC: U.S. Department of Energy. February.

DeCicco, J.M. 1992. A Critique of the National Research Council Study of the Potential for Improving Automotive Fuel Economy. Presentation to the 1992 SAE Government/Industry meeting. Washington, DC: American Council for an Energy-Efficient Economy. April.

DeCicco, J., and A. deLaski. 1995. The Green Machine Challenge: a Concept for Promoting Ultra-Efficient Vehicles. Washington, DC: American Council for an Energy-Efficient Economy. March.

DeCicco, J.M., and D. Gordon. 1995. Steering with Prices: Fuel and Vehicle Taxation as Market Incentives for Higher Fuel Economy. Chapter 10 in D. Sperling and S. Shaheen (eds.), Transportation and Energy: Strategies for a Sustainable Transportation System. Washington, DC: American Council for an Energy-Efficient Economy.

DeCicco, J.M., H.S. Geller, and J.H. Morrill. 1993. Feebates for Fuel Economy: Market Incentives for Encouraging Production and Sales of Efficient Vehicles. Washington, DC: American Council for an Energy-Efficient Economy. May.

DeCicco, J.M., and M. Ross. 1993. An Updated Assessment of the Near-Term Potential for Improving Automotive Fuel Economy. Washington, DC: American Council for an Energy-Efficient Economy. November.

DeCicco, J., and M. Thomas. 1997. An Integrated Methodology for Rating Car and Light Truck Environmental Performance. Draft report. Washington, DC: American Council for an Energy-Efficient Economy. July.

DeLuchi, M.A. 1992. Hydrogen Fuel-Cell Vehicles. Research Report UCD-ITS-RR-92-14. Davis, CA: University of California, Institute of Transportation Studies. September.

DeLuchi, M.A., Q. Wang, and D.L. Greene. 1992. Motor vehicle fuel economy: the forgotten HC control strategy? Report ORNL-6715, Oak Ridge National Laboratory, Oak Ridge, TN, June 1992.

DOE. 1992. Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector, Technical Report 10: Analysis of Alternative Fuel Fleet Requirements. DOE/PE-0103P. Washington, DC: U.S. Department of Energy. May.

DOE. 1995. EPACT Initiatives for Alternative Fuel Vehicles. Washington, DC: U.S. Department of Energy, Office of Transportation Technologies. March.

DOE. 1996a. Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector, Technical Report 14: Market Potential and Impacts of Alternative Fuel Use in Light-Duty Vehicles: A 200/2010 Analysis. DOE/PO-0042. Washington, DC: U.S. Department of Energy. January.

DOE. 1996b. Policies and Measures for Reducing Energy Related Greenhouse Gas Emissions, Lessons from the Recent Literature. DOE/PO-0047. Washington, DC: U.S. Department of Energy. July.

Doi, D.A. 1992. Major Automotive Firms' Engine Technology Development (1980-1990). M.S. Thesis. Cambridge, MA: Massachusetts Institute of Technology, School of Management. May.

Dow Jones Newswires. 1997. Toyota Pips Rivals to Show Off Electric-Gasoline Hybrid Car. New York: Dow Jones & Co., May 30.

Duleep, K.G. 1997a. The Potential for Evolutionary and Revolutionary Technologies to Improve Automotive Fuel Economy. In J. DeCicco and M. Delucchi (eds.), Transportation, Energy, and the Environment: How Far Can Technology Take Us? Washington, DC: American Council for an Energy-Efficient Economy.

Duleep, K.G. 1997b. Parameters representing EEA estimates of the costs of fuel economy improvement. Personal communication to author, March.

EIA. 1994. Alternatives to Traditional Transportation Fuels: An Overview. Washington DC: U.S. Department of Energy, Energy Information Administration. June.

EIA. 1996a. Annual Energy Outlook 1996, with Projections to 2015. Report DOE/EIA-0383(96). Washington, DC: U.S. Department of Energy, Energy Information Administration. January.

EIA. 1996b. Alternatives to Traditional Transportation Fuels 1994, Vol. 1. Report DOE/EIA-0585(94)-1. Washington DC: U.S. Department of Energy, Energy Information Administration. February.

EPA. 1980. Passenger Car Fuel Economy: EPA and Road. Report EPA 460/3-80-010, Ann Arbor, MI: U.S. Environmental Protection Agency, September.

EPA. 1994. Determinants of Effectiveness for Environmental Certification and Labeling Programs. Report EPA 742-R-94-001, Office of Pollution Prevention and Toxics. Washington, DC: U.S. Environmental Protection Agency. April.

EPA. 1997 (annual). Gas Mileage Guide. Washington, DC: U.S. Department of Energy and Environmental Protection Agency.

EPACT. 1992. Energy Policy Act of 1992. 102nd Congress, 2nd Session, Report 102-1018. Washington, DC: U.S. Government Printing Office, October 5.

Federal Fleet Conversion Task Force. 1993. First Interim Report of the Federal Fleet Conversion Task Force. Report DOE/PO-001, U.S. Department of Energy, Washington, DC, August.

Geller, H., and S. Nadel. 1994. Market Transformation Strategies to Promote End-Use Efficiency. Washington, DC: American Council for an Energy-Efficient Economy. June.

German, J. 1997. Personal communication to author. (U.S. Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI).

GM. 1996. EV1 Media Information. Folder of press releases and specification sheets. Detroit, MI: General Motors Corporation. December.

GM/Allison. 1993. Research and Development of Proton-Exchange Membrane (PEM) Fuel Cell Systems for Transportation Applications: Initial Conceptual Design Report. Prepared for the U.S. Department of Energy, Office of Transportation Technologies. Indianapolis, IN: General Motors Corporation, Allison Gas Turbine Division. November.

Greene, D.L. 1983. A Note on Implicit Consumer Discounting of Automobile Fuel Economy: Reviewing the Available Evidence. Transportation Research 17B(6): 491-499.

Greene, D.L. 1990. CAFE or Price? An Analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Price on New Car MPG, 1978-1989. Energy Journal 11(3):37-57, September.

Greene, D.L. 1996. Transportation & Energy. Lansdowne, VA: Eno Foundation for Transportation.

Greene, D.L., and K.G. Duleep. 1993. Costs and benefits of automotive fuel economy improvement: a partial analysis. Transportation Research 27A(3):217-235.

GSA. 1991. Federal Motor Vehicle Report for FY 1991. U.S. General Services Administration, Washington, DC.

Heavenrich, R.M., and K.H. Hellman. 1996. Light-Duty Automotive Technology and Fuel Economy Trends through 1996. Report EPA/AA/TDSG/96-01. Ann Arbor, MI: U.S. Environmental Protection Agency, Office of Mobile Sources. August.

Hill, N.W., and R.P. Larsen. 1990. Evaluation of the Federal Fuel Economy Information Program. Interim Report. Argonne, IL: Argonne National Laboratory, Center for Transportation Research. October.

Honda. 1991. "Honda develops new engine that offers high fuel efficiency and excellent performance" and "Background on VTEC-E in the U.S. market." Press release and background paper. Washington, DC: American Honda Motor Co., July.

IPCC. 1996. Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, England: Cambridge University Press.

Johnson, R. 1994. The Japanese Come Roaring Back. Automotive News, p. 1, December 5.

Kempton, W., J.S. Boster, and J.A. Hartley. 1995. Environmental Values in American Culture. Cambridge, MA: MIT Press.

Knight, B. 1995. The Honda Civic VX, Briefing on the Concept, Technology, and Market Impact of a High-Mileage Vehicle. Paper presented to the U.S. Federal Advisory Committee on Personal Motor Vehicle Greenhouse Gas Reduction. Torrance, CA: Honda North America, Inc., January.

Lewis, E.J., and E. Weltman. 1992. Forty Ways to Make Government Purchasing Green. Washington, DC: Center for Study of Responsive Law.

Lovins, A. 1995. Hypercars: The Next Industrial Revolution. Chapter 5 in D. Sperling and S.A. Shaheen (eds.), Transportation and Energy: Strategies for a Sustainable Transportation System. Washington, DC: American Council for an Energy-Efficient Economy.

Majority Report. 1995. Majority Report to the President by the Policy Dialog Advisory Committee to Recommend Options for Reducing Greenhouse Gas Emissions from Personal Motor Vehicles. Washington, DC: U.S. Environmental Protection Agency, Air Docket. October.

Mark, J. 1996. Zeroing Out Pollution: The Promise of Fuel Cell Vehicles. Cambridge, MA: Union of Concerned Scientists. May.

Miaou, S.P., P.S. Hu, and J.R. Young. 1992. Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices. Report ORNL-6717. Oak Ridge, TN: Oak Ridge National Laboratory. May.

Mintz, M.M., A.R.D. Vyas, and L.A. Conley. 1993. Differences between EPA-test and in-use fuel economy: are the correction factors correct? TRB Paper No. 931104, Washington, DC: Transportation Research Board, January.

McNutt, B. 1989. In Sperling, D. (ed.). Alternative Transportation Fuels: an Environmental and Energy Solution. New York: Quorum Books.

Miyoshi, N., et al. 1995. Development of New Concept Three-Way Catalyst for Automotive Lean-Burn Engines. Paper SAE 950809. Warrendale, PA: Society of Automotive Engineers.

Murrell, J.D. 1995. Fuel Economy and Market Analysis: Light Duty Trucks. Report prepared for the American Council for an Energy-Efficient Economy. January.

Murrell, J.D., K.H. Hellman, and R.M. Heavenrich. 1993. Light-duty automotive technology and fuel economy trends through 1993. Report EPA/AA/TDG/93-01, U.S. Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI, May 1993.

NAFA. 1995. Fleet Acquisition Survey. NAFA Fleet Executive Magazine. Iselin, NJ: National Association of Fleet Administrators.

NEC. 1996. Report to the President of the Interagency Steering Committee on the Outcome of the Deliberations of the Policy Dialog Advisory Committee to Assist in the Development of Measures to Significantly Reduce Greenhouse Gas Emissions from Personal Motor Vehicles. Washington, DC: National Economic Council. February

NHTSA. 1996. Summary of Fuel Economy Performance. Semi-annual report, NHTSA Docket No. FE-GR-013. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration. February.

Ogden, J.M., E.D. Larson, and M.A. Delucchi. 1994. Technical and Economic Assessment of Renewable Transportation Technologies. Report prepared for the Office of Technology Assessment. Princeton, NJ: Princeton University, Center for Energy and Environmental Studies. May.

OTA. 1991. Improving Automobile Fuel Economy: New Standards, New Approaches. Report OTA-E-504. Washington, DC: U.S. Congress, Office of Technology Assessment. October.

OTA. 1995. Advanced Automotive Technology: Visions of a Super-Efficient Family Car. Report OTA-ETI-638. Washington, DC: U.S. Congress, Office of Technology Assessment. September.

NEC. 1996. Report to the President by the Interagency Steering Committee on the Outcome of the Deliberations of the Policy Dialog Advisory Committee to Assist in the Development of Measures to Significantly Reduce Greenhouse Gas Emissions from Personal Motor Vehicles. Washington, DC: National Economic Council. February.

NRC. 1992. Automotive Fuel Economy: How Far Should We Go? Report of the National Research Council, Committee on Fuel Economy of Automobiles and Light Trucks. Washington, DC: National Academy Press.

PNGV. 1995. Partnership for a New Generation of Vehicles. Program Plan. Washington, DC: U.S. Department of Commerce. November.

Porsche. 1995. Ultra-Light Steel Auto Body, Phase 1.B Findings. Porsche Engineering Services, Inc., August.

Resolve. 1995. Policy Dialog Advisory Committee to Assist in the Development of Measures to Significantly Reduce Greenhouse Gas Emissions from Personal Motor Vehicles. Interim Report to the President. Washington, DC: Resolve, Inc., March.

Ross, M., M. Ledbetter, and F. An. 1991. Options for Reducing Oil Use by Light Vehicles: an Analysis of Technologies and Policy. Washington, DC: American Council for an Energy-Efficient Economy. December.

Shprentz, D.S. 1996. Breath-Taking: Premature Mortality due to Particulate Air Pollution in 239 American Cities. Washington, DC: Natural Resources Defense Council. May.

Singh, M. 1996. Fleet AFV Sales Estimates. Memorandum. Washington, DC: Argonne National Laboratory. July 3, with update of August 9.

Singh, M., and M. Mintz. 1997. Alternative Fuels and Vehicles: Transition Issues and Costs. In J. DeCicco and M. Delucchi (eds.), Transportation, Energy, and the Environment: How Far Can Technology Take Us? Washington, DC: American Council for an Energy-Efficient Economy.

Skinner, N. and S. Cohen. 1994. Strategies for Reducing the Energy Consumed by Municipal Fleets and Employee Job-Related Travel. Green Fleets Project Report. Toronto, Ontario: International Council for Local Environmental Initiatives. June.

Sperling, D. 1995. Future Drive: Electric Vehicles and Sustainable Transportation. Washington, DC: Island Press.

SRI. 1991. Potential for Improved Fuel Economy in Passenger Cars and Light Trucks. Report prepared for the Motor Vehicle Manufacturers Association. Melno Park, CA: SRI International. July.

Stisser, P. 1994. A Deeper Shade of Green. American Demographics, 24-29. March.

Stodolsky, F., A. Vyas, and R. Cuenca. 1995. Lightweight Materials in the Light Duty Passenger Vehicle Market: Their Market Penetration Potential and Impacts. Washington, DC: Argonne National Laboratory. March.

Sustainable Energy Blueprint. 1992. Washington, DC: Public Citizen, Critical Mass Energy Project.

Sweeney, J.L. 1979. Effects of Federal Policies on Gasoline Consumption. Resources and Energy 2:3-26.

Toyota. 1996. Toyota Develops New D-4 Fuel Efficient, High-Output Direct-Injection Gasoline Engine. Press Release. Tokyo: Toyota Motor Corporation, 5 August.

Toyota. 1997. Toyota Introduces New Passenger Vehicle Hybrid System. Press Release. Tokyo: Toyota Motor Corporation, 25 March.

Train, K. 1986. Qualitative Choice Analysis. Cambridge, MA: MIT Press.

USCAR. 1996. PNGV Technical Accomplishments. Detroit, MI: United States Council for Automotive Research. July.

Walsh, M. 1996. EU Commission Releases Comprehensive Auto Pollution Proposal. Car Lines 96-4:1, July.

Westling, H. 1996. Co-operative Procurement: Market Acceptance for Innovative Energy-Efficient Technologies. Stockholm, Sweden: Nutek.

Woodruff, D., and K.L. Miller. 1993. Chrysler's Neon--Is This the Small Car Detroit Couldn't Build? Business Week, May 3.