Chapter 6

TRANSPORTATION SECTOR[1]

6.1 INTRODUCTION

The U.S. transportation sector includes highway, air, rail, shipping, pipeline, and off-road transport as well as miscellaneous categories such as recreational boats and military fuel consumption. In 1997, the sector consumed about 25 quads of primary energy, 27 percent of total U.S. energy consumption. The sector is also the nation's primary oil consumer at 12.1 million barrels per day (mmbd) in 1997, about 65 percent of total U.S. consumption. Transportation is responsible for almost one-third of U.S. carbon emissions, substantial amounts of most air pollutants, and two-thirds of U.S. oil consumption (Table 6.1). In the same year, the sector had carbon emissions of 478 million metric tons (MtC), 32 percent of the U.S. total carbon emissions. In the face of strong continuing demand for transportation services, slow turnover of fleets, gasoline's dominance of light-duty vehicle fueling infrastructure, and low energy prices that provide only modest incentives for improved efficiency, U.S. transportation energy consumption and greenhouse emissions are expected to grow robustly over the next few decades.

Table 6.1 Contribution of the Transportation Sector to National Issues and Problems

National Issue	1997 Amount	1997 % of U.S. Amount
Climate Change – Carbon Emissions	473.1 Million metric tons carbon	32.0%
Air Pollution – CO	60.9 Million metric tons	76.6%
Air Pollution – Nox	10.5 Million metric tons	49.2%
Air Pollution – VOC	7.0 Million metric tons	39.9%
Air Pollution – PM-10	0.7 Million metric tons	2.2%
Air Pollution – PM-2.5	0.6 Million metric tons	7.4%
Air Pollution – SO2	1.3 Million metric tons	6.8%
Oil Dependence – Oil Use	24.11 Quads	66.3%

Source: Davis, S.C., 1999, tables 3.6, 4.1 and 1.10.

In this chapter, we estimate the impacts on transportation energy consumption and greenhouse emissions of a series of new government policies, embedded in two scenarios of increasing public concern over global warming and other energy and environmental issues. The Energy Information Administration's (EIA's) 1999 Annual Energy Outlook (AE099) Reference Case represents a "Business-as-Usual" (BAU) future with no policy changes (EIA, 1998). The two policy-driven scenarios are created by rerunning the EIA's NEMS model with extensive changes to its input and some changes in its code to reflect the new policies and changed social conditions in the scenarios.

The chapter is organized as follows. We first discuss some inherent limitations of estimating technological and market impacts of future policy measures. We then review the current status and trends in energy use and greenhouse gas (GHG) emissions in the U.S. transportation sector. Brief discussions of

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key technologies that seem likely to have major impacts over the next few decades come next. Supplementary material is presented in Appendix C-3. This is followed by a description of the BAU scenario. The next section addresses policies that could advance clean energy technologies and their acceptance, including a discussion of the barriers these policies are intended to overcome. How the policy pathways were implemented in the context of the NEMS model is the subject of Section 6.4. After that, we present in turn the Moderate and Advanced scenarios and the resulting CEF-NEMS projections. Several sensitivity cases were run to test the impacts of assumptions about key technologies and policies on the forecast results. The chapter concludes with some observations about where additional analysis might produce more valuable insights, followed by a attempt to summarize the key conclusions of the chapter.

6.1.1 Uncertainties and Limitations

In our view, it is critical that the reader understands the strong uncertainties associated with these analyses. First, the results depend critically on the costs and performance of technologies, some of which are under development, and these costs and performance values can be *highly* uncertain. In general, the range of uncertainty increases when technologies not already in use in commercial vehicles are included, as in the case here. Recent studies limited to a 10-year time horizon suggest that passenger car fuel economy can be improved to somewhere between 32 and 41 mpg at costs close to $750 per car, 1998 $ retail price equivalent (Greene and DeCicco, 1999). Studies considering longer time horizons or new technologies project mpg levels ranging from 38 to 52 at costs below $1,000 per car. None of the studies reviewed by Greene and DeCicco (1999) considers the full range of technologies included in this study, nor do they take account of technological advances since 1997. Cost and performance estimates more optimistic and less optimistic than those we use here can be found in the literature. And although we have not done a full sensitivity analysis of the effects of cost and performance assumptions, the sensitivity cases presented in Section 6.5, below, suggest that our conclusions are robust with respect to the cost, performance, or availability of any *single* technology. The effect of this uncertainty about the cost and performance of technologies is mitigated somewhat by the existence of a portfolio of technologies under development or in the early stages of commercialization that will compete for market dominance in the future. Historically, large reductions in cost and improvements in performance have occurred for a number of transportation technologies, and we believe it is reasonable to assume that some members of the portfolio will experience future cost reductions and performance improvements of a similar magnitude.

Second, there is no accepted analytical method to forecast the results of increases in research and development funding (EIA, 1999, p. xv), a crucial component of our policy strategy, and we are forced to rely essentially on judgment. The outcome of an RD&D program is inherently uncertain, depending on many factors such as market conditions, the amount of effort invested and the intelligence with which the effort is applied. As noted above, however, the existence of a substantial portfolio of technologies in the R&D “pipeline” offers a level of redundancy that adds to the probability of substantial improvements in performance and cost-effectiveness in several technologies. There are reasons to be optimistic. We note that since the Five-Lab Study, significant advances have been achieved in fuel cell technology, and two major automotive manufacturers have announced commercial introductions of hybrid vehicles five to ten years sooner than we had expected. At the same time, it is not reasonable to assume that all technologies can achieve the advances needed for market success. The best we can do is make an educated guess about which seem most likely to achieve breakthroughs, but we readily acknowledge the uncertainties in such judgments.

Third, consumer-purchasing behavior will obviously play a critical role in determining the future market share of crucial technologies, and how consumers will respond to new technologies is uncertain. Forecasters generally use market surveys to project consumer behavior, but much of the data about consumer preferences for new technologies comes from consumer responses to theoretical questions about whether they would purchase vehicles whose characteristics they know little about and have minimal experience with. Surveys of this sort are unreliable. Also, consumer preferences have undergone drastic changes at times; for example, recent sharp increases in consumer preference for safety features and for vehicles with proven records of high levels of safety. Similar changes are possible in the future but cannot be reliably predicted.

Fourth, the policies we examine in each scenario are assumed to be compatible with the qualitative scenario descriptions (and conversely, we leave out some policies because we assume they are incompatible with the descriptions), but the connection between societal conditions and public policy is by no means straightforward or non-controversial. For example, it is far from clear how far the Federal government will go in trying to force future improvements in automobile and light truck fuel economy. For several years the Congress, acting through the appropriations process, has expressly forbidden the Department of Transportation (DOT) from even analyzing potential changes in Corporate Average Fuel Economy (CAFE) rules. Further, the industry has shown strong opposition to increased CAFE standards. However, according to recent trade press reports, there is some (minority) sentiment in Congress to increase these standards. And some of our reviewers believe that regardless of public opinion about global warming, the U.S. market entry of practical hybrid-electric vehicles (scheduled to be introduced by 2000) and large increases in Japanese and European fleet fuel economy (responding to Kyoto initiatives) will lead to public demands that U.S. policy bring similar changes to the U.S. fleet. We have responded to the ambiguity in future policy shifts by assuming no change in CAFE rules for the Moderate scenario and examining two policy possibilities in the Advanced Scenario: Voluntary Agreements between the government and auto industry as a "base" Advanced policy, and still more stringent CAFE standards as a sensitivity case.

Of particular concern here is the difficulty of predicting how future purchasers of new light duty vehicles will trade off fuel economy against competing vehicle attributes such as acceleration performance, vehicle size, luxury features, and towing capacity. Previous forecasts of transportation energy use projected increasing light duty fleet fuel economy over time. Despite the widespread adoption of new technologies (see discussion of trends, below), these forecasts have been proven wrong and fuel economy has actually declined over time. There is an ongoing argument in the transportation community about whether market incentives (tax incentives for high efficiency vehicle purchases, reduced technology costs obtained by increasing R&D spending) will be sufficient to stimulate significant mpg gains, or whether regulatory action will be required to achieve such an increase.

Translating policies to CEF-NEMS model inputs often involves subjective judgments. As discussed below and in Appendix A, some of the modeling changes are close representations of the policies of conditions, for example reduced technology costs in the model to reflect a policy of technology subsidies or tax credits. Others are less analytical representations of the policies, for example, earlier technology introduction and reduced costs in the model to represent the effect of increases in research and development funding. The projected changes in dates of introduction and costs are based on industry announcements, technical analyses by government, private, and academic sources, consumer surveys, and other sources.

In the end, we must use our own judgment about these matters, tempered by external expert review. We are careful to be explicit about the assumptions we make about technology, consumer preferences, producer behavior and policies. All changes we have made to the NEMS model and its data inputs are documented in Appendix A[2].

The primary focus of this analysis is on energy consumption and GHG emissions, but the policies and technologies embodied in the two scenarios will also reduce oil imports, emissions of criteria air pollutants, other environmental damages associated with fossil fuel use.

6.1.2 Overview of the Sector

The U.S. transportation sector is dominated by highway travel, which consumes 75 percent of the total energy used by the sector and accounts for 75 percent of the sector's carbon emissions. In the highway sector, light-duty passenger travel is dominant, accounting for 74 percent of highway energy consumption and carbon emissions, and 56 percent of *total* transportation energy consumption and carbon emissions. Fig. 6.1 and Fig. 6.2 show the modal breakout of carbon emissions and energy consumption, respectively.

The characteristics of the various fleets in the sector and recent trends in energy use provide important clues to the likely future energy use in the sector and the potential for reducing GHG emissions. Some critical points:

- New light-duty passenger vehicles have been adopting fuel-efficient technologies over the past decade and a half, but increasing vehicle size, weight and especially performance have nullified the fuel economy gains these technologies might have brought.
- Important new technologies that enter the fleet include port fuel injection, 4 valves/cylinder engines, variable valve control, structural redesign using supercomputers, growing use of high strength steel and steel substitutes such as aluminum and plastics, and low rolling resistance tires.
- Counteracting trends include the growing sales share of light-duty trucks, especially Sport Utility Vehicles which now comprise 46 percent of light-duty vehicle sales, up from 17 percent in 1980; horsepower to weight ratios 45 percent higher than in 1980, a 20 percent increase in weight over 1980 vehicles (Heavenrich and Hellman, 1999); greater shares of 4-wheel drive installed on 47 percent of 1999 model year light trucks, and other luxury features, and continued increases in the stringency of emissions and safety standards.
- As a result of a decade of low gasoline prices, consumer surveys show that today's auto purchasers generally are uninterested in fuel economy.
- The "potential technology" portfolio for automobiles has been enhanced substantially by the Partnership for a New Generation of Vehicles (PNGV), a government/industry joint research and development program (NRC, 1999a). PNGV's effects are both direct and indirect – in addition to its own advances, it has stimulated competitive developments in Europe and Japan.
- Freight transport now consumes about 30 percent of U.S. transportation energy, with freight energy use but *not* gross ton miles dominated by heavy truck carriage (over 50 percent of energy use, about one-quarter of ton-miles) (Davis, 1998, table 2.13), the most energy-intensive mode aside from air freight. Air freight and freight truck energy use are the most rapidly growing freight modes because of the U.S. economy's shift towards higher value (and more time-sensitive) goods. A countervailing trend is greater use of multi-modal shipments, advanced by the rationalization of U.S. freight railroads and the benefits of improved computerized information systems.

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[2] These changes would have been far more difficult to make and the chances for mistakes would have been greatly increased had we not had the benefit of the expert advice and full cooperation of the NEMS model experts at the EIA. We are grateful for their invaluable assistance with the use of NEMS. Any remaining errors are, of course, our responsibility.

Fig. 6.1 1997 Transportation Carbon Emissions by Mode (477.9 MtC total)

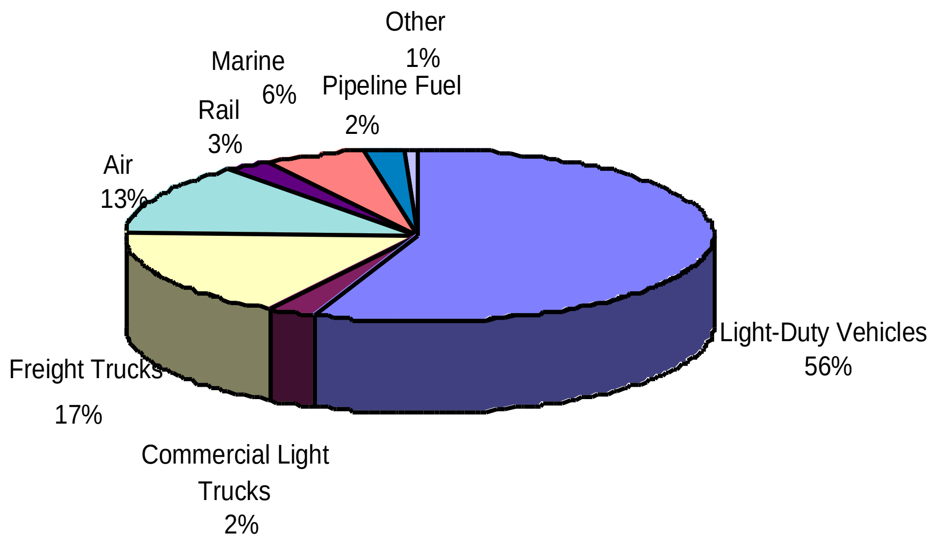
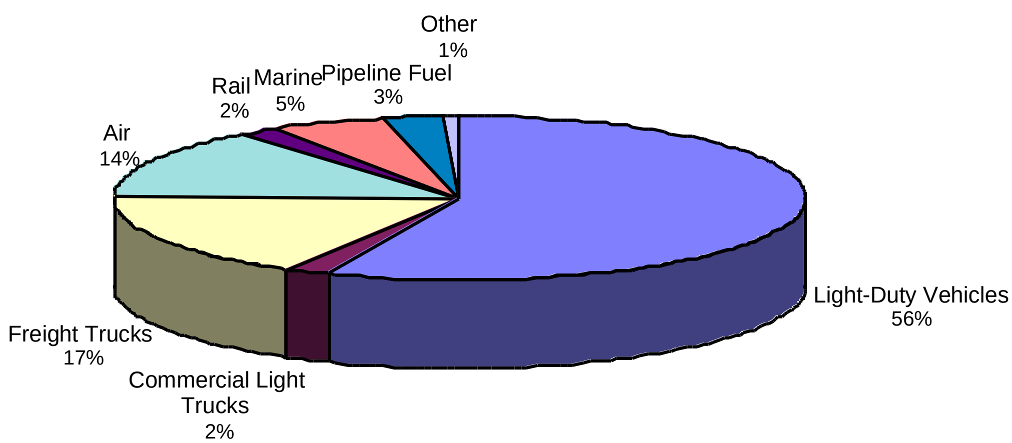


Fig. 6.2 1997 Transportation Energy Use, by Mode (25 Quads total)



6.1.3 Examples of Promising Technologies

The transportation sector has a wide variety of available and emerging technologies – the technology "portfolio" noted above – that offer the potential to reduce significantly the energy use and GHG emissions associated with transportation services. At the most mundane level, some "technologies" involve simply the constant redesign and improvement of existing technologies, for example, the steady reduction in engine friction from introduction of lighter materials in valve-trains, changes in machining, design, and assembly that yield improved tolerances, and other incremental changes. Others are technologies that have gained moderate market share – variable valve timing is an important example – but whose fuel economy benefits are not highly valued in today's market (variable valve timing is probably used today primarily for its ability to flatten an engine's torque curve, obtaining high torque throughout the engine's speed range). Finally, there are a range of technologies that are either just entering the marketplace or are under advanced development. Some of the most promising are described below.

Cellulosic Ethanol. About one billion gallons of ethanol produced from corn is currently used annually in U.S. transportation markets as a blend stock for gasoline (Davis, 1998). Although the efficiencies and fuel choices used over the fuel cycle in producing this ethanol vary widely (e.g., fuel choices for powering the distillery can be corn stover, natural gas, or coal), recent studies show that the use of this ethanol provides a moderate GHG advantage over gasoline of about 20 percent or so (Wang, 1999). Processes to produce ethanol from cellulose – from woody biomass or municipal wastes – for use as a gasoline blending agent or neat fuel offer to reduce greenhouse gases about 80 percent compared to gasoline (Wang et al., 1999). A Department of Energy (DOE) program at the National Renewable Energy Laboratory has been working intensively to improve the efficiency and cut the costs of producing ethanol to about half of current level (NREL, 1999). Program success could allow significant quantities of cellulosic ethanol to enter the market over the next decade, though a critical factor in its commercialization will be the world market price of oil.

Land requirements could ultimately limit cellulosic ethanol production. About 15 billion gallons of ethanol (1.2 Quads) could be produced annually by converting municipal and agricultural wastes with minimal land requirements (Lynd, 1997). If about 35 million of the roughly 60 million acres idled by Federal programs were used for energy crops, about 25-32 billion gallons, or about 3-4 Quads of ethanol could be produced annually (assumptions: 8.4 dry tons/acre/year crop productivity, 107.7 gallons of ethanol/ton yield) (Lynd, 1997). If only 10 billion gallons of ethanol were produced annually, this would leave 200 million dry tons of biomass for other uses, such as biomass power.

Hybrid Electric Drivetrains. A hybrid electric drivetrain combines an internal combustion engine or other fueled power source with an electric drivetrain including an electric motor and battery (or other electrical power source, e.g., an ultracapacitor). Potential efficiency gains involve recapture of braking energy (with motor used as generator, captured electricity stored in the battery); potential to downsize the engine, using the motor/battery as power booster; potential to avoid idling losses by turning off the engine or storing unused power in the battery; and increasing average engine efficiency by using the storage and power capacity of the electric drivetrain to keep the engine operating away from low efficiency modes. Toyota recently introduced a sophisticated hybrid subcompact auto, the Prius, in Japan and will introduce a version into the U.S. market within a year; Honda introduced its two-seater Insight hybrid in December 1999. Ford, GM, and Daimler/Chrysler all have hybrids in advanced development (Reuters, 1998; Jost, 1998; Bucholz, 1999a, 1999b).

Hybrids can be built in various configurations that trade off fuel efficiency, performance, and cost (for example, the most efficient configurations would downsize the engine, which would reduce the vehicle's towing capability). The most fuel-efficient configurations potentially could boost fuel economy by as much as 50 percent or so at near-constant performance under average driving conditions. Hybrids attain their greatest efficiency advantage – potentially greater than 100 percent – over conventional vehicles in slow stop-and-go traffic, so that very attractive applications might be urban taxicabs, transit buses, and service vehicles such as garbage trucks. Estimates of the fuel economy improvement in slow urban traffic of a hybrid medium truck over its conventional counterpart range from 55 to 124 percent; a (hybrid) heavy garbage truck could achieve gains as high as 140 percent (An et al., 2000).

Lower Weight Structural Materials. The use of alternative materials to reduce weight has been historically restrained by cost considerations, manufacturing process technology barriers, and the difficulty of these materials in meeting automotive requirements for criteria such as surface finish quality, predictable behavior during crash tests, or repairability. The last few years have seen significant developments in overcoming such barriers, through design changes such as a space frame-based structure, advanced new manufacturing technology for plastics and aluminum, and improved modeling techniques for evaluating deformablity and crash properties. Ford has displayed an advanced lightweight prototype (the P2000 Diata) that is a mid-size car with a weight of only 2000 pounds, as compared to vehicles weighing 3200 pounds today (Ford, 1997). Equipped with a direct-injection diesel engine it gets 63 mpg (Jost, 1998b). The Auto Aluminum Alliance, a working group within USCAR, has set a goal of 40 percent weight reduction via substitution of aluminum and is developing advanced manufacturing, repair and recycling technologies to attain that goal. Some aluminum intensive luxury cars have already been introduced (for example, the Audi A8) and Ford is known to be considering the introduction of such a vehicle in the mass market. Audi recently announced the introduction in Europe of the A2, the world's first volume-production aluminum car. According to the manufacturer, the car weighs 43 percent less than if built using steel and conventional processes (Birch, 1999c). In the U.S., Honda's Insight vehicle uses an all-aluminum body structure, which, along with a drag coefficient of 0.25 and 40 percent lower rolling resistance, is said to be responsible for 35 percent of the vehicle's improvement to 75 mpg (estimated 65 mpg in actual use in the United States) (Yamaguchi, 1999).

Aside from the "leading edge" structural redesigns discussed above, advanced design techniques and increased use of new materials can lead to lesser weight reductions throughout the fleet. For example, even without a shift away from steel, new ULS (ultralight-weight steel) designs claim up to a 36 percent reduction in weight for the basic automobile "body-in-white" structure at essentially zero cost (AISI, 1998).

Direct Injection Gasoline and Diesel Engines. Direct injection lean burn gasoline engines have already been introduced in Japan and Europe, but have been restricted here by a combination of tight emission standards and high sulfur content in gasoline. Honda's Insight hybrid vehicle, however, uses a lean-burn small-displacement gasoline engine, and has been certified to California's Ultra Low Emission Vehicle Standard (Yamaguchi, 1999). Mitsubishi for example, now manufactures 10 gasoline direct-injection (GDI) models in Japan, which reportedly reduce fuel consumption by 20 percent, with a 10 percent increase in power output (Demmler, 1999). The catalytic converters capable of reducing NO_x emissions from lean burn engines are very sensitive to fuel sulfur content, and no simple remedy has been found. Recently, Environmental Protection Agency (EPA) has proposed new Tier 2 standards that require the introduction of low sulfur gasoline, and have also increased the stringency of NO_x standards for 2004 and beyond. While the sulfur reduction allows GDI engines to be introduced, it is not yet clear that fuel efficiency benefits can be retained at the new NO_x levels. Preliminary evaluations suggest that benefits may be in the 12 to 15 percent range rather than the 16 to 20 percent range available in Japan and Europe, but even this assumes some advances in after-treatment technology. Engine costs, however, seem quite moderate, in the range of $200 to $300 (in retail price) more than a conventional engine. Evidence that emissions barriers are being broken down can be inferred from GM's intention to introduce a family of GDI light truck engines in 2001 (Robinson, 1999). An 8-10 percent fuel economy benefit is anticipated at a cost of $265 to $370 per truck.

Direct injection diesel engines have long been available for heavy trucks, but recently have become suitable for automobiles and light trucks as noise and emission problems have been reduced. These new engines are about 40 percent more fuel efficient, on a per gallon basis, than conventional gasoline engines (OTA, 1995) and about 25 percent more efficient on the basis of carbon emissions over the fuel cycle (Wang, 1999b). California's new emission regulations require diesels to attain the same (low) NO_x levels as gasoline engines, as well as stringent particulate levels; these and potential new federal standards present a challenge to diesel's viability (see the following box).

Further improvements in diesel technology also offer substantial promise in heavy-duty applications, especially heavy trucks but also including marine and rail applications. Current DOE research programs are aiming at achieving maximum efficiencies of about 50 percent in heavy-duty diesels, with low emissions (U.S. DOE, 1997).

Both gasoline and diesel direct injection engines have been shown to emit relatively large quantities of fine particles, even when total particulate weight is low. Current emissions standards are weight-based, but continuing research on particulate matter (PM) health effects conceivably could lead to new standards based on the number of particles rather than their weight. Such standards could pose a challenge to all direct injection engines.

Fuel Cells. Fuel cells have received considerable attention recently, with both Ford (Birch, 1999d) and Daimler/Chrysler (1999) announcing their intention to introduce such vehicles by the 2004 model year. Nissan has announced plans to introduce a methanol-reforming fuel cell vehicle in the Japanese market between 2003—2005 (Bucholz, 1999). General Motors Europe announced that it will have a fuel-cell-powered car ready for the European market by 2004 (Birch, 1999a) and Renault is planning a 2005 introduction date for its fuel cell car (Birch, 1999b). Fuel cells have been virtually the "Holy Grail" of clean powertrain technology, promising zero or near-zero criteria pollutant emissions with very high efficiency. The recent optimism has been driven by strong advances in technology performance, including rapid increases in specific power that now allow a fuel cell powertrain to fit into the same space as a conventional engine without sacrificing performance (Griffiths, 1999). However, fuel cells remain extremely expensive, and long-term costs are by no means clear; further, important technical roadblocks remain, e.g., operation in extreme weather conditions. Manufacturers are expressing optimism, however. For example, General Motors Europe has been quoted as believing that within 5-10 years after introduction the use of modular construction, falling costs and scale economies will make it possible to sell fuel cell vehicles at a lower price than cars with internal combustion engines (Birch, 1999a).

Another central issue is the fuel choice. Fuel cells need hydrogen, either carried onboard or produced by reforming methanol or gasoline. Carrying hydrogen may yield the cheapest and most fuel-efficient vehicle, but there is no hydrogen distribution and refueling infrastructure. A gasoline vehicle overcomes the infrastructure problem but is the most expensive and least efficient vehicle; further, developing an adequate gasoline processor remains a critical task, with significant improvements required in processor weight and size, cost, response time, efficiency, and output of carbon monoxide, which can poison the fuel cell stack (NRC, 1999a). Methanol may be a reasonable compromise, though it too requires a substantially improved fuel processor and, as yet, has no real infrastructure for distribution. Although vehicle fuel economy depends on far more than just the power plant, it appears that a fuel cell vehicle using methanol, with a lightweight, low drag body and low rolling resistance tires, should be capable of achieving 65 mpg (gasoline equivalent). Gasoline powered fuel cell vehicles using equivalent body structure, tires, and other components should be capable of about 60 mpg whereas similar fuel cell vehicles powered by compressed hydrogen could get 90 mpg. Both hydrogen and liquid fuel versions are likely to be initially more expensive than an equivalent conventional automobile.

Aircraft Technology. Several major technologies offer the opportunity to improve the energy efficiency of commercial aircraft by 40 percent or more. The Aeronautics and Space Engineering Board of the NRC (1992, p. 49) concluded that it was feasible to reduce fuel burn per seat mile for new commercial aircraft by 40 percent by about 2020. Of the 40 percent, 25 percent was expected to come from improved engine performance, and 15 percent from improved aerodynamics and weight. A reasonable preliminary goal for reductions in NO_x emissions was estimated to be 20-30 percent. Technologies such as laminar flow control to reduce drag, greater use of composite materials to reduce weight, and advanced propulsion concepts such as ultra-high bypass turbofan and propfan engines could all contribute.

Noting that the energy efficiency of new production aircraft has improved at an average rate of 1-2 percent per year since the dawn of the jet era, a recent IPCC (Lewis and Niedzwiecki, 1999) expert panel

Diesel's Future Viability

The future viability of diesel engines in the light-duty fleet, and perhaps in the heavy-duty fleet as well, will depend on the interplay of emission standards for NO_x and particulates and progress in diesel fuels, engine design, and emissions after-treatment technology (Mark and Morey, 1999). It will also depend on consumer acceptance, which is by no means guaranteed. Diesels have been selling well – and obtaining a price premium that appears to exceed that dictated by cost difference – in the light truck fleet. GM recently unveiled a new direct-injection diesel engine for light trucks in anticipation of industry-wide sales of 250,000 units/year in the near future (Broge, 1999). Diesels have a miniscule share of automobile sales, however, and may have to overcome consumer reluctance based on past mechanical failures and performance shortcomings. New turbocharged direct injection diesels bear little resemblance to diesels of the past, but their future acceptance by auto purchasers must be considered uncertain.

Emissions requirements are growing far more stringent for diesels (as for gasoline-fueled vehicles as well). California's new light-duty Low Emission Vehicle (LEV) NO_x standard for 2004 is 0.05 g/mi, versus 0.3 g/mi today, and applies equally to gasoline and diesel vehicles; its new 2004 particulate standard for diesels is .01 g/mi, versus .08 g/mi today. Federal "Tier 2" standards, now being promulgated, are expected to be similar, though they may provide some added flexibility that could help diesels. And the potential for still more stringent standards arises from the continuing research on the effects of diesel exhaust on health. Current knowledge is limited by deficiencies in several areas: quantitative measures of exposure to humans; data over a wide population; and confirming data on disease mechanisms (Nauss, 1999). If ongoing research yields strongly negative results, pressure will grow to restrict diesel emissions still more. An important issue here, however, is the extent to which potentially conflicting societal goals, in this case reduced health-associated emissions and reduced GHG emissions and oil use, are actually being weighed against each other in making policy choices about emissions standards. The National Research Council (NRC), in its recent PNGV review report (NRC, 1999a), states "the responsible government agencies participating in the PNGV have pursued their specific agency objectives without taking into account the interdependency of these issues."

In the face of the new standards and the potential for additional emissions requirements, diesel's viability depends strongly on advances in several areas (Howden, 1999; Lyons, 1999) in which considerable progress is being reported (e.g., Birch, 1999e, 1999f):

- Fuels: especially economical reduction of sulfur to at least 30 ppm and possibly considerably lower; also changes in density, aromatics and polycyclics content, cetane, etc.
- Engine design: particularly in combustion chamber design, improved exhaust gas recirculation, improved fuel injection.
- NO_x after-treatment: e.g., lean-burn catalysts, NO_x traps (absorbers), non-thermal plasma systems.
- Particulates after-treatment: e.g., regenerative PM traps and oxidation catalysts.

The PNGV currently is working on all of these systems, as are private companies in Europe, Japan, and the United States.

concluded that a significant though somewhat lower rate of improvement could be expected through 2050. The panel predicted about a 20 percent improvement in seat-kilometers per kg of fuel for 1997-2015 (Table 6.2).

Table 6.2 Historical and Future Improvements In New Production Aircraft Energy Efficiency (Percent)

Time Period	Airframe	Propulsion	Total	%/Year
1950-1997	30	40	70	1.13
1997-2015	10	10	20	1.02
1997-2050	25	20	45	0.70

Source: Lewis and Niedzwiecki, 1999, table 7.1.

The "blended wing body" is a revolutionary airframe design that transforms an aircraft into essentially a flying wing, resembling the military's stealth aircraft in appearance. The extension of the cabin into the wing allows the drag associated with the traditional aircraft body to be reduced, and permits some weight reduction, as well. With this radical new design, fuel burn could be "reduced significantly relative to that of conventionally designed transports" (Lewis and Niedzwiecki, 1999, p. 7-13). With an aggressive R&D effort, an initial version could enter service in 2020 (ibid).

6.2 BUSINESS-AS-USUAL SCENARIO

In the BAU scenario for the transportation sector, we accepted the sectoral assumptions of the AEO99 Reference Case scenario despite some disagreements we have with certain portions of it, which are discussed in Section 6.2.2. The CEF-NEMS baseline scenario results have some slight differences with the AEO99 results because of the effect of changes made to the Reference Case in other economic sectors. These differences are quite small, less than one percent, and we will not discuss them.

6.2.1 Policies in the BAU Scenario

The CEF-NEMS baseline scenario (and the AOE99 Reference Case scenario) adopts the following policies:

1. Emissions standards: Tier 2 vehicle emission standards have not yet been promulgated by EPA and are not included in the scenario. These standards could have strong impacts on transportation technology introduction and market share, for example, stringent NO_x standards could hinder widespread introduction of efficient direct injection diesel engines into the light-duty fleet unless major advances in emissions control are achieved.
2. Alternative fuel requirements: EPACT rules for purchase of alternative fuel vehicles by fleet operators, including Federal and fuel provider fleets, are included. California's Low Emission Vehicle Program, which includes requirements for zero emission vehicles (10 percent of sales by 2003), is assumed in place. Massachusetts and New York are assumed to have delayed their programs to conform to the California 2003 limits.
3. Kyoto Protocol: Potential policy actions that may be taken to satisfy the Kyoto Protocol are not included. However, Climate Change Action Plan programs are assumed to be in place and successful. These are: reform Federal subsidy of employer-provided parking; adopt a transportation

system efficiency plan; promote telecommuting; and develop fuel economy labels for tires. The first three are assumed to achieve a 1.6 percent reduction in vehicle miles traveled (vmt) by 2010; the tire labels are assumed to achieve a 4 percent/vehicle improvement in fuel efficiency for those vehicles switching to more efficient tires.

4. Fuel economy standards: no further increase in current auto and light truck standards.

6.2.2 Alterations to the EIA Base Case

As noted above, we made no alterations to the EIA Reference Case, although we do have concerns about various aspects of that Case. Two key concerns:

1. **Vehicle performance projections.** In the light-duty fleet, the last decade and a half has seen substantial increases in acceleration performance and corresponding increases in average horsepower and horsepower/weight values in the fleet. EIA has assumed that these factors will continue to increase over the lifetime of the estimate, leading ultimately to passenger cars averaging 250 horsepower by 2020. These performance increases dampen substantially the efficiency impact of new technologies forecast to enter the fleet during this period, so that the average new car fuel economy is forecast to increase from 27.9 mpg in 1997 to only 32.1 mpg in 2020 despite the penetration of a substantial amount of new efficiency technology. Some industry analysts consider this small an increase unrealistic in the face of programs like the PNGV, whose goal is to triple light-duty vehicle fuel economy, as well as the impending introduction of hybrid electric vehicles such as Toyota's Prius and Honda's Insight. On the other hand, current CAFE standards have appeared to act as a floor holding up fleet fuel economy at its current levels, and other analysts question whether fleet fuel economy will increase *at all* given expected continuation of very low fuel prices and the clear low valuation of fuel economy held by recent vehicle purchasers.
2. **Travel projections.** EIA is projecting a growth rate in car and light truck travel of 2.0 percent over 1997-2010, and 1.6 percent/yr over 1997-2020, versus a 1974-1995 growth rate of 2.8 percent/yr that has been remarkably robust except for brief periods during the oil crises. The slowdown presumably results from projections and assumptions about changes in population, aging of the population, female driving, and income, as well as the CCAP programs noted earlier. Interestingly, EIA states that the female/male-driving ratio reaches 100 percent by 2010 (from 56 percent in 1990) and that (recent) increased driving among retirees is taken into account – factors that should boost vmt. This issue is discussed in greater detail in Appendix E-2.

6.2.3 Results

Tables 6.3 and 6.4 present 10-year results for travel, efficiency, and energy used by mode, and energy used by fuel.

Table 6.3 Results of BAU Scenario

	1997	2010	2020
Level of Travel by Mode (Billion)			
Light Duty Vehicles (vehicle miles traveled)	2301	2886	3303
Commercial Light Trucks (vehicle miles traveled)	69	91	104
Freight Trucks (vehicle miles traveled)	177	243	270
Air (seat miles demanded)	1049	1813	2462
Rail (ton miles traveled)	1229	1516	1698
Marine (ton miles traveled)	756	877	961
Energy-Efficiency Indicator by Mode			
New Light-Duty Vehicle (MPG)[a]	24	25.5	26.5
New Car (MPG)	27.9	31.7	32.1
New Light Truck (MPG)	20.2	20.8	22
Light-Duty Fleet (MPG)	20.5	20.3	21.4
New Commercial Light Truck (MPG)	19.9	19.8	21
Stock Commercial Light Truck (MPG)	14.6	15	15.6
Aircraft (seat miles/gallon)	51	55.7	59.6
Freight Truck (MPG)	5.6	6.1	6.3
Rail (ton miles/kBtu)	2.7	2.9	3.1
Site Energy Use by Mode (Quadrillion Btu)			
Light-Duty Vehicles	13.9	18.1	19.6
Commercial Light Trucks	0.6	0.8	0.8
Freight Trucks	4.2	5.3	5.7
Air	3.4	5.2	6.4
Rail	0.5	0.6	0.7
Marine	1.3	1.6	2.0
Pipeline Fuel	0.7	0.9	1.0
Other	0.2	0.3	0.3
Total	24.9	32.8	36.4
Energy Use by Fuel Type (Quadrillion Btu)			
Distillate Fuel	4.6	6.0	6.6
Jet Fuel	3.3	5.1	6.3
Motor Gasoline	15.1	18.7	19.9
Residual Fuel	0.8	1.0	1.3
Liquefied Petroleum Gas	0.0	0.2	0.2
Other Petroleum	0.3	0.3	0.4
Petroleum Subtotal	24.10	31.32	34.67
Pipeline Fuel Natural Gas	0.7	0.9	1.0
Compressed Natural Gas	0.0	0.3	0.4
Renewables (E85)[b]	0.0	0.1	0.1
Methanol	0.0	0.1	0.1
Liquid Hydrogen	0.0	0.0	0.0
Electricity	0.1	0.2	0.2
Total Site Energy	24.9	32.8	36.4
Electricity Related Losses	0.1	0.3	0.4
Total Primary Energy	25.0	33.1	36.8

[a] Light-duty vehicles are passenger cars and light trucks combined.

[b] The CEF-NEMS model reports renewables blended with gasoline as "Motor Gasoline." For an accounting of cellulosic ethanol blended with gasoline, please see the discussion in section 6.5.1.

Table 6.4 Transportation Carbon Emissions: BAU (million metric tons C)

	1997	*2010*	*2020*
Carbon emissions by mode (MtC)			
Light Duty Vehicles	267.0	346.4	376.3
Commercial Light Trucks	11.3	14.5	16.1
Freight Trucks	82.4	100.8	108.0
Air	63.3	98.8	122.1
Rail	12.2	14.1	15.0
Marine	27.3	33.7	40.8
Pipeline Fuel	10.6	12.8	14.1
Other	3.8	7.4	7.7
Total	477.8	628.4	700.2
Carbon emissions by fuel type (MtC)			
Other	91.6	118.7	130.4
Jet Fuel	63.3	98.0	121.3
Motor Gasoline	289.7	358.2	381.5
Residual Fuel	15.9	21.7	27.7
Liquefied Petroleum Gas	0.7	3.0	3.8
Other Petroleum	3.0	3.6	3.9
Petroleum Subtotal	464.1	603.2	668.5
Pipeline Fuel Natural Gas	10.6	12.8	14.1
Compressed Natural Gas	0.2	3.7	4.9
Renewables (E85)	0.0	0.0	0.0
Methanol	0.0	1.3	1.9
Liquid Hydrogen	0.0	0.0	0.0
Electricity	2.9	7.4	10.7
Total	477.8	628.4	700.2

In the Baseline, carbon emissions grow from 478 MtC in 1997 to 700 MtC in 2020, a growth of 46.5 percent over the period. Similarly, energy use rises from 25.0 Quads in 1997 to 36.8 Quads in 2020, a 47.2 percent growth (Fig. 6.3).

The reasons for this strong growth in both energy use and carbon emissions are straightforward: the demand for travel is forecast to increase inexorably (though generally more slowly than the historic rate), whereas travel energy efficiency is forecast to increase only modestly over the period (Fig. 6.4 and Fig. 6.5). Specifically, the 1997-2020 vmt, smt (seat-miles traveled), and tmt (ton-miles transported) growth and efficiency improvements by transportation modes are:

Mode	% Growth in Travel	% Growth in Efficiency
Light-duty vehicles	43.5 (vmt)	10.4/4.4 (new/stock)
Freight trucks	52.5 (vmt)	12.5 (stock)
Air	136.7 (smt)	16.9 (stock)
Rail	39.3 (tmt)	14.8 (stock)
Marine	27.1 (tmt)	----

Fig. 6.3 Projected Growth in Transport Energy Use, 1996 - 2020, EIA Reference Case

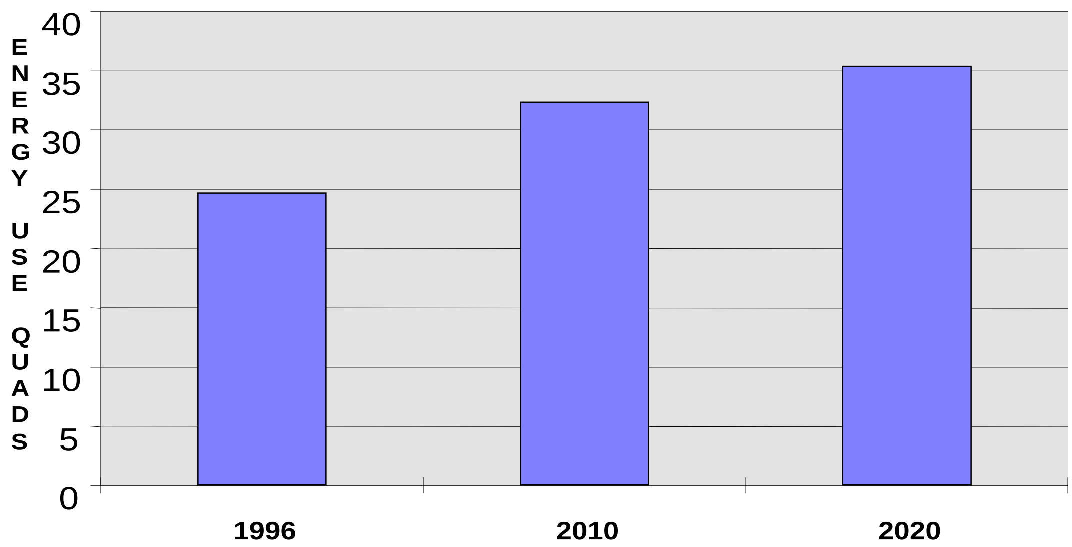


Fig. 6.4 Transportation Efficiency Indicators: Fractional Increase, 1996 - 2020

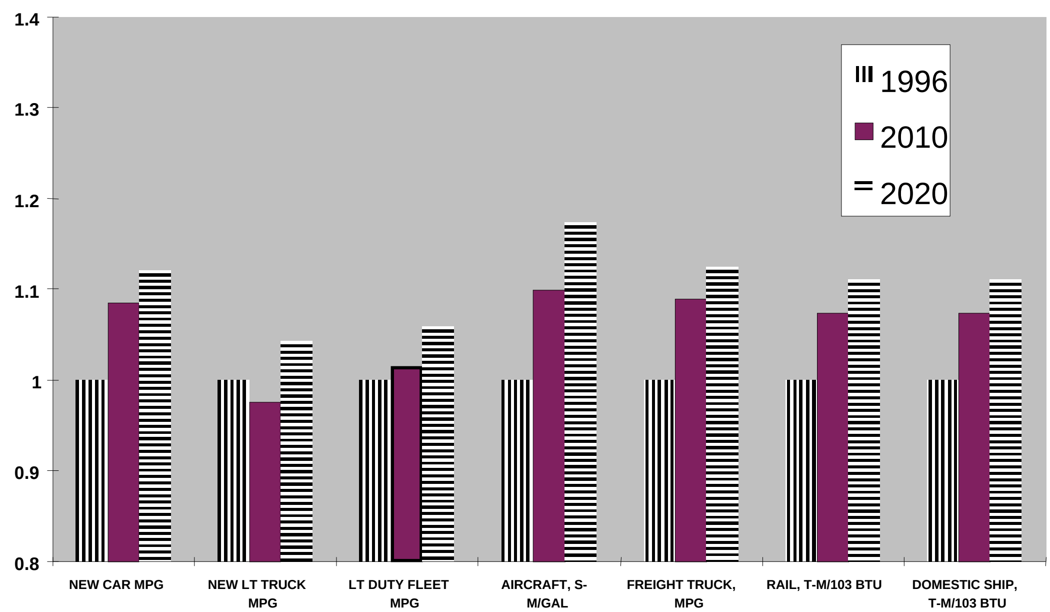
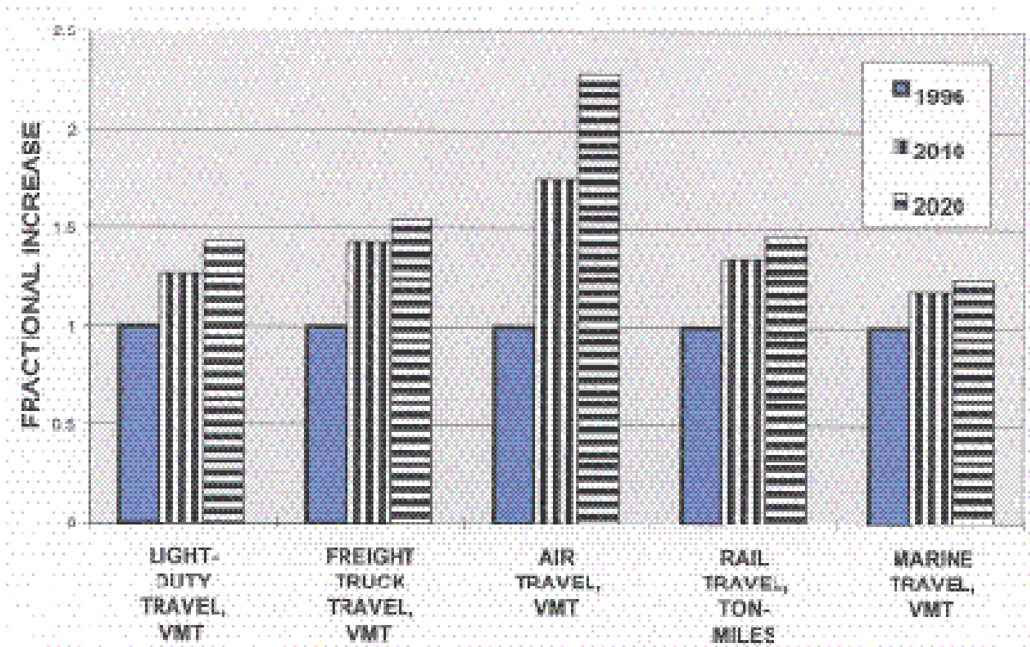


Fig. 6.5 Projected Travel Growth, 1996 - 2020, EIA Reference Case



The modest 23-year improvement in light-duty fleet efficiency is perhaps the most problematic aspect of the scenario results, because at present the auto industry appears poised to introduce a variety of exciting new technologies ranging from hybrid-electric drivetrains to fuel cells. The NEMS model does take account of new technologies, but the Baseline forecast projects modest market shares for many of them because of high first costs and, in some cases, delays in market introduction because of remaining development requirements. Thus, in the BAU Scenario, fuel cell vehicles do not enter the market until 2006, and do not reach 10,000 vehicle sales/year – an exceedingly modest number – until 2015. Thus, they play essentially no role in fleet fuel consumption throughout the period; there are only 110,000 fuel cell vehicles out of 254 million *total* vehicles in the 2020 light-duty fleet. Electric-diesel hybrids, another potentially important efficiency technology, are in the fleet in 2000 but, due to high costs, never exceed sales of 12,000 autos/yr or 25,000 light trucks/yr throughout the period.

6.3 POLICY IMPLEMENTATION PATHWAYS

6.3.1 Definition of Pathways

We have modeled two policy implementation pathways. The Moderate scenario contains policies that would fit a changed political climate that would allow low-cost policies aimed at reducing GHG emissions from the sector. The Advanced scenario contains policies that would fit a political climate that would allow somewhat more aggressive policies, including Voluntary Agreements that result from at least the *threat* of new, higher CAFE standards (a Sensitivity Case examines the effect of such standards). Table 6.5 lists the policies for the two scenarios.

The choice of policy options to be included in the scenarios reflects our assessment of the political feasibility and likely effectiveness of a wide variety of potential policies under the conditions defined in the scenario descriptions. Obviously this type of assessment is extremely subjective and uncertain:

seasoned politicians routinely miscalculate their ability to get proposed legislation enacted into law, and legislative surprises are a fact of life in political circles. As noted above, a case can be made that the policies we selected for light-duty vehicles – golden carrot awards in the form of the tax credits for high efficiency vehicles suggested by the Administration and, for the Advanced scenario, a Voluntary Agreement between automakers and the U.S. government to increase light-duty fleet fuel economy – are either too ambitious ("U.S. automakers will never willingly adopt Voluntary fuel economy targets") or too cautious ("why not include CAFE standards?"). As noted, we do explore the impact of new CAFE standards in a Sensitivity Case within the Advanced scenario. The polices we have examined are as follows:

Table 6.5 Transportation Policy Pathways

Moderate Scenario	Advanced Scenario
➢ 50% increase in government/industry R&D investment	· 100% increase in government/industry R&D investment
➢ Tax credit for high efficiency vehicles	· Same
➢ Acceleration of air traffic management improvements	· Same
➢ Program to promote investment in cellulosic ethanol production	· Same
➢ Invigorated government fleet program promoting alternative fuels and efficiency	· Same, more rigorous requirements
➢ No change in LDV fuel economy standards	· Voluntary Agreements to improve fuel economy, for LDVs, freight trucks, and aircraft (Sensitivity Case: new CAFE standards)
➢ Telecommuting stimulation	· Same
	· Domestic carbon trading system with assumed permit price of $50/tC · Variabilization polices (pay-at-the-pump auto insurance) · Intelligent traffic systems controls

Air Traffic Management Improvements. The EPA and FAA have a joint program aimed at rationalizing air traffic management to substantially reduce the time spent waiting "on line" on the ground and circling around airports while waiting for landing slots. This program, known as CNS/ATM (Communications, Navigation, and Surveillance/Air Traffic Management) involves substantial changes in flight procedures coupled with installation of a network of ground and airborne technologies involving digital communication and computer interpretation of flight instructions, and satellite systems that precisely locate aircraft. Successful implementation of this program will substantially reduce both energy losses and emissions of criteria pollutants. A recent FAA analysis estimates savings in energy use of up to 6 percent for North America (FAA, 1998); we have adopted a five percent savings as our target level for 2020. Additional benefits beyond reduced fuel cost and greenhouse emissions include significant reductions in criteria emissions (9 percent for NOx, 12 percent for CO, and 18 percent for HC), improved aircraft utilization, and time savings for passengers.

CNS/ATM involves six technology groups:

- P-FAST – Passive final approach spacing tool, designed to narrow the allowable gaps between aircraft.
- SMA – Surface movement advisor, a tool designed to more efficiently move aircraft from touchdown to gate or gate to takeoff.
- CDM – Collaborative decision making, designed to find optimal reroutings when aircraft meet unexpected conditions and must change flight plans.
- TMA – Traffic Management Advisor, another collaborative decision-making tool that will predict delays at an airport and reschedule traffic at other airports to avoid overloading the first airport.
- URET – User request evaluation tool, which performs after-the-fact analysis of flight performance
- CTAS – Center Terminal Automation System, incorporating parts of P-FAST and TMA for smaller airport operations.

FAA has adopted promotion of CNS/ATM as a goal of its Strategic Plan ("Achieve progress toward global implementation of satellite-based communication, navigation, surveillance, and air traffic management (CNS/ATM) by assisting planning and implementation efforts in each world region." (FAA, 1996)). However, there currently is no formal mechanism for implementing this program, and the FAA budget appears insufficient to include the large capital investments needed. In a BAU environment, with continuing low prices for jet fuel, implementation would likely be slow despite its benefits. If FAA analysis is correct, however, the program should easily pay for itself in fuel savings, improved aircraft utilization, and other savings. Therefore, we expect rapid implementation to fit easily within both the Moderate and Advanced scenarios.

Carbon Permit Program. Carbon permit programs define acceptable levels of carbon emissions and allocate these emissions to carbon emitters by auctioning permits or allocating the permits to individual sources, with trading allowed. The impact of a carbon permit program that results in a $50/metric ton price for carbon in 2005 through 2020, a price that translates to about $0.12/gallon of gasoline given gasoline's carbon content, is reflected in the Advanced scenario. This modest increase in gasoline price – about 10 percent if prices remain low – will yield a small reduction in projected levels of transportation demand and carbon emissions.

Studies done in the 1970s and early 1980s of fuel price effects on fuel demand (Dahl, 1986) found that fuel demand was very responsive to fuel price over the long term – that a 10 percent increase in price would cause a drop in fuel use of approximately the same percentage, with half the drop coming from improved vehicle efficiency and half from reduced travel. More recent estimates, discussed in Plotkin and Greene (1997) project only about a 5 to 6 percent decrease in fuel use from a 10 percent price increase. Thus, a 50 cents per gallon increase in gasoline price – about the level added by the combination of carbon permit system and 2010 "Pay-at-the-Pump" (PATP) insurance policy discussed below (added to a baseline $1.25/gallon) might be expected to reduce gasoline use by perhaps 20 percent over the long run. The latter values reflect the full experience in gasoline markets over the past three decades and should be more credible. Note that a 50 cents per gallon gasoline price increase would cost a typical driver (12,000 miles/yr. 20 mpg) about $300/year.

Cellulosic Ethanol Commercialization Program. The use of cellulosic ethanol in vehicles would be extremely useful in reducing GHG emissions because, over the fuel cycle, such use generates a small fraction of the emissions generated by the equivalent use of gasoline – about 10 or 20 percent depending on assumptions. The DOE has an active research program aiming to develop commercializable processes for producing ethanol from energy crops, forest and agricultural residues, and municipal wastes (NREL, 1999). If successful, cellulosic ethanol would first be used primarily as a blending agent with gasoline, with added value as an octane enhancer and oxygenate.

Current market incentives for ethanol use include exemption from most federal taxes on gasoline for gasoline/ethanol blends, mandated oxygenate levels in Federal reformulated gasoline (RFG) required in ozone nonattainment areas (and other areas that have joined the RFG program), alternative fuel fleet requirements mandated by EPACT, and CAFE credits associated with the sale of alternative fuel vehicles. The latter two incentives affect vehicle production and sales only, and do not currently have any effect on ethanol production.

In the scenarios, we use the 1990 AEO assumptions about extension of the current "gasohol" tax break: that it will not expire in 2007 but continue at the nominal level of $0.51 per gallon. The value of the credit will thus be eroded by inflation over time to $0.27 per gallon in 2020. We also assume a program of loan guarantees, tax breaks, or subsidies to reduce or eliminate the added risk of investment in new ethanol plants. In addition, we envision substantial reductions in the *cost* of cellulosic ethanol production (to 50 percent of current corn ethanol costs (based on Bowman and Leiby, 1998; NREL, 1999; and NRC, 1999a) resulting from focused research on ethanol production processes associated with increases in transportation R&D funding in both scenarios. A recent assessment of DOE's bio-ethanol research program by the National Research Council (1999b) made several recommendations for redirecting and expanding the effort, including:

1. improvement in pretreatment efficiency to minimize enzyme requirements,
2. development of less expensive more effective digestive enzymes,
3. improved design to minimize costs, improve efficiency, and maximize coproduct value,
4. research in bioengineering and genomics to improve yield, pest resistance and stress resistance, and
5. research into feedstock changes to improve processing and conversion efficiency.

Tax Credit for High Efficiency Vehicles. A set of tax credits has been proposed for purchasers of significantly more fuel-efficient vehicles. The proposed schedule is shown in Table 6.6, where efficiency improvement levels are matched with vehicle technologies. The model assumes the tax credit will be phased out as sales increase much beyond 50,000 units per year, which would be expected to greatly reduce the penetration of hybrids relative to a tax credit that did not have a cap.

Table 6.6 Schedule of High Fuel Economy Tax Credits and Associated Technologies

MPG Increase	Technology	Credit
1/3	Gasoline hybrid	$1,000
2/3	Diesel-electric	$2,000
Twice	Gasoline and methanol fuel cell	$3,000
Three times	Hydrogen fuel cell	$4,000

The modeled tax credits reflect the Administration's early tax proposals. The current Administration proposal has changed the credits to reflect the "degree of electrification" of the powertrain rather than the efficiency gain. We have not attempted to model this latest proposal. Existing tax credits for battery electric vehicles are assumed to continue in effect in all scenarios.

Invigorated Government Fleet Programs. EPACT regulations require Federal and State vehicle fleets and some private fleets (of alternative fuel suppliers) to introduce alternative fuel vehicles on a rigorous schedule. AEO99 assumes that the EPACT schedules will be met. However, these fleets are well behind schedule in their compliance, and few if any analysts believe that full compliance will occur. Consequently, in accepting the AEO99 Reference Case as our Baseline Case, we are implicitly assuming that a shift in government policy concerning fleet vehicle purchases will allow full compliance; BAU would *not* yield compliance with EPACT schedules.

R&D Spending Increase. The Federal government, primarily the DOE, currently spends several hundred million dollars annually in support of the development of advanced vehicle technology, including fuel cells, hybrid drivetrains, advanced diesel power plants, advanced materials, and so forth. Other agencies, e.g., Department of Transportation (DOT), National Aeronautics and Space Administration (NASA), Department of Defense (DoD), and so forth, sponsor additional research in other transportation areas. Traditionally, Federal R&D funding for aircraft and highway vehicle technology has been much greater than in other areas, e.g., funding in rail and maritime freight hauling has been minimal.

The most prominent Federal transportation R&D program in recent years has been the PNGV, a joint federal/industry program under which both partners have contributed about $300 million/year. The NRC has concluded that the PNGV has made substantial progress in reaching its goal of an (up to) 80 mpg family car, for example, the three industry partners now have prototype family-size cars capable of about 60 mpg on the EPA test cycle. However, NRC also concluded that PNGV has significant challenges remaining, in particular emissions and cost problems with direct-injection engines, high costs for power electronics and electric motors, cost and performance problems with high-power batteries for hybrid vehicles, and immature technology for multi-fuel processing for fuel cells. The Council's overall conclusion is that the dollar amounts provided to the PNGV are "far below the level needed to meet the challenges on a timely basis" (NRC, 1999a). An increase in funding for this and other highway vehicle programs under the auspices of DOE's Office of Transportation Technologies (OTT) may allow better results from the ongoing R&D programs in the form of earlier commercialization of new technologies, reduction in first costs, and increased performance (in fuel economy and other consumer attributes). Similar increases in programs under other federal agencies, e.g., NASA, DoD, DOT, etc. should provide similar results.

The following box (Increased Transportation R&D Investment) describes some key characteristics of a 50 or 100 percent increase in Federal transportation R&D spending.

Telecommunications Programs. Telecommuting involves the substitution of telecommunications services for commuting in the workplace; that is, workers would work out of home or satellite offices and communicate with their offices via computers. The primary candidates for telecommuting appear to be white collar workers with a managerial and professional specialty, or workers in sales and clerical jobs, e.g., workers who deal primarily with creating, distributing, or using information (OTA, 1994). Over 50 percent of U.S. jobs fit this description, e.g. upward of 70 million jobs could theoretically be candidates for telecommuting. DOT projections indicate there could be as many as 50 million telecommuters by 2020 (U.S. DOT, 1993). Aside from commuting trips, telecommunications will also affect other trip categories, e.g. shopping (internet sales, for example).

Increased Transportation R&D Investment

The Federal government currently spends several hundred million dollars per year on research aimed primarily at improving energy efficiency and reducing GHG emissions in the transportation sector. The U.S. DOE is a major sponsor of this R&D, with its OTT contributing $244 million to the effort in FY99.

To be effective, a 50 or 100 percent increase in this federal transportation R&D budget will require both a careful targeting of funds to critical research areas, and a gradual rampup of funds to allow for careful planning, assembly of research teams, and expansion of existing research teams and facilities. Well-focused and intelligently managed technology R&D programs average societal rates of return on the order of 50 percent per year (PCAST, 1997). The Moderate and Advanced scenario proposals envision a 5-year rampup time.

Examples of promising research areas for increased funding include:

Light Duty Highway Vehicles

- Direct injection engines, particularly NOx after-treatment for GDI engines, NO_x and PM emissions reduction in CIDI engines.
- Proton exchange membrane fuel cell systems, particularly reforming liquid fuels, hydrogen storage options, contaminant removal from reformate, fuel cell balance of plant, and systems integration.
- High power energy storage systems for hybrids, including reactivation of research on ultracapacitors and flywheels.
- Power electronics and electric motors.
- Advanced lightweight materials, particularly vehicle manufacturing technologies and vehicle design.
- Fuels, esp. lower cost, more energy-efficient production of cellulosic ethanol, hydrogen, and clean liquid fuels from natural gas.
- Advanced onboard storage technologies for hydrogen (see above) and natural gas.
- Electric vehicle batteries, especially lithium polymer but also cost reduction and performance enhancement of nickel metal hydride batteries, safety and electrolyte and cathode performance for lithium-ion batteries.

Medium-duty delivery vehicles and transit buses

- Hybrid-electric drivetrains
- Advanced TDI diesel engines, especially emission control.
- Natural gas storage and system design
- Advanced lightweight materials

Heavy-duty highway vehicles

- Advanced diesel engines and emission controls
- Advanced aerodynamic drag reduction technologies
- Ultra-low rolling resistance tires
- Accessory load reduction strategies
- Low friction drivetrains

Air travel

- Laminar flow control and other advanced aerodynamic technologies
- Blended wing-body aircraft
- Unducted fan engines
- Thermodynamic improvements to turbine engines
- NO_X control technologies

Maritime

- Compressed and liquefied natural gas onboard diesel-powered coastal vessels
- Molten carbonate fuel cell propulsion, with liquefied natural gas as a fuel
- PEM fuel cell propulsion with hydrogen fuel

Rail travel

- Fuel cell propulsion systems
- Advanced electric motors
- Oxygen-enrichment systems for locomotive diesel engines
- Advanced diesel engines
- Advanced rail lubrication systems
- Intermodal/rail competitiveness research, including improved door-to-door service management and improved equipment management through advanced command, control, communication, and information systems.

Sectoral analysis

- Further development of the transport sector models in the National Energy Modeling System

Although telecommuting will eliminate many work trips, it can have “take back” effects such as stimulation of sprawl (workers can live in rural areas if they don’t commute, or commute only once or twice a week). Further, telecommuting clearly will have different receptions from workers depending on their family situations, personalities, and other factors. At moderate levels of telecommuting, and where it is largely voluntary, telecommuting’s reception should be quite positive since it allows workers freedom from commuting and greater flexibility in dealing with family requirements. On the other hand, some analysts believe that there may be a backlash to increased telecommuting due to negative impacts on workers including lack of communication, social isolation, loss of benefits, lack of career advancement, and stress from mixing work and home life (OTA, 1994). Obviously, the design of the specific programs will have a great impact on the willingness of workers to participate.

A 1994 DOE study on the direct and indirect impacts of expanded telecommuting estimated that, by 2010, telecommuting could save about one percent of total motor fuel use (Greene et al, 1994). The DOE study adopted the earlier DOT study’s estimate of 30 million telecommuters by 2010, telecommuting 3 to 4 days per week, and assumed that 80 percent of them would be working at home. Although the direct impact of this level of telecommuting was estimated to be the avoidance of nearly 70 billion miles of commuting per year, DOE estimated that about half of the potential fuel savings would be lost to increases in travel demand due to improved traffic flow and the travel impacts of increased urban sprawl caused by the telecommuting.

Some public policy measures have been proposed to promote telecommuting, notably Regulation XV, proposed by the Southern California Air Quality Management District in 1987 but not enacted, that would have required larger employers (with over 100 employees) to adopt plans for alternative commuting options, and the travel demand management funding provided by ISTEA at the Federal level (OTA, 1994). Policies that would promote telecommuting include eased IRS provisions to allow “teleworkers” to more easily deduct computer and telecommunications equipment as a business expense on personal income taxes, and tax credits for businesses’ startup costs for telecommuting programs, e.g., worker training and equipment costs. Policy changes at the local level include easing of restrictions on home-based work and amendment of zoning requirements to allow a reduction in the minimum number of parking spaces in office buildings, to account for telecommuting (OTA, 1994).

Intelligent Traffic Systems Controls. Intelligent traffic systems controls, including intelligent roadway signing, staggered freeway entry, and electronic toll collection, are being introduced into U.S. cities, and their use is expanding. In the Advanced scenario, both increased R&D and government investment in these systems above anticipated levels lead to a wider range of systems available and faster expansion of their use.

Voluntary Agreements. As discussed more extensively in the Industry chapter, voluntary agreements are “agreements between government and industry to facilitate voluntary actions with desirable social outcomes.” Such agreements are more common outside of the United States; the most relevant for this case is the agreement between the European automobile manufacturers’ association, ACEA, and the European Union to cut carbon dioxide emitted from car exhausts by 25 percent/vehicle over the next 10 years (EC & ACEA, 1999). This pledge would increase average new car fuel efficiency from 30.6 mpg today to 40.7 mpg by 2008. Among the car companies agreeing to this are subsidiaries of American manufacturers. In the Advanced scenario, we assume that all manufacturers of light-duty and heavy-duty highway vehicles will commit to voluntary standards to increase fuel economy. The light-duty standards are 40 mpg in 2010 and 50 mpg in 2020 for automobiles, and 26 mpg in 2010 and 33 mpg in 2020 for light trucks. Heavy-duty standards are not specified at this time.

Obviously, the precise form of any voluntary standards would be determined in negotiations between the industry and the Federal government. We presume that such standards would allow “trading” of mpg credits among companies and would make no distinctions between domestic and import fleets, to avoid market distortions. Whether standards are in the form of a single target value applying to every company or a variable target that accounted for market segment differences among companies would affect the identity of "winners and losers" among the companies, but would likely not affect the industry-wide outcome very much.

"Variabilization" Policies. The objective of variabilization policies is to transfer the incidence of what are currently fixed costs of motor vehicle operation to variable costs. Perhaps the most significant of these proposed policies is "Pay-at-the-Pump" (PATP) automobile insurance. If only about one-fourth of the total cost of automobile insurance were variabilized by means of a tax on gasoline, it would amount to $0.25 to $0.50/gallon additional cost. Other potential targets of variabilization are free parking, or road revenues currently raised by property or general sales taxes. We propose to focus in this analysis on PATP, as representative of this class of policies because it produces a substantial change in fuel prices and is readily modeled in NEMS.

Numerous variations on the basic idea of PATP have been proposed (El-Gassier, 1990; Sugarman, 1991; Dougher and Hogarty, 1994; Gruenspecht et al., 1994; Khazzoom, 1997) with the intent to approximate a per-mile insurance fee by means of a surcharge on gasoline. Since at least some of the risk drivers impose on other travelers *is* proportional to miles driven, PATP could effectively internalize at least a portion of a public safety externality, thereby increasing economic efficiency (Kavalec and Woods, 1997). Whether this can be achieved depends on a number of complex factors, including the efficiency of the existing system. Charging per gallon is an imprecise way of charging per mile because of the large variation in mpg across the vehicle fleet. On the other hand, larger, heavier vehicles, which generally represent the less fuel-efficient portion of the fleet, impose greater risks on other travelers, an argument for larger insurance premiums. To date, these issues remain largely unresolved. However, one clear benefit of PATP will be an elimination of *some* part of the problem of uninsured drivers, since PATP can automatically provide partial coverage to all drivers.

Our design for the PATP fee is simple. For the year 2003 to 2012, a surcharge of $0.34 per gallon of gasoline equivalent energy is added to the price of all motor fuels. From 2013 on, the surcharge is increased in one large step to $0.51 per gallon of gasoline equivalent energy to roughly correct for the increasing efficiency of the light-duty vehicle fleet.

6.3.2 Barriers to Energy Efficiency

Barriers to increased energy efficiency and reduced GHG emissions in transportation energy use include external costs and benefits, imperfect information, and imperfect competition. Fuel prices and transportation services do not reflect total social costs such as air pollution and climate change. Uncertainty about the costs and benefits to consumers of increased efficiency, caused by uncertainty about future fuel prices and a lack of explicit information about the incremental costs of higher efficiency may lead to under-investment in fuel economy technology. The inability of companies to capture the full benefits of advances in the science and technology of efficiency leads to under-investment in R&D. And the financial risks to manufacturers posed by the introduction of new technologies requiring substantial design changes that may or may not be well received by consumers can lead to the under-adoption of new technology in an oligopolistic market.

Underpriced Fuels and Transportation Services. A strong case can be made that energy fuels are underpriced, because market prices do not take full account of a variety of social costs associated with fuel use, and especially oil use (transportation is 95 percent dependent on petroleum products for fuel). Those externalities most directly tied to fuel use are greenhouse gases from direct fuel use by vehicles; air, water, and land pollution, including greenhouse gases, associated with discovering, extracting, processing, and distributing gasoline and other transportation fuels; and the energy security and economic impacts associated with the uneven geographic distribution of oil resources, that is, military expenditures associated with Persian Gulf political instability; monopsony costs associated with artificially high oil prices; and the costs to the U.S. and world economies associated with occasional oil price shocks.

Transportation services also are underpriced, for reasons that include but go beyond underpriced transportation fuels. Social costs more closely tied to transportation *services* than to energy use include air pollution – excluding greenhouse gases – associated with vehicle use, environmental impacts associated with transportation infrastructure, societal costs associated with transportation accidents (especially on the highways), the costs of highway congestion, and so forth. These costs as well as the costs of petroleum use in transportation have been examined by a number of analysts, most notably Delucchi (1997), and for the United States probably run into the hundreds of billions of dollars annually.

Imperfect Information. In making vehicle purchases, consumers and businesses experience difficulty in making rational choices about trading off the costs and benefits of different levels of energy efficiency. One cause is the difficulty in determining the true costs of higher efficiency *despite* the information on fuel economy posted on new autos and light trucks. Vehicle purchasers are rarely given explicit choices in efficiency coupled with explicit price differences associated with these choices. Instead, these price differences are buried in base prices or in the price of complete subsystems such as engines, with efficiency differences always coupled with substantive differences in other critical consumer attributes such as acceleration performance, level of luxury, vehicle handling, and so forth. Additionally, properly trading off fuel savings versus changes in vehicle price involves trading off the time-discounted value of the fuel savings against the present cost of the vehicle – a calculation that many vehicle purchasers are not familiar with. Note, however, that if consumers were extremely concerned about energy savings and determined to base their purchasing decisions on them, automakers and dealers would have a strong incentive to provide them with the information that is now lacking in the marketplace, as well as with vehicle choices that provided clearer tradeoffs. It can be argued that the lack of such information and choices is simply the consequence of consumer disinterest in improved fuel economy in the context of low fuel prices.

It is also worth noting that new car purchasers – who have a dominant influence on the design decisions of automakers – are not representative of the driving public, many of whom purchase their vehicles secondhand. In particular, new car purchasers are substantially wealthier than average drivers, which should skew their purchase preferences away from considerations of fuel use and towards considerations of ride quality, power, and other vehicle qualities.

Another potential source of difficulty in making rational vehicle choices is the substantial uncertainty associated with future fuel prices. Over the past two decades, the price of a barrel of oil has varied by fourfold, reaching highs in the early 1980s and lows within a few years thereafter. Recently, oil prices have more than doubled from near historic lows, and energy analysts widely acknowledge that disturbances to oil markets could cause future prices to escalate rapidly to multiples of even today's higher prices (and stay there for periods ranging from a few weeks to a few years). Also, there is growing controversy about the potential for oil resource shortages, coupled with higher prices, possibly beginning within the lifetime of most vehicles purchased today.

Difficulty in Capturing the Market Benefits of Technology Advances. Another barrier to firms' investments in research to develop energy efficient technology is the ability of other firms to appropriate technological advances. By this we mean that increases in knowledge of new designs and technology are easily transferred to other industry entities without necessarily benefiting the individuals or company that provided the research investment that lead to the innovation. Further, companies that absorb the market risk of introducing new technology generally will not reap the full benefits of trailblazing new markets because the attention and car owner trust brought about by a successful market launch may be transferable to a competitor's version of the new technology. Both attributes tend to yield under-investment in technology development and reluctance to introduce new technologies in areas where markets are not well established.

Risks to Manufacturers. Redesigning motor vehicles for substantial fuel economy improvements requires massive capital investments. In an intensely competitive car market a negative reaction by consumers, even to subtle aspects of a new technology, could result in massive financial losses to manufacturers. Manufacturers will therefore be understandably reluctant to commit to rapid, sweeping design changes to improve fuel economy, a matter of relatively small concern to motorists.

Table 6.7 outlines the programs and policies adopted in the two scenarios, and the barriers they address.

Table 6.7 Policies to Address Barriers to Efficiency Improvements in Transportation

		Barriers to Efficiency Improvement				
Policies	**Scenario**	**Underpriced Fuels**	**Underpriced services**	**Rational choices**	**Technology fungibility**	**Manufacturers risk**
R&D spending increase	Both	X	X		X	
Voluntary agreements	Advanced	X	X			X
Pay-at-the-pump	Both	X	X			
Tax credits for efficient vehicles	Both	X	X		X	
Air traffic management	Both	X			X	
Government fleets	Both	X		X		X
Cellulosic ethanol	Both	X				
Emissions and fuels standards	Both	X	X	X		X
Carbon trading system	Advanced	X				
Tele-commuting	Both		X			
Intelligent traffic systems	Advanced	X	X			

6.4 METHODOLOGY FOR ANALYZING POLICY IMPACTS

This section outlines the methods used to translate the policies of the Moderate and Advanced scenarios to inputs and changes to the CEF-NEMS model. A detailed description of each modification to NEMS input data or source code can be found in Appendix A-3.

6.4.1 Policy: Air Traffic Management Improvements

This policy is expected to achieve a five percent reduction in air traffic fuel use. This is simulated by increasing the rate of increase in the efficiency of existing stock, an effect historically due primarily to retrofitting existing airframes with newer, more efficient engines. The intention here is to reflect a general improvement in aircraft operating efficiency due to more effective flight planning and reductions in excessive time spent waiting in the air or waiting on the ground due to traffic congestion. Specifically, the annual rates of change in fleet-wide efficiency were increased from 0.18 percent to 0.34 percent for wide-body aircraft, and from 0.44 percent to 0.60 percent for narrow-body planes.

6.4.2 Carbon Permit Program

The carbon permit program is implemented at the national level in the integrated runs of CEF-NEMS. A charge of $50 per metric ton of carbon is imposed to simulate the effect of a tradable permit program. Although there are no programming changes made to the transportation sector modules, the carbon charge raises the price of transportation fuels, reducing transportation demand and shifting technology choices within the transportation sector.

6.4.3 Cellulosic Ethanol Commercialization Program

Several key assumptions were added to NEMS to reflect the success of research to reduce the costs of cellulosic ethanol and programs to promote its use. The AEO99 Reference Case continues tax credits for ethanol but in nominal dollars so that the value of the credits in constant dollars decreases gradually with time. We retain this assumption in all scenarios. The AEO99 also includes risk premiums for investment in cellulosic ethanol production to reflect the uncertainties associated with the market for a new fuel supported, in part, by government subsidies. We assume that a loan guarantee or subsidy program is created by the federal government to eliminate these added risks, so that funds can be borrowed for investment in ethanol production at prime rates. Finally, the AEO99 assumes that by 2020 the costs of producing ethanol from cellulose can be reduced by 20 percent over the current costs of production from corn, about $1.40 per gallon of ethanol. We assume that a 50 percent cost reduction is possible by 2020, more in line with the goals of the DOE's R&D program, and consistent with the most optimistic estimates reported by the National Research Council, $0.70 per gallon in 2015 (NRC, 1999, table 2-2).

6.4.4 Tax Credit for High Efficiency Vehicles

The tax credit was implemented in NEMS by reducing the low-volume prices of alternative fuel vehicles by the amounts indicated in Table 6.5 above. In matching low-volume prices only, we are assuming that the tax credits will be phased out as sales increase much beyond 50,000 units per year. The gasoline hybrid is an exception, since it is handled by the FEM subroutine rather than the AFVM. The FEM does not allow for phasing out of the credit with increasing sales volume, and so the $1,000 credit is maintained throughout.

6.4.5 Invigorated Government Fleet Programs

The principal effect of invigorated government fleet programs for alternative fuel vehicles is reflected in increased retail availability of alternative fuels. The availability of alcohol fuels and hydrogen were increased gradually from negligible levels today to 50 percent by 2020. Details are provided in Appendix A-3.

6.4.6 R&D Spending Increase

The effect of increased spending on research, development, and demonstration is represented by:

1. Advancing the introduction dates for new technology (for light-duty vehicles by 30 percent in the Moderate case and, with the additional incentive of the voluntary standards for higher fuel economy, by 40 percent in the Advanced case),
2. Adding a few new technologies (two advanced materials technologies for light-duty vehicles, two new technologies for heavy-duty vehicles, and a wing-body aircraft design for the air mode),
3. Incrementally reducing the cost, and
4. Increasing the mpg performance of selected technologies.

Details of the changes made to the original NEMS assumptions are provided in Appendix A-3.

NEMS currently has the capability of modeling a large but not unlimited number of fuel efficiency technologies. There are technologies we have not modeled, and within those modeled, only some are assumed to undergo significant price reductions under the Moderate and Advanced scenarios. **This is not to imply that we have perfect foresight of which technologies will be commercially successful, and which will respond substantially to increases in research emphasis.** Clearly we do not, and we imagine that, were the societal conditions and policies postulated in the scenarios actually to come about, the U.S. fleet of transportation vehicles would be far from a perfect match of the fleet characteristics projected by CEF-NEMS in this exercise. While we have made our technology assumptions with care, we recognize that some we have included will not be realized while others we have excluded will succeed in the marketplace. It is entirely possible, for example, that significant improvements in natural gas vehicle storage technologies, coupled with changes in gas availability and other factors, could lead to a far greater penetration of the fleet by natural gas vehicles than is projected here. Similarly, a breakthrough in lithium-polymer battery technology, perhaps coupled with greater-than-expected cost reductions in power electronics and electric motors, could lead to a larger penetration of the fleet by electric vehicles. And inadequate progress in emission controls for diesel vehicles, or further tightening of fine particulate matter standards based on new health effects research or greater demands by the public, could lead to far *smaller* penetration of diesel technology (we explore this possibility in a "no diesel" sensitivity run of the Advanced scenario, below). We cannot overcome these uncertainties. However, as noted earlier, there exists a large enough portfolio of promising efficiency technologies to provide some comforting redundancy. By using the great deal of information available about the status of the technology portfolio and the historic record of technological progress for similar technologies, we believe we can make a reasonable estimate of the likely *overall* effect of increased R&D even if we get the precise details wrong.

6.4.7 Telecommuting Programs

As discussed previously, the 1999 AEO vmt projection reflects a rate of growth (1.6 percent/yr.) that is quite low by historical standards (3.1 percent from 1970-96; 3.0 percent from 1986-96), and we believe a higher rate, perhaps closer to 2.0 percent, would be more realistic. In a sense, then, it could be argued that some transportation demand management programs, including telecommuting programs, are already implicitly included in the Reference Case. And even given the implementation of vmt reduction programs that could credibly be implemented under the definitions of the Moderate and Advanced scenarios, we are skeptical that they could reduce vmt enough to achieve the EIA 1.6 percent rate of increase. Thus, we have chosen not to further reduce this rate in the scenarios, but simply to consider the

1.6 percent rate in the two policy scenarios to be somewhat more realistic than the same rate in the Reference Case.

6.4.8 Intelligent Traffic Control Systems

To simulate the effect of increased usage of ITS systems in the Advanced scenario, we reduced by one percentage point the degradation factor in NEMS that translates EPA values of fuel economy into "on-road" values. The factor accounts for congestion and other factors that increase fuel usage over the value that would be computed using the EPA values.

6.4.9 Voluntary Agreements

In the advanced case only, voluntary fuel economy targets are implemented with changes to NEMS inputs intended to simulate greater manufacturer attention to fuel economy relative to other vehicle attributes. The dates for first introduction of future fuel economy technologies were foreshortened by 40 percent. However, no date was moved closer to the present than 2003. The weight increases projected in the AEO99 Reference Case (20 percent for passenger cars and 30 percent for light trucks) were reduced to actual increases through 1998 for both vehicle types. In addition, for the Moderate scenario, the AEO99 factors that relate the demand for performance to changes in vehicle horsepower were changed to (lower) factors developed by Energy and Environmental Analysis, Inc. (EEA), which helped develop this version of NEMS; for the Advanced scenario, the EEA factors were cut in half to reflect the pressure on automakers to restrict power increases in order to be able to comply with the Voluntary Agreement. As a result, in both scenarios, the demand for larger engines was considerably reduced, though horsepower increases were still allowed through 2020. Given the substantial reductions in vehicle weight in this scenario, there is still scope for significant increases in performance as measured by the ratio of horsepower to weight. Similar changes were made to accelerate the introduction of fuel economy technology in heavy-duty vehicles, as described in detail in Appendix A-3.

Finally, the EIA Reference Case assumption that consumers estimate the value of fuel economy based on only the first four years of fuel savings, discounted to present value at 8 percent real, was changed to a discounting of fuel savings over the full 12 years of expected vehicle life at a 15 percent per year, real discount rate. The function of these parameters in the NEMS models is to represent manufacturers' decisions about how consumers will perceive the value of fuel economy, rather than to actually represent consumers' decision-making. Thus, these changes are intended to reflect changes in manufacturers' willingness to adopt fuel economy technology driven by their commitment to a Voluntary Agreement rather than a change in consumers' attitudes towards higher mpg.

6.4.10 "Variabilization Policies" (Pay-at-the-Pump Insurance)

For the Advanced scenario only, variabilization policies were simulated by adding a Pay-at-the-Pump insurance surcharge to all motor fuels. This surcharge pays for a minimum level of liability insurance for all motor vehicles, leaving the net cost of highway travel roughly constant. What is usually paid as part of an annual or semi-annual fixed cost now is "variabilized" and paid for with the purchase of fuel.

6.4.11 New CAFE Standards (Sensitivity Case)

The NEMS Transportation Sector Model permits the specification of alternative CAFE standards for passenger cars and light trucks[3]. We specified identical standards for domestic and imported vehicles, and set the non-compliance fine to $150 per mpg (vs. $50 per mpg for the current standard) by which a manufacturer's corporate average fuel economy falls below the standard. If domestic or imported passenger cars or light trucks fail to meet the standard in any year, NEMS adds the fine to the dollar value of higher fuel economy for that class in its technology selection subroutine, increasing the market penetration of fuel economy technologies. In addition, NEMS advances the first date of technology adoption by one year, to reflect the belief that manufacturers faced with a known standard will accelerate the introduction of technologies, if necessary.

The CAFE constraint operates only on the NEMS submodel dealing with gasoline-fueled vehicles; alternative fueled vehicles (including diesels) are treated in a separate model of NEMS, and NEMS does not apply the CAFE constraint to this submodel. This means that obtaining a given level of fleetwide fuel economy requires some trial and error, experimentation with different levels of "gasoline-only" CAFE constraints until the total fleet reaches the desired mpg average. For example, obtaining a 65 mpg CAFE for the automobile fleet required the use of a 55 mpg target CAFE in the gasoline vehicle submodel.

6.5 SCENARIO RESULTS

6.5.1 Moderate Scenario

In the Moderate scenario, primary energy consumption increases from 25.0 Quads in 1997 to 34.1 Quads in 2020, a 36.4 percent increase or about 7 percent less than the energy consumption projected in the Baseline Case. Similarly, carbon emissions increase from 478 MtC in 1997 to 646 MtC in 2020, a 35.1 percent increase and about 7 percent less than in the Baseline Case.

Table 6.8 presents the 10-year results in travel, energy efficiency, and energy consumption for the several transportation modes, and energy consumption by fuel type. Table 6.9 presents carbon emissions by mode and fuel type.

The seven percent drop (from the Baseline) in energy consumption and carbon emissions has a few key components:

- **Greater improvement in light-duty fuel economy.** Light-duty fleet mpg improves by 2.8 versus 0.9 in the BAU scenario (Table 6.7). This results primarily from the estimated efficiency improvements and cost reductions achieved by the 50 percent increase in R&D funding in the Moderate scenario. The model year 2020 mpg values attained are, respectively, 38.0 mpg (versus 32.1 mpg in the Baseline scenario) for autos and 24.8 mpg (vs. 22 mpg) for light trucks.
- **Improved freight truck efficiency.** Freight truck mpg rises to 7.6 mpg in 2020 from 5.6 mpg in 1997 (vs. 6.3 mpg in the Baseline), yielding a 16 percent reduction in freight truck fuel consumption in 2020 (Table 6.7). This improvement results from the vigorous R&D push for advanced heavy-duty diesel technology, as well as a variety of other technologies.

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[3] We attempted to use this feature in the 1997 "5-Lab" study, but found that it did not function properly. With the assistance of Mr. Dan Mezler of EEA, Inc., we were able to identify and correct a "bug" in the program so that the CAFE features functioned as intended. This is apparently the first instance of the use of CAFE constraints in the NEMS model.

Table 6.8 Results of Moderate Scenario

	1997	***2010***	***2020***
Level of Travel by Mode (Billion)			
Light Duty Vehicles (vehicle miles traveled)	2301	2892	3320
Commercial Light Trucks (vehicle miles traveled)	69	91	104
Freight Trucks (vehicle miles traveled)	178	245	272
Air (seat miles demanded)	1050	1818	2471
Rail (ton miles traveled)	1235	1508	1666
Marine (ton miles traveled)	757	882	967
Energy Efficiency Indicator by Mode			
New Light Duty Vehicle (MPG)[a]	24	27.4	30.5
New Car (MPG)	27.9	34.7	38.0
New Light Truck (MPG)	20.2	22.1	24.8
Light-Duty Fleet (MPG)	20.5	20.9	23.4
New Commercial Light Truck (MPG)	19.9	21.1	23.5
Stock Commercial Light Truck (MPG)	14.6	15.3	16.5
Aircraft (seat miles/gallon)	51.1	56.7	62.6
Freight Truck (MPG)	5.6	6.5	7.6
Rail (ton miles/kBtu)	2.7	3.1	3.5
Site Energy Use by Mode (Quadrillion Btu)			
Light-Duty Vehicles	13.9	17.7	18.2
Commercial Light Trucks	0.6	0.7	0.8
Freight Trucks	4.2	5.0	4.8
Air	3.4	5.1	6.1
Rail	0.5	0.6	0.6
Marine[b]	1.3	1.6	2.0
Pipeline Fuel	0.7	0.8	0.9
Other	0.2	0.3	0.3
Total	24.9	31.9	33.7
Energy Use by Fuel Type (Quadrillion Btu)			
Distillate Fuel	4.6	5.7	6.1
Jet Fuel	3.3	5.0	6.0
Motor Gasoline	15.1	18.1	17.8
Residual Fuel	0.8	1.0	1.3
Liquefied Petroleum Gas	0.0	0.1	0.2
Other Petroleum	0.3	0.3	0.4
Petroleum Subtotal	24.10	30.38	31.75
Pipeline Fuel Natural Gas	0.7	0.8	0.9
Compressed Natural Gas	0.0	0.2	0.3
Renewables (E85)[c]	0.0	0.1	0.2
Methanol	0.0	0.2	0.3
Liquid Hydrogen	0.0	0.0	0.0
Electricity	0.1	0.2	0.2
Total Site Energy	24.9	31.9	33.6
Electricity Related Losses	0.1	0.3	0.5
Total Primary Energy	25.0	32.2	34.1

[a] Light-duty vehicles are passenger cars and light trucks, combined.

[b] In review, we discovered that the efficiency improvements described in the text for marine transport had not been input to the model due to an oversight. These improvements would have reduced marine energy use by approximately 0.04 quads in 2010 and 0.1 quads in 2020.

[c] The CEF-NEMS model reports renewables blended with gasoline as “Motor Gasoline.” For an accounting of cellulosic ethanol blended with gasoline, please see the discussion in section 6.5.1.

Table 6.9 Transportation Carbon Emissions: Moderate Scenario (million metric tons C)

	1997	*2010*	*2020*
Carbon emissions by mode (MtC)			
Light Duty Vehicles	267.0	337.6	348.0
Commercial Light Trucks	11.3	14.2	15.2
Freight Trucks	82.4	95.3	91.0
Air	63.3	97.5	117.2
Rail	12.3	13.6	14.2
Marine[a]	27.3	33.5	40.6
Pipeline Fuel	10.6	12.1	12.7
Other	3.8	7.2	7.1
Total	477.9	611.0	646.0
Carbon emissions by fuel type (MtC)			
Other	91.6	113.4	121.5
Jet Fuel	63.3	96.7	116.4
Motor Gasoline	289.7	347.5	340.3
Residual Fuel	15.9	21.7	27.6
Liquefied Petroleum Gas	0.7	2.3	2.7
Other Petroleum	3.0	3.6	3.9
Petroleum Subtotal	464.1	585.1	612.5
Pipeline Fuel Natural Gas	10.6	12.1	12.7
Compressed Natural Gas	0.2	3.0	3.8
Renewables (E85)*	0.0	0.0	0.0
Methanol	0.0	2.9	5.3
Liquid Hydrogen	0.0	0.0	0.0
Electricity	3.0	7.8	11.7
Total	477.9	611.0	646.0

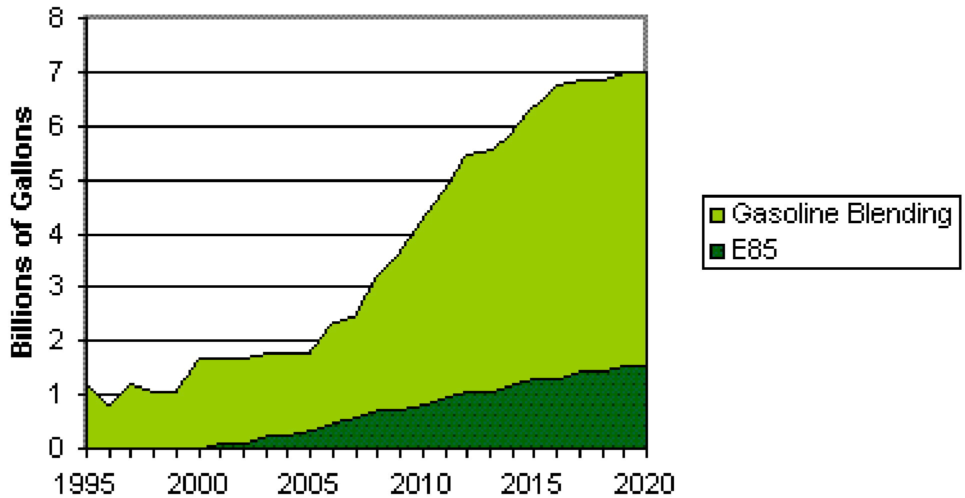
[a]In review, we discovered that the efficiency improvements described in the text for marine transport had not been input to the model due to an oversight. These improvements would have reduced marine carbon emissions by approximately 0.8 MtC in 2010 and 2.0 MtC in 2020.

- **A modest drop in projected air travel energy use** from improvements in operational efficiency, resulting from a more rapid implementation of current plans for operational advances.

The light-duty fleet experiences significant changes in composition from the baseline fleet. In particular, diesel sales increase substantially – for 2020, over 2,100,000 vehicles/yr in the Moderate scenario vs. less than 200,000/yr in the Baseline scenario. Also, alternative fuel vehicles expand much more rapidly than in the Baseline. By 2020:

- Alcohol flex-fuel ICEs sell 1,175,000 units/yr vs. about 317,000/yr in the Baseline
- Alcohol ICEs sell 350,000/yr vs. 92,000/yr
- Both diesel-electric hybrids and fuel cell vehicles of all types play essentially no role, vs. a modest role (e.g., 29,000 diesel electric hybrids sold/yr in 2010) in the Baseline. This is a result of changes to the NEMS Alternative Fuel Vehicles model parameters (see Appendix A-3 for details) rather than a result of changed conditions in the scenario.

Fig. 6.6 Use of Ethanol for Motor Fuel
MODERATE CASE



6.5.2 Advanced Scenario

In the Advanced scenario, primary energy consumption increases from 25.0 Quads in 1997 to 28.9 Quads in 2020 (Table 6.10), a 16 percent increase; the 2020 transportation energy consumption is about 21 percent less than the Baseline 2020 value. Carbon emissions increase from 478 MtC in 1997 to 545 MtC in 2020, a 14 percent increase; the 2020 emissions are about 23 percent less than in the Baseline. The slightly smaller percentage increase in carbon emissions than in energy consumption implies that the Advanced scenario has managed to reduce carbon intensity somewhat from the level in the Baseline scenario, due to increased use of cellulosic ethanol and other alternative fuels.

Table 6.10 presents the 10-year results in travel, energy efficiency, and energy consumption for the several transportation modes, and energy consumption by fuel. Table 6.11 breaks down carbon emissions by mode and fuel type.

Table 6.10 Results of the Advanced Scenario

	1997	*2010*	*2020*
Level of Travel by Mode (Billion)			
Light Duty Vehicles (vehicle miles traveled)	2301	2829	3184
Commercial Light Trucks (vehicle miles traveled)	69	90	103
Freight Trucks (vehicle miles traveled)	178	246	273
Air (seat miles demanded)	1067	1781	2425
Rail (ton miles traveled)	1236	1352	1428
Marine (ton miles traveled)	758	883	968
Energy Efficiency Indicator by Mode			
New Light Duty Vehicle (MPG)[a]	24	32.8	41.6
New Car (MPG)	27.9	41.5	51.4
New Light Truck (MPG)	20.2	26.4	33.9
Light-Duty Fleet (MPG)	20.5	22.8	28.3
New Commercial Light Truck (MPG)	19.9	24.3	29.2
Stock Commercial Light Truck (MPG)	14.6	16	18.7
Aircraft (seat miles/gallon)	52	59.9	65.8
Freight Truck (MPG)	5.6	6.8	9
Rail (ton miles/kBtu)	2.8	3.4	3.9
Site Energy Use by Mode (Quadrillion Btu)			
Light-Duty Vehicles	13.9	15.9	14.4
Commercial Light Trucks	0.6	0.7	0.7
Freight Trucks	4.2	4.8	4.0
Air	3.4	4.8	5.8
Rail	0.5	0.5	0.5
Marine	1.3	1.6	2.0
Pipeline Fuel	0.7	0.9	0.9
Other	0.2	0.3	0.3
Total	24.9	29.5	28.6
Energy Use by Fuel Type (Quadrillion Btu)			
Distillate Fuel	4.6	5.9	5.7
Jet Fuel	3.3	4.7	5.7
Motor Gasoline	15.1	16.1	13.7
Residual Fuel	0.8	1.0	1.3
Liquefied Petroleum Gas	0.0	0.1	0.1
Other Petroleum	0.3	0.3	0.4
Petroleum Subtotal	24.10	28.13	26.83
Pipeline Fuel Natural Gas	0.7	0.9	0.9
Compressed Natural Gas	0.0	0.2	0.2
Renewables (E85)[b]	0.0	0.0	0.0
Methanol	0.0	0.1	0.2
Liquid Hydrogen	0.0	0.0	0.1
Electricity	0.1	0.2	0.2
Total Site Energy	24.9	29.5	28.5
Electricity Related Losses	0.1	0.3	0.4
Total Primary Energy	25.0	29.8	28.9

[a]Light-duty vehicles are passenger cars and light trucks, combined.

[b]In review, we discovered that the efficiency improvements described in the text for marine transport had not been input to the model due to an oversight. These improvements would have reduced marine energy use by approximately 0.07 quads in 2010 and 0.18 quads in 2020.

[c]The CEF-NEMS model reports renewables blended with gasoline as "Motor Gasoline." For an accounting of cellulosic ethanol blended with gasoline, please see the discussion in section 6.5.1.

Table 6.11 Transportation Carbon Emissions: Advanced Scenario

	1997	2010	2020
Carbon emissions by mode (MtC)			
Light Duty Vehicles	267.0	304.5	274.3
Commercial Light Trucks	11.3	13.4	13.1
Freight Trucks	82.4	91.7	76.5
Air	63.3	91.4	110.2
Rail	12.3	11.5	10.9
Marine[a]	27.3	33.3	40.2
Pipeline Fuel	10.6	12.2	13.1
Other	3.8	7.0	6.6
Total	477.9	565.1	544.9
Carbon emissions by fuel type (MtC)			
Other	91.6	116.0	113.3
Jet Fuel	63.3	90.6	109.4
Motor Gasoline	289.7	308.2	261.9
Residual Fuel	15.9	21.6	27.5
Liquefied Petroleum Gas	0.7	2.1	2.2
Other Petroleum	3.0	3.6	3.9
Petroleum Subtotal	464.1	542.1	518.2
Pipeline Fuel Natural Gas	10.6	12.2	13.1
Compressed Natural Gas	0.2	2.8	3.2
Renewables (E85)*	0.0	0.0	0.0
Methanol	0.0	1.8	3.0
Liquid Hydrogen	0.0	0.0	0.0
Electricity	3.0	6.2	7.4
Total	477.9	565.1	544.9

[a]In review, we discovered that the efficiency improvements described in the text for marine transport had not been input to the model due to an oversight. These improvements would have reduced marine carbon emissions by approximately 1.5 MtC in 2010 and 3.6 MtC in 2020.

The 21 and 23 percent drops (from the Baseline) in energy consumption and carbon emissions, respectively, have the following components:

- **Improvements in light-duty fuel economy.** The on-road fuel economy of the fleet improves by 7.8 mpg by 2020, vs. 0.9 mpg in the Baseline (Fig. 6.7). New car mpg (Fig. 6.8) increases to 51.4 mpg by 2020 (vs. 32.1 mpg Baseline) and light truck mpg (Fig. 6.9) increases to 33.9 mpg (vs. 22.0 mpg). These increases in fuel economy result from the combination of Voluntary Agreements, tax credits for high efficiency vehicles (as originally proposed by the Administration), a significant economic incentive afforded by the increase in gasoline prices associated with carbon credits and the PATP price add-on, and technology cost reductions and performance improvements associated with a doubling of the R&D budget.
- **Freight truck efficiency gains.** Freight truck efficiency rises to 9 mpg in 2020 from about 5.6 mpg in 1997, vs. 6.3 mpg in the 2020 Baseline and 7.6 mpg in the 2020 Moderate scenario. This yields a 30 percent reduction in energy consumption from the 2020 Baseline and a 17 percent reduction from the Moderate scenario results.
- Further modest improvements in aircraft and rail energy efficiency.

- **A drop in railroad freight movement.** From the Baseline level of 1,698 billion ton miles in 2020 rail freight traffic decreases to 1426 billion ton-miles in the Advanced scenario due to reduction in coal use, and therefore shipments to power plants.

Fig. 6.7 Light-Duty Vehicle Stock Fuel Economy

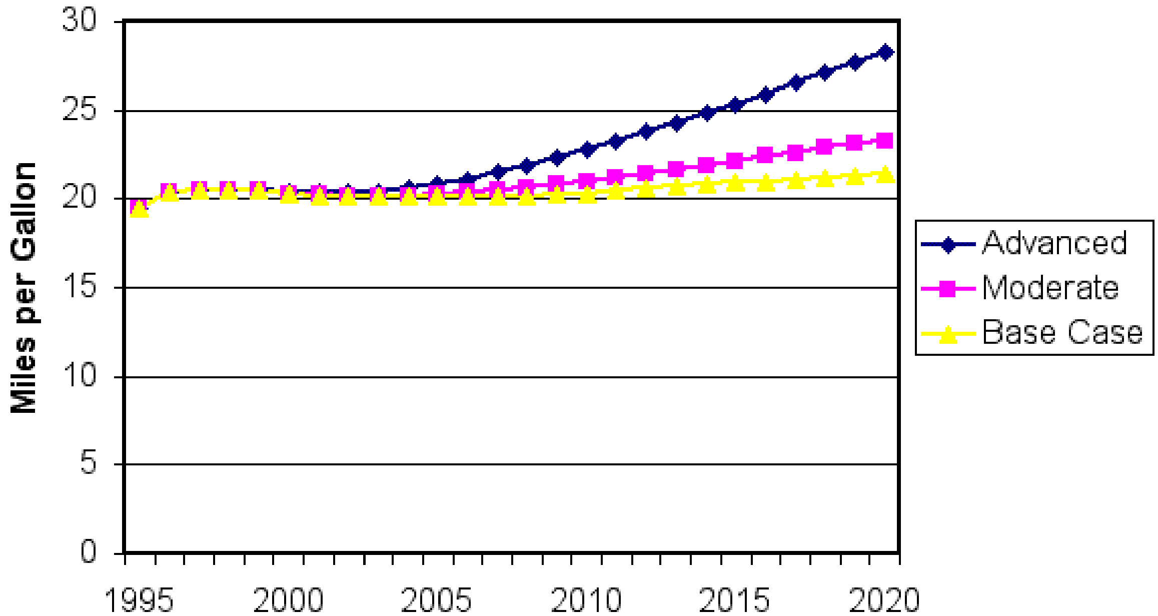


Fig. 6.8 New Passenger Car Fuel Economy

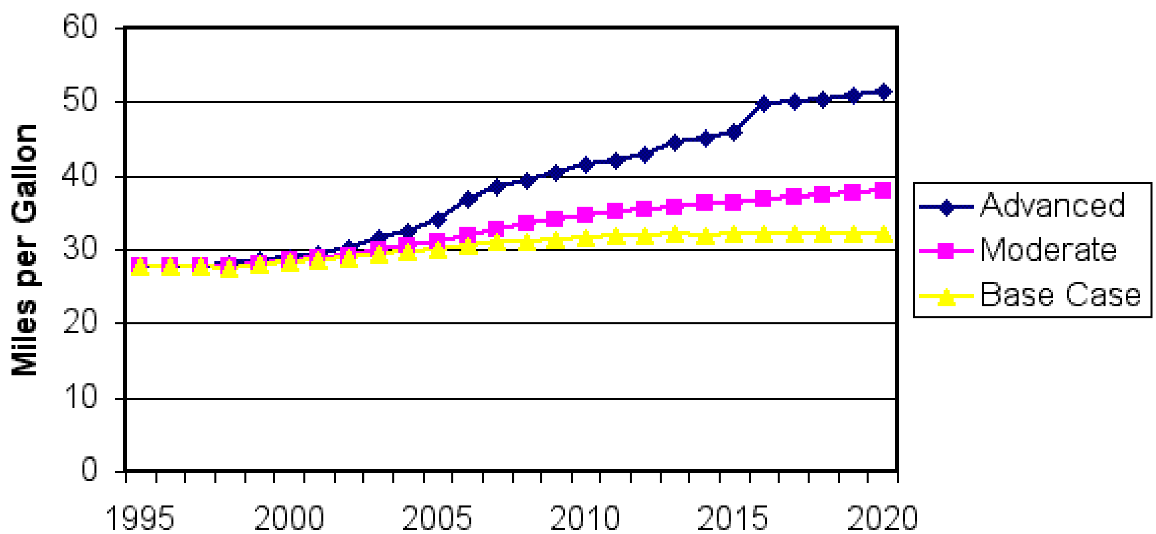
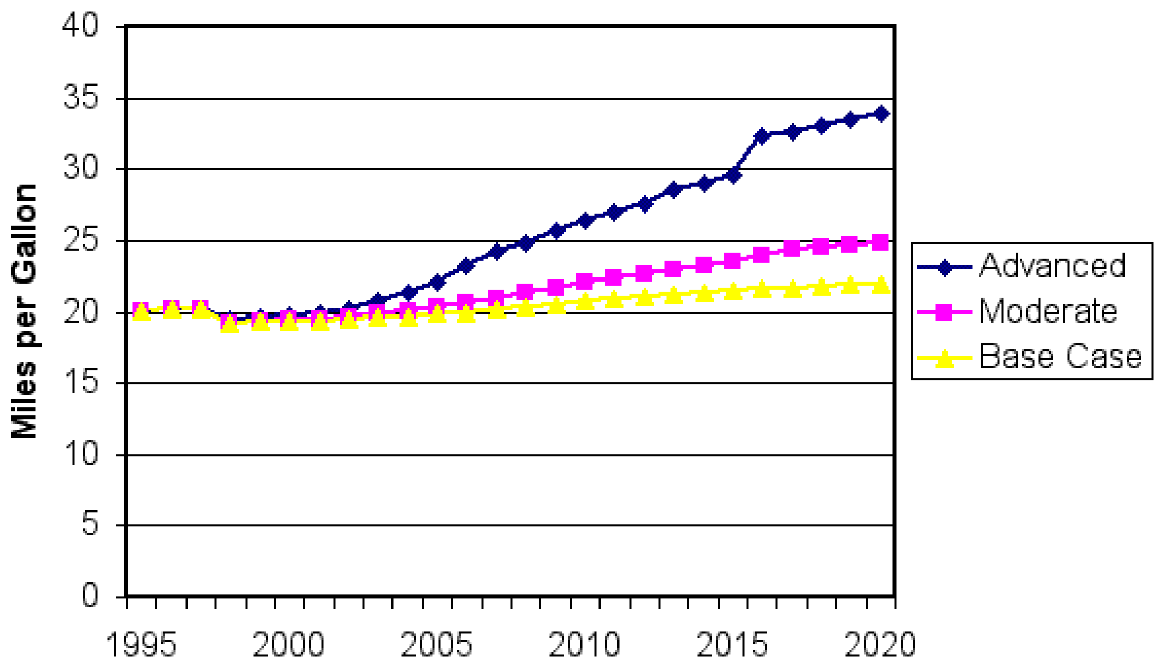


Fig. 6.9 New Light Truck Fuel Economy



Interesting changes in the light-duty fleet composition occur in the Advanced scenario, including:

- Fuel cell vehicles achieve a significant market share after 2015 (Fig. 6.10). In 2020, 2.2 million fuel cell passenger cars and light trucks are sold in the Advanced scenario (10 percent of light-duty vehicles sold that year). About 0.9 million are passenger cars while 1.3 million are light trucks. By 2020 there are 9.4 million fuel cell vehicles in a total population of 255 million light-duty vehicles.
- Fuel economy improvements to gasoline-powered vehicles were led by a variety of engine technology improvements, especially advanced valve-timing and lift controls, friction reductions, direct-injection, and 4- and 5-valve designs. Next in relative importance were gasoline-hybrid technology and materials substitution, especially aluminum and plastics (Fig. 6.11).
- Hydrogen fuel cell vehicles, which according to our assumptions are cheaper and more energy efficient, are the most successful, accounting for 1.0 million of the 2.2 million total sales in 2020. In 2020, there are 3.9 million hydrogen fuel cell vehicles on the road consuming 0.1 quads of hydrogen annually.
- Hybrid vehicles have an earlier impact, accounting for 13 percent of light-duty vehicle sales in 2010 and 15 percent in 2020.
- Even in 2020, the 47 percent of new light-duty vehicles are powered solely by gasoline internal combustion engines.
- TDI diesels continue to play a major role in the light-duty vehicle fleet, with sales exceeding 1 million after 2005 and standing at 2.6 million per year in 2020. By 2020, there are 30 million TDI diesel light-duty vehicles on the road which, together with 7 million diesel-electric hybrids, comprise almost 15 percent of the light-duty vehicle population.

- Diesel-electric hybrids achieve a modest market share early on, and retain it through 2020. New light-duty vehicle sales exceed 350,000 by 2007, peak at over 700,000 in 2013, and decrease to just over 380,000 in 2020 as the fuel cell vehicles begin to succeed.

Fig. 6.10 Alternative Fuels and Vehicles Market Shares, Advanced Scenarios

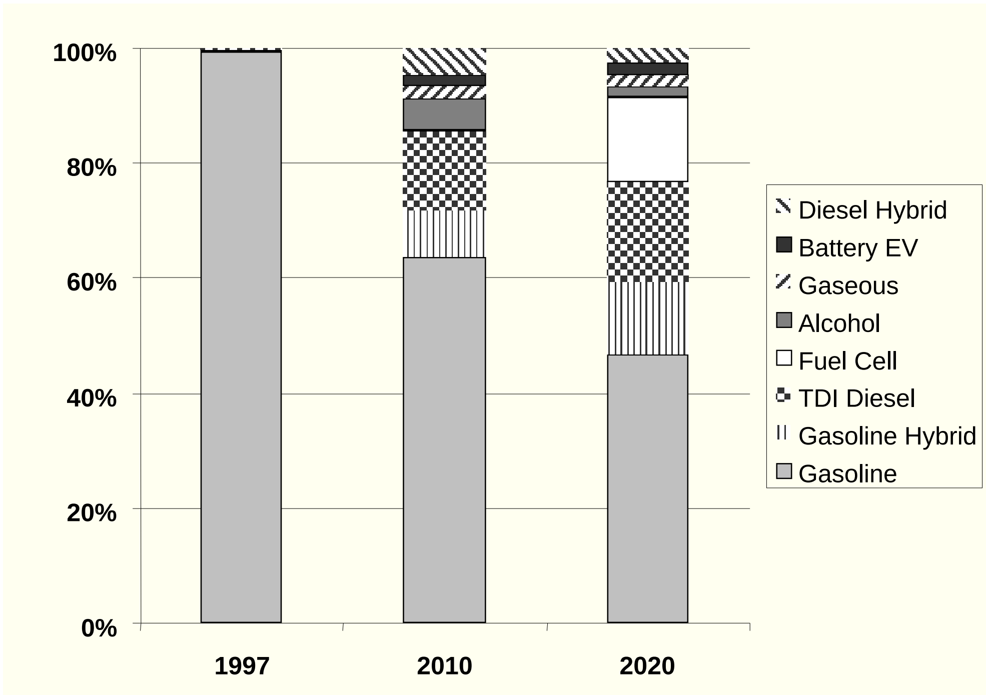
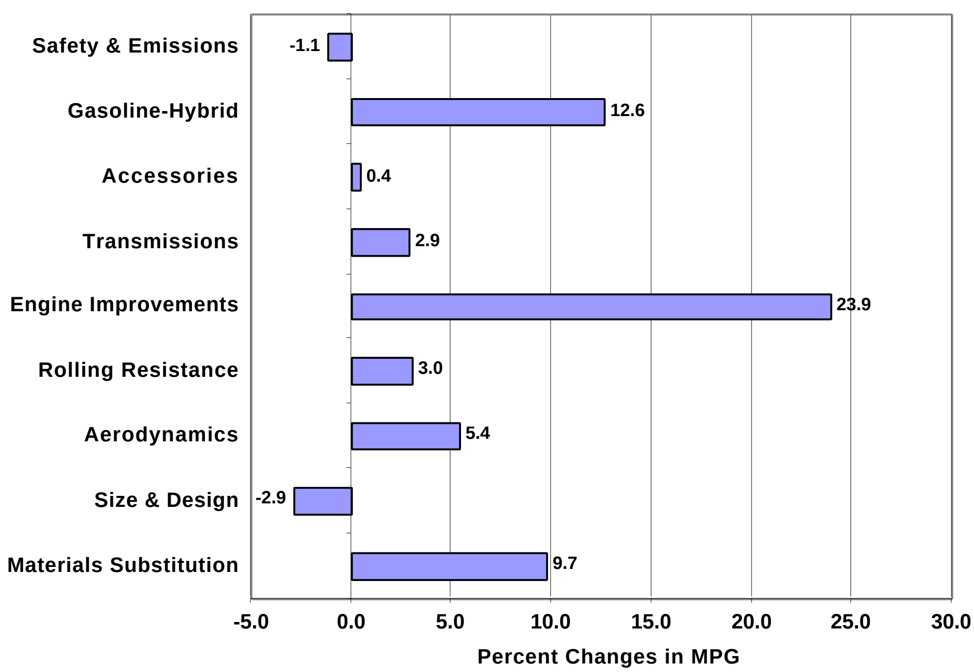
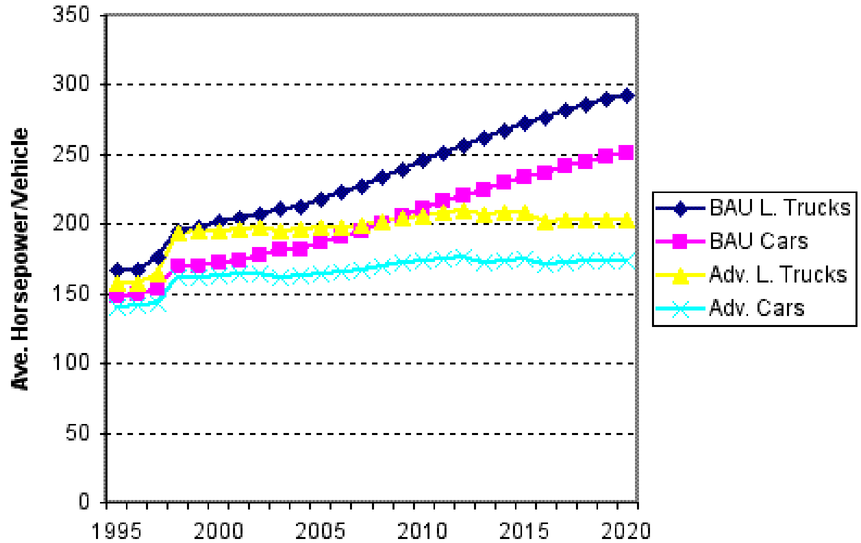


Fig. 6.11 Sources of Passenger Car MPG Improvements: Gasoline Engine Technology Only, Advanced Scenario, 2020 (28.6 to 44.1 MPG)



- The enormous growth of vehicle horsepower is restrained in the Advanced scenario. In 1998, the average horsepower of new passenger cars sold in the United States was 155 (NHTSA, 1999). In the BAU case, passenger car horsepower increases to 251 by 2020 (Fig. 6.12). Light truck horsepower increases even more, from 189 in 1998 to 293 in 2020. The Advanced Case foresees much more modest increases, to 174 hp for cars and 199 hp for light trucks. However, vehicle weight decreases in the advanced scenario by about 12 percent for passenger cars, so that vehicle acceleration performance would still be about 25 percent faster than today's cars.

Fig. 6.12 Projected Engine Power of Light-Duty Vehicles



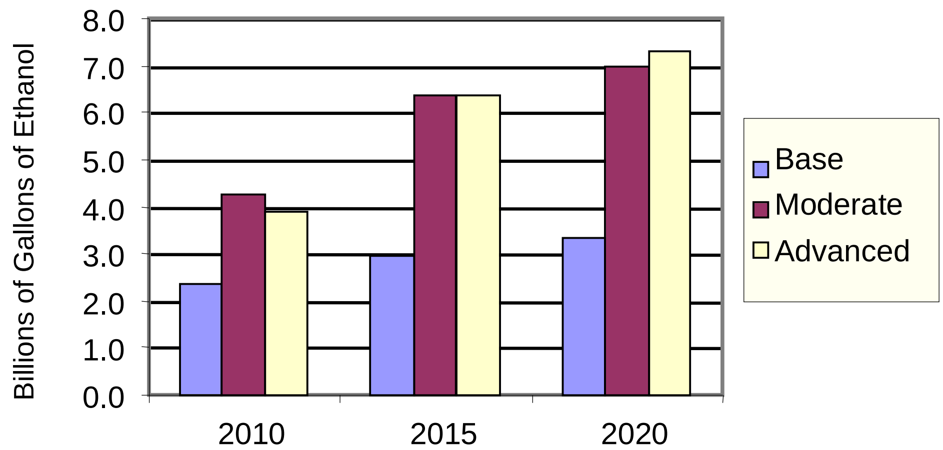
Cellulosic Ethanol – Advanced. Use of ethanol for motor fuel increases from 1.1 billion gallons in 1999 to 3.9 billion in 2010, to 6.4 billion gallons in 2015, and 7.3 in 2020 (Fig. 6.13). Ethanol's share of the gasoline market also increases from 3.8 percent in 2015 to 4.7 percent in 2020 (5.3 percent to 6.6 percent, by volume). The much lower demand for gasoline in the Advanced scenario depresses demand for ethanol. Comparison of Tables 6.7 and 6.8 shows that gasoline use in the Advanced scenario is down 12 percent in 2010 and 24 percent in 2020 versus the Moderate scenario. Ninety-five percent of the demand for ethanol as a motor fuel is for gasoline blending. Once again, these projections do not account for the potential impact of an MTBE ban, which would tend to increase demand for ethanol as a blending stock.

A potential policy for stimulating renewable fuels use is a target for the percentage of renewable fuels in highway fuels. Senator Daschle has proposed a requirement that all gasoline sold in the nation have a renewable fuel component. A recent version of the draft legislation requires that all gasoline in commerce contain a 2.1% "fuel derived from a renewable source" component and a separate 1.0% cellulosic ethanol component, to be phased in by 2008. Although cellulosic ethanol *is* renewable, the legislation appears to require a total renewable content of 2.1+1.0, or 3.1 percent. For the gasoline demand forecast by the EIA Reference Case, this target would translate into a requirement for at least 4.7 billion gallons of renewable fuels (presumably mostly ethanol) by 2010, versus a projected production without such a policy of less than 2.5 billion gallons[4]. The requirement would be less than this for the

[4] Assuming that the requirement is volumetric, that is, 2.1 gallons of ethanol or other renewable fuel for every 100 gallons of gasoline.

Moderate and Advanced Scenarios (approximately 4.5 and 4.0 billion barrels, respectively), because future gasoline demand is lower in these scenarios.

Fig. 6.13 Ethanol Use for Motor Fuel



Requirements of this sort can have two opposite effects. They can raise costs by requiring producers to turn to more expensive feedstocks or production facilities. And they can lower costs by stimulating increased R&D that can allow access to new, less expensive feedstocks or reduce processing costs. In the context of the two policy scenarios, however, we have already assumed that increased R&D funding has yielded a 50 percent decrease in overall ethanol production costs, producing a significant increase in ethanol use as a blending stock in gasoline. For both scenarios, ethanol use is projected to be about 4 billion gallons in 2010 *without* the stimulation of a renewable fuels requirement (see Fig. 6.12). In other words, we project that the market-driven level of ethanol production in our policy scenarios would be similar to the production level required under the proposal by Senator Daschle.

6.5.3 Advanced Scenario Sensitivity Cases

No Diesel Case. In both the Moderate and Advanced scenarios, the market shares of advanced diesel engines increase significantly. The diesel's acceptability in the future will depend on its ability to meet stringent emissions standards. It is by no means certain that a practical, clean diesel able to meet increasingly stringent standards, can be developed. At present, diesels produce more NO_x and particulate emissions than gasoline engines of comparable power. Unless these emissions can be reduced to acceptable levels, the light-duty diesel will not have a place in a clean energy future (see, e.g., Mark and Morey, 1999).

This is an excellent example of the uncertainties inherent in projecting future transportation energy use and GHG emissions. It might appear that the success of diesel technology is crucial to achieving both scenarios' reductions in energy use and GHG emissions, since except for the fuel cell, no single technology offers larger fuel economy benefits. The TDI diesel achieves a full 40 percent fuel economy improvement over a conventional gasoline vehicle of the same size and performance, while the diesel-electric hybrid increases miles per gallon by approximately two thirds. To examine the dependence of the scenarios' outcome on diesel technology, we ran a sensitivity case based on the Advanced scenario but removing the light-duty diesel from the vehicle mix. **In comparing this new case to the original scenario, both sets of results are from "unintegrated runs," that is, the runs are not precisely the same as those shown in the previous section because the effects of changes in other sectors on the transportation sector are not incorporated.** This should have little effect on the results.

In the (unintegrated) Advanced scenario, sales of TDI diesels increase from 60 thousand in 1999 to 2.2 million annually in 2010 and over 3.1 million in 2020 (Fig. 6.14). Sales of diesel-electric hybrids in the scenario grow from 0 in 2002 to peak at over 800,000 units in 2013. Diesel sales contribute to an overall increase in combined new passenger car and light truck fuel economy from 24.0 MPG in 2000 to 33.5 MPG in 2010 and 41.9 MPG in 2020. In the unintegrated Advanced scenario, energy use by all light duty vehicles increases from 14.5 in 1999 to 15.5 quads in 2010, then falls to 14.1 quads in 2020.

We simulated the absence of light-duty diesel technologies by raising their prices in the Advanced scenario by $10,000 per vehicle after 2003. The NEMS AFV model responded by reducing their predicted sales to 0. Fig. 6.15 shows how vehicle sales have changed in this scenario. The effects on light-duty vehicle fuel economy and energy use, however, were relatively modest. With no diesels, the fuel economy of light-duty vehicles increased from 24.0 in 2000 to 31.4 in 2010 and to 40.5 in 2020, just 1.4 MPG below the scenario with advanced diesels (Fig. 6.16). Energy use by all light-duty vehicles increased to 15.7 quads in 2010, then declined to 14.6 in 2020, just 0.5 quads higher than the Advanced scenario (Fig. 6.17).

The relatively modest impact of removing the diesel option can be attributed to three factors.

- Although diesel sales are substantial, they are still a minority of passenger car and light truck sales. With 24 percent of 2020 light-duty vehicle sales, the impact of these high-efficiency vehicles on sales-weighted harmonic mean fuel economy is attenuated[5].
- Second, removal of the diesels causes an increase in the sales of other high-efficiency technologies, for example, fuel cells. Sales of fuel cells and battery electric vehicles in 2020 increase from 2.7 million in the Advanced scenario to 4.3 million in the No Diesels scenario. This substitution of other advanced technologies for the diesel mitigates the impact of its loss.
- Third, diesel cars and light trucks are a much smaller fraction of the on-road vehicle population than of new vehicle sales. Even a twenty-year forecast does not allow sufficient time for both market maturation and turnover of the vehicle stock. Thus the impacts in 2020 of withdrawing diesels is smaller than it would be in the longer run.

This sensitivity case suggests that the Advanced scenario results are relatively robust to the success or failure of a single technology, even one as important as the diesel. Similar results can be seen in tests of sensitivity to fuel cell cost assumptions discussed below. Instead, the scenario is dependent on a combination of technological advances and scenarios, brought about by a general level of technological success and societal commitment to developing clean energy technologies and energy sources.

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[5] To illustrate how the weighted harmonic mean may differ from intuition, that a 20 mpg vehicle averaged harmonically with a 40 mpg vehicle does not result in a 30 mpg average, as one might expect, but in a 26.7 mpg average. You would need to average a 20 mpg vehicle with a 60 mpg vehicle to obtain a combined harmonic average of 30 mpg.

**Fig. 6.14 Sales of Alternative Fuel Vehicles:
Stand-Alone Advanced Case**

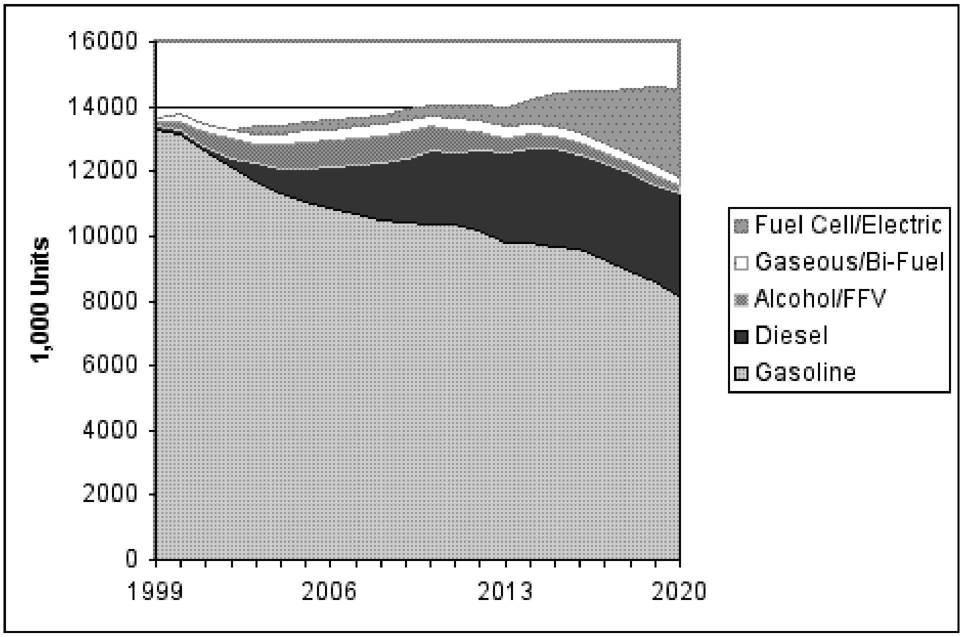


**Fig. 6.15 Sales of Alternative Fuel Vehicles:
No Diesel Case**

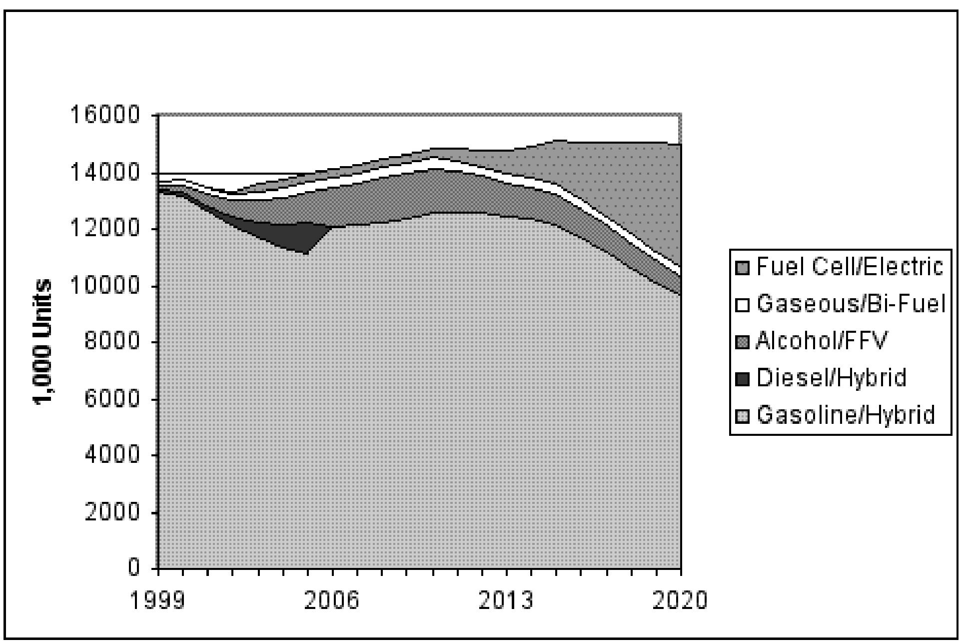


Fig. 6.16 New Light-Duty Vehicle Fuel Economy: Advanced vs. No Diesels Scenarios

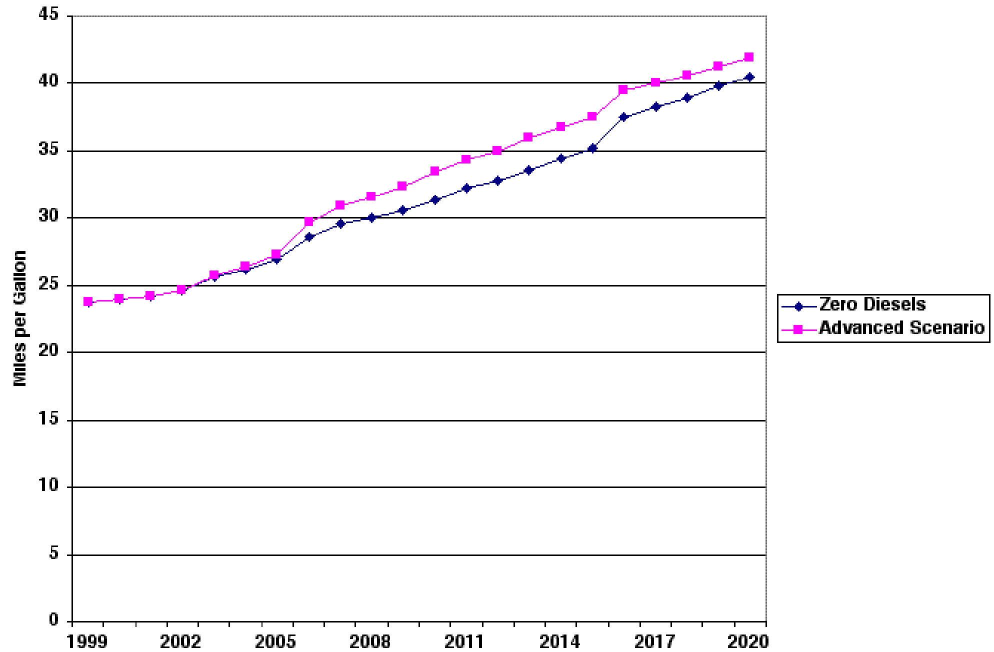
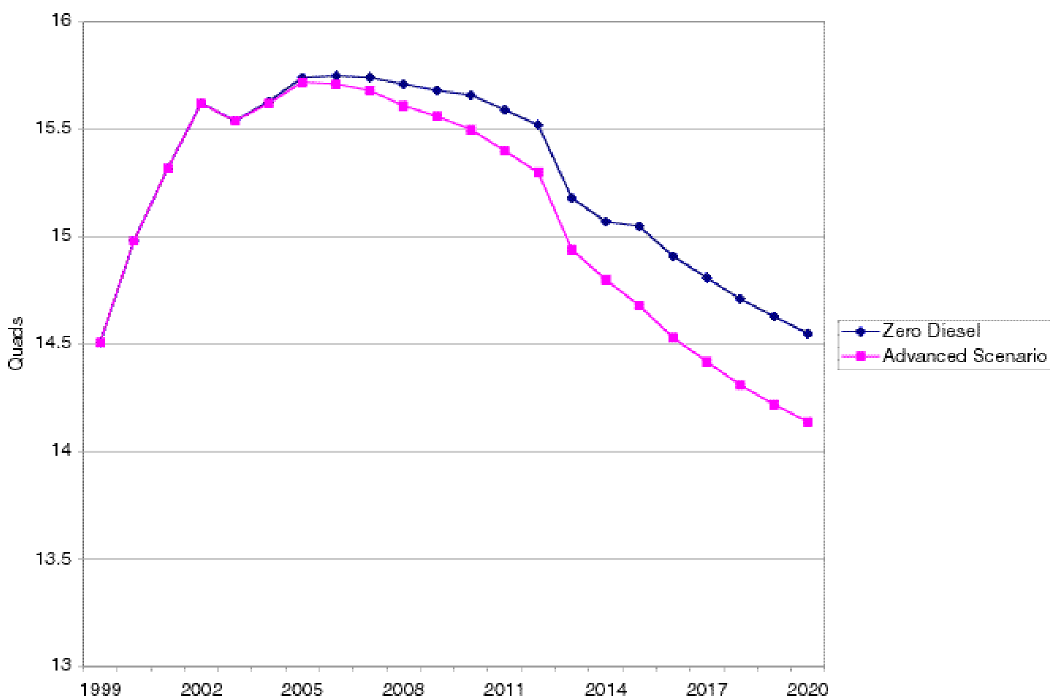


Fig. 6.17 Light-Duty Vehicle Energy Use: Advanced vs. No Diesels Scenario



CAFE Sensitivity Case. In this section we report the results of a stand-alone sensitivity case to illustrate the potential impacts of mandatory fuel economy standards. According to economic theory, voluntary environmental standards require at least the threat of mandatory standards to be taken seriously by firms (Segerson and Miceli, 1998). While such theories often omit the importance to firms of less tangible economic incentives for accepting voluntary standards, such as creating and maintaining a positive public image, the possibility of more stringent mandatory standards is undoubtedly a strong incentive for firms to commit to voluntary standards. For this reason, and because mandatory standards are now in effect in the United States and played a major role in the light-duty vehicle fuel economy improvements achieved over the past 25 years (e.g., Greene, 1998), it is appropriate to assess how mandatory standards might influence the levels of fuel efficiency, fuel consumption and carbon emissions in the Advanced scenario[6].

For this case, we simulate a new combined passenger car and light truck standard beginning in the year 2005[7]. Starting in 2005, the standards increase gradually to 50 mpg for combined passenger car and light truck sales (Fig. 6.18). Domestic and import fleets are also combined, and credit trading between companies is allowed. For this CAFE Sensitivity case, we eliminated the financial subsidies for 50 percent to three times more efficient vehicles included in both the Moderate and Advanced scenarios, on the grounds that the CAFE standards would supersede such incentives. The fine for non-compliance with the new standard is $150 per 1 mpg by which a manufacturer's corporate average fuel economy falls below the standard (the current standard has a fine of $50/mpg).

In comparison to the Advanced scenario, new light-duty vehicle fuel economy is about 10 mpg higher in the CAFE Sensitivity Case, reaching 52 mpg in 2020 (Fig. 6.18). The effects on the stock of light-duty vehicles are more modest because of the substantial time it takes to roll over the light-duty fleet by retiring older vehicles and adding new ones (Fig. 6.19). For the fleet as a whole, fuel economy in the CAFE case is about four mpg greater than in the Advanced scenario, and annual energy use by the fleet is more than one and one-half Quads lower.

Imposing CAFE constraints tends to increase the use of advanced fuel economy technologies in passenger cars and trucks. In the Advanced scenario, gasoline hybrids comprise 12.7 percent of gasoline vehicle sales in 2010 and 23.0 percent in 2020. In the CAFE Case, this jumps to 31.1 percent and 56.6 percent, respectively (Table 6.12). Use of direct injection gasoline engines also increases markedly, as do the market shares of advanced materials (primarily aluminum and plastics) and advanced drag reduction technologies[8].

This greater use of fuel economy technologies does increase the average price of new vehicles. For example, for gasoline-powered vehicles[9], the cost of fuel economy technologies in the Advanced scenario averages $811 per passenger car in 2010 and $1,548 in 2020, versus $1,337 in 2010 and $2,383 in 2020 in

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[6] In this section, as in the "No-Diesel" case, we compare results not to the integrated Advanced Scenario, but to a stand-alone version which is only slightly different but more directly comparable to the sensitivity cases which are all run in stand-alone mode.

[7] The NEMS model, AEO99 version allows separate passenger car and light truck standards to be specified, but only for gasoline-powered vehicles. Details of the modifications to NEMS inputs to simulate the combined standard are provided in Appendix A-3.

[8] Advanced materials include NEMS materials categories V-VII. Advanced drag is Drag Reduction V.

[9] We have not been able to devise a way to calculate the additional costs of alternative fuel technologies using outputs produced by NEMS. In principle, the AFV purchases are the outcome of market decisions by consumers, so that in the context of NEMS, the value of the AFVs to consumers exceeds their cost. Thus, in focusing on the cost of gasoline vehicle technologies, we are focusing on the only area where, at least in theory, costs could exceed direct benefits to consumers.

Fig. 6.18 Fuel Economy in the CAFE Sensitivity Case

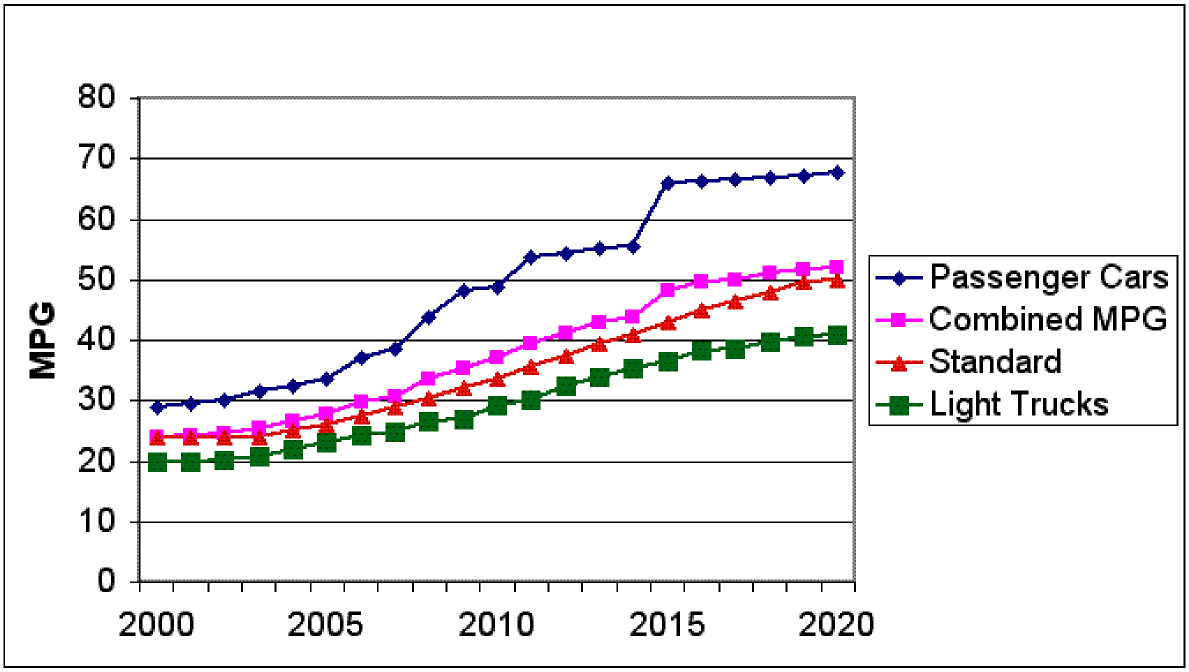


Fig. 6.19 Light-Duty Stock Fuel Economy and Energy Use, CAFE Sensitivity Case

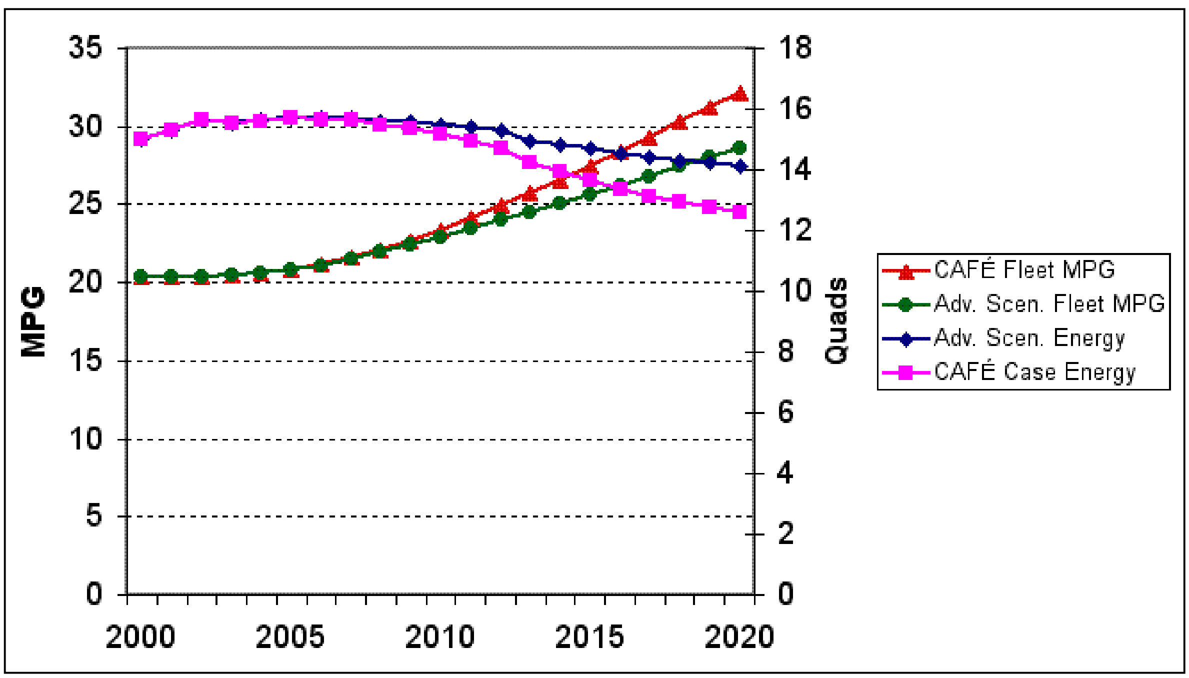


Table 6.12 Market Penetrations of Selected Fuel Economy Technologies in Passenger Cars in the CAFE Scenario

Technology	2010 Advanced	2010 CAFE	2020 Advanced	2020 CAFE
Gasoline Hybrid	12.7%	31.1%	23.0%	56.6%
Gasoline Direct Injection 4-cyl.	9.5%	16.5%	22.9%	36.1%
Gasoline Direct Injection 6-cyl.	5.3%	11.1%	13.2%	27.5%
Advanced Materials	0.0%	0.0%	34.2%	53.8%
Advanced Drag Reduction	8.2%	9.5%	36.5%	58.6%

the CAFE case. For light trucks, the CAFE case requires $1,365 worth of fuel economy technologies in 2010 and $3,305 in 2020, as compared with $1,028 and $2,040 in the Advanced scenario. The approximate values of fuel savings for the resulting changes in mpg are summarized in Tables 6.13 and 6.14 (these estimates should be considered rough approximations, since it was not practical to exactly replicate the NEMS model's accounting for technology notes and horsepower adjustments[10]). Even with the higher CAFE standards, the total value of fuel economy savings by consumers exceeds their cost in 2010. In 2020, however, estimated costs exceed estimated benefits, at a 15 percent annual discount rate.[11] In comparison to a base passenger car at 27.6 mpg, the 44.2 mpg 2010 CAFE case vehicle would emit 4.8 fewer MtC per year at a net savings because reductions in fuel costs outweigh the added vehicle cost. The 53 mpg 2020 vehicle would emit 6.4 fewer MtC annually, at an average net cost of $16/MtC. The *marginal* costs of carbon reduction are much higher, however. The costs per ton of C saved by model year 2020 versus 2010 vehicles is about $300. The estimates for light trucks show a similar pattern.

6.5.4 Impacts on U.S. Oil Dependence

Transportation is not the sole user of petroleum in the U.S. economy, but it is the dominant user. In 1998, the U.S. transportation sector accounted for over 66 percent of U.S. petroleum consumption. Moreover, transportation uses nearly all the high-value, light products that drive petroleum markets. In the reference case, the transportation sector's dominance of petroleum demand actually increases to 71 percent of U.S. consumption by 2020. Here we briefly review the impacts of changes in all sectors on U.S. oil dependence. Changes in the transportation sector, however, are by far the most important.

Policies and technologies implemented in the Moderate and Advanced scenarios significantly reduce U.S. petroleum consumption and imports though care must be taken in interpreting the predicted decline in imports, as explained below. Total U.S. oil consumption rises to 24.5 mmbd in the BAU scenario, but falls to 19.4 mmbd in the Advanced scenario (Fig. 6.20). In the BAU scenario, U.S. petroleum imports rise from 10.6 million barrels per day (mmbd) in 2000 to 15.9 mmbd in 2020. Of this, 4.0 mmbd are in the form of petroleum products, 12.0 mmbd are crude oil. CEF-NEMS suggests that total imports would be 14.0 mmbd in the Moderate scenario, of which only 2.2 mmbd are products. In the Advanced scenario, only 11 mmbd are imported in 2020. Under BAU, U.S. oil imports increase from 49 percent of U.S. demand today, to 65 percent in 2020. In the Advanced scenario the share of imports also increases, but to only 56 percent.

[10] These estimates were computed by adding up the market share-weighted fuel economy improvement benefits of each technology and multiplying one plus the sum times an adjusted base mpg. The base year 1997 mpg was adjusted to account for factors such as increased weight and horsepower and safety and emissions mandates that would otherwise cause mpg to decrease over the period in question. The estimates are only approximate in that no adjustment was made for synergies among technologies. Had these been taken into account, the estimated fuel economy gain and therefore the value of fuel economy improvements would have been slightly smaller.

[11] Use of the term discount rate is somewhat inappropriate in this context, since what it actually represents is the consumers' rate of return on capital, taking into consideration that the consumer's investment in fuel economy technology is a depreciating asset.

Table 6.13 Retail Costs and Value of Fuel Savings for Light-Duty Vehicle Fuel Economy Improvements, Advanced Scenario (GASOLINE ENGINE TECHNOLOGIES ONLY)

	Fuel Economy Improvement		
	BASE	**2010**	**2020**
Passenger Cars			
% Gain		33.4%	54.1%
MPG	27.6	38.1	44.1
Annual Fuel Savings		$308	$427
C Emissions Reductions (mtC)		3.6	5.0
		Technology Cost	
All Changes		$1,488	$2,227
Fuel Economy Technologies		$811	$1,548
Present Value Fuel Savings		$1,285	$1,780
Cost per tonne C		-$131	-$46
Marginal Cost per mtC 2010 to 2020			$174
	Fuel Economy Improvement		
	BASE	**2010**	**2020**
Light Trucks			
% Gain		35.6%	57.4%
MPG	19.6	27.7	32.1
Annual Fuel Savings		$460	$629
C Emissions Reductions (mtC)		5.4	7.4
		Technology Cost	
All Changes		$1,629	$2,641
Fuel Economy Technologies		$1,028	$2,040
Present Value Fuel Savings		$1,921	$2,625
Cost per tonne C		-$166	-$80
Marginal Cost per mtC 2010 to 2020			$156

Assumptions

Miles/Year	Rate of Decrease in Annual Use	On-Road MPG Factor	Vehicle Lifetime	Discount Rate	Gasoline Price $/gal.	Gasoline Price $/gal.
15,640	6.7%	0.85	12	15.0%	$1.67	$1.71

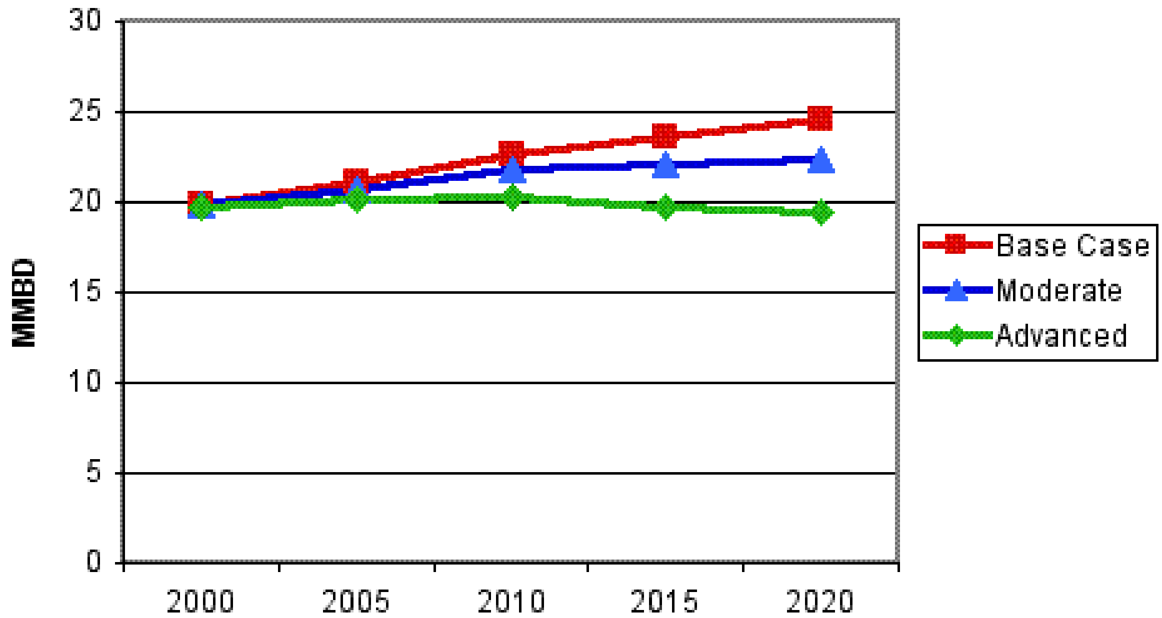
Table 6.14 Retail Costs and Value of Fuel Savings for Light-Duty Vehicle Fuel Economy Improvements, CAFE Sensitivity Case (GASOLINE ENGINE TECHNOLOGIES ONLY)

	Fuel Economy Improvement		
	BASE	**2010**	**2020**
Passenger Cars			
% Gain		53.6%	85.3%
MPG	27.6	43.9	53.0
Annual Fuel Savings		$414	$547
C Emissions Reductions (mtC)		4.8	6.4
		Technology Cost	
All Changes		$2,036	$3,110
Fuel Economy Technologies		$1,337	$2,383
Present Value Fuel Savings		$!,728	$2,28
Cost per tonne C		-$81	$16
Marginal Cost per mtC 2010 to 2020			$317
	Fuel Economy Improvement		
	BASE	**2010**	**2020**
Light Trucks			
% Gain		43.5%	85.2%
MPG	19.6	29.3	37.8
Annual Fuel Savings		$518	$773
C Emissions Reductions (mtC)		6.1	9.0
		Technology Cost	
All Changes		$1,906	$3,928
Fuel Economy Technologies		$1,365	$3,305
Present Value Fuel Savings		$2,161	$3,224
Cost per tonne C		-$131	$9
Marginal Cost per mtC 2010 to 2020			$294

Assumptions

Miles/Year	Rate of Decrease in Annual Use	On-Road MPG Factor	Vehicle Lifetime	Discount Rate	Gasoline Price $/gal.	Gasoline Price $/gal.
15,640	6.7%	0.85	12	15.0%	$1.67	$1.71

Fig. 6.20 U.S. Primary Petroleum Consumption

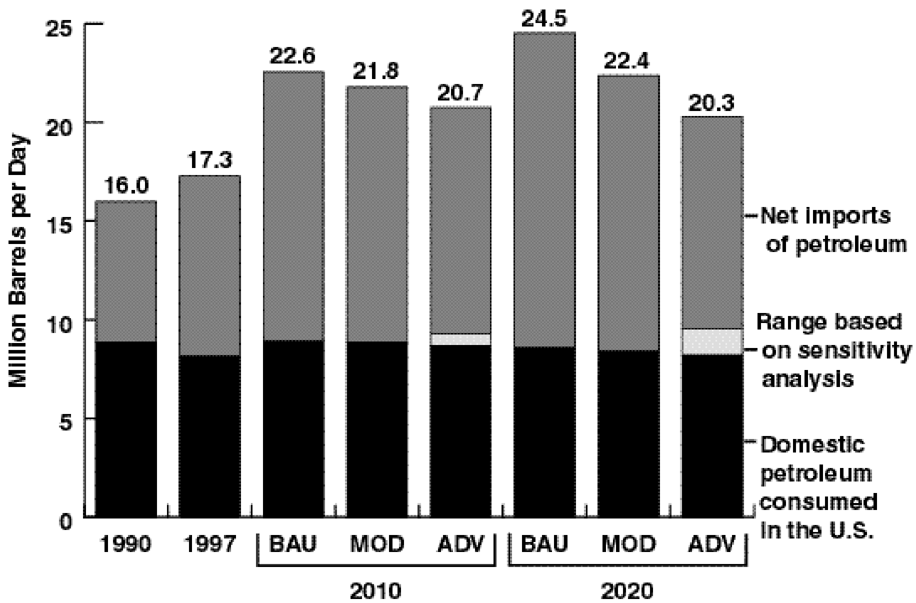


Because the CEF-NEMS model does not estimate the impacts of reduced U.S. oil demand on world oil prices, it will overestimate the reduction of oil imports but underestimate the economic benefits. Significant reduction in U.S. oil demand, such as predicted in the Moderate and Advanced scenarios, would exert downward pressure on world oil prices, other things equal. At lower prices, U. S. oil suppliers would produce somewhat less oil, tending to diminish the reduction in imports predicted by the CEF-NEMS assuming constant oil prices. At the same time, the economic benefits would be greater than those described here, because the price of every barrel of oil consumed, not just the imports, would be lower.

The 1.9 mmbd reduction in imports in the Moderate scenario, and 4.9 mmbd reduction in the Advanced scenario reduce the U.S. bill for imported crude oil and petroleum products in 2020 from $135 B/year to $89 B/year (Fig. 6.21). Thus, the change in balance of payments is $45 B in favor of the U.S. The assumed price of imported crude oil and petroleum products in all scenarios in the year 2020 is $22.73 per barrel. Even the integrated runs do not estimate the full impacts of reductions in U.S. oil demand on world oil prices, because the benefits of reduced consumption in the form of lower prices for both imported and domestic oil cannot be estimated by CEF-NEMS.

World oil prices are higher than the marginal cost of production, as a result of the concentration of oil production. Pricing above marginal costs produces a transfer of wealth from consumers to producers. In the BAU scenario, OPEC's share of the world oil market increases from 39 percent in 2000 to 51 percent in 2020. If one assumes that the price of oil in competitive world oil markets would be about $10 per barrel (see, e.g., Greene et al., 1998, p. 58) then the annual transfer of wealth from U.S. oil consumers to world oil exporters would be $74 B in the BAU scenario and $51 B in the Advanced scenario, for a net annual savings of $23 B to U.S. consumers in avoided wealth transfer. Note that while this wealth transfer is not an economic loss from a global perspective, it is a real loss from the perspective of the U.S. economy.

Fig. 6.21 U.S. Consumption of Domestic and Imported Crude Oil and Petroleum Products



6.5.5 Analysis of Alternative World Oil Market Outcomes in the CEF Advanced Scenario

The Advanced scenario estimates significant reductions in U.S. oil imports as a result of reductions in U.S. oil demand. In part, the predicted reductions are a result of the conventions of the CEF-NEMS model's representation of world oil market behavior. These conventions hold world oil price trajectories constant, essentially assuming that non-domestic production falls commensurate with the decline in U.S. demand. Without a fall in world oil prices, U.S. producers do not change their output.

In contrast, OPEC and other countries might not cut production to accommodate the full reduction in U.S. oil demand. In that case, the additional supply of oil would cause world oil prices to decrease. The lower world oil prices would cause U.S. and other competitive producers to reduce output, and would also cause U.S. and other oil consumers to increase demand for oil. In the end, U.S. oil demand would be slightly higher and oil imports would not be reduced by as much as in the Advanced scenario, but the lower prices would be an additional benefit for the U.S. economy.

A simple model of world oil supply and demand is used to illustrate these effects. Linear, lagged adjustment equations are used to represent U.S. and rest-of-world (ROW) oil supply and demand. ROW oil supply does not include OPEC, but ROW demand does. Price elasticities vary with price and quantity in a linear model. Representative (Greene et al., 1998) short-run elasticities for the U.S. and ROW are summarized in Table 6.15. Long-run elasticities are ten times as large.

Table 6.15 Short-run Oil Supply and Demand Elasticities Used in the Simulation

	Supply and Demand Short-run Elasticities at Various Fuel Prices				
	(Price (97 $/BBl)	Demand MMBD	Short-run Elasticity	Supply MMBD	Short-run Elasticity
U.S.	$20	17.10	-0.038	9.68	0.028
	$28	16.84	-0.054	9.79	0.039
	$35	16.60	-0.069	9.88	0.049
ROW	$20	50.25	-0.038	31.83	0.024
	$28	49.49	-0.054	32.13	0.033
	$35	48.80	-0.069	32.40	0.041

First, the model was calibrated to match the Advanced scenario oil market conditions. Next, OPEC production was increased to the level of the Business-As-Usual (BAU) scenario, and a new supply and demand equilibrium found by adjusting the price of oil to clear the market. The key results are new levels for: (1) world oil price, (2) U.S. oil supply, (3) U.S. oil demand, (4) U.S. oil imports, and (5) U.S. expenditures on oil. Expenditures on oil are not a full measure of the economic benefit of lower oil prices. The correct measure would be the sum of consumers' and producers' surpluses throughout the economy, but such a measure is beyond the scope of this analysis.

At nearly 5 mmbd, the reduction in U.S. oil demand identified in the Advanced scenario would be sufficient to affect world oil markets, placing downward pressure on oil prices and potentially changing production levels domestically and internationally. How world oil markets react to this reduced demand depend in large part on how OPEC, representing a large share of 2010 to 2020 world oil production, responds. Other areas of production, both in the U.S. and in the rest of the world (ROW) tend to have higher costs of production and their individual production decisions have less of an impact on world energy prices.

Rather than attempt to characterize a specific world oil market response to reduced U.S. demand, this study reports two estimates which characterize a possible range of responses. OPEC countries are modeled as the swing world oil producers based on their typically lower costs of production and large market share.

- In the Advanced Scenario, CEF-NEMs holds world oil prices constant; the model assumes that OPEC oil production falls sufficiently to avoid any decline in world oil prices.

- At the other end of this range, the Adjusted Advanced scenario models OPEC countries as holding production at their BAU levels, allowing world oil prices to fall. In this case, both U.S. and ROW oil producers respond to this price reduction, to varying degrees, by reducing their expected production levels. At the same time, U.S. consumers respond by consuming a bit more oil than expected in the Advanced scenario.

These two results bracket the likely range of world oil prices and U.S. imports, and by extension, U.S. production levels. From Table 6.16 it is clear that regardless of the response by world oil markets, U.S. oil demand falls substantially. In 2020 in the Adjusted Advanced case, the overall drop in U.S. oil consumption is 4 mmbd rather than the nearly 5 mmbd expected in the Advanced case. U.S. oil production is about 5% lower than expected in the Advanced scenario. However, total U.S. expenditures for oil, domestic and international are lower in the Adjusted Advanced scenario than in the Advanced scenario.

Fig. 6.22 Effect of Increased OPEC Supply on World Oil Price in the Advanced Scenario

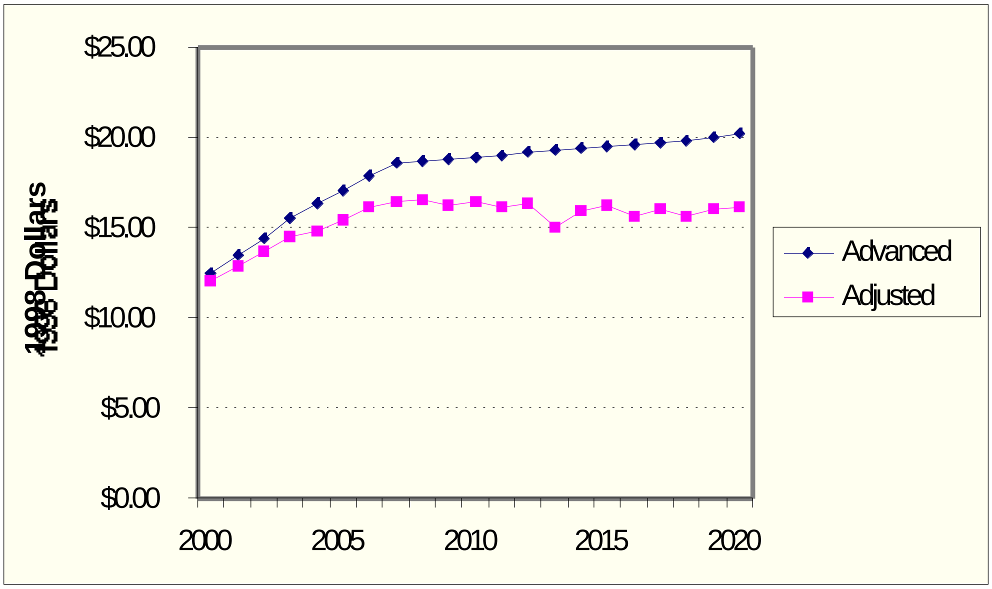


Table 6.16 Effect of Increasing OPEC Oil Supply in the Advanced Scenario

Year	Price Maintained 1998 $/bbl	U.S. Oil Supply mmbd	U.S. Oil Demand mmbd	U.S. Net Imports mmbd	Oil Expenditure B 1998 $
2000	$12.40	9.23	19.88	10.63	90
2005	$17.08	8.93	20.20	11.27	126
2010	$18.90	8.86	20.34	11.48	140
2015	$19.44	8.74	19.76	11.02	140
2020	$20.17	8.59	19.33	10.74	142
	Production Maintained 1998 $/bbl	**U.S. Oil Supply mmbd**	**U.S. Oil Demand mmbd**	**U.S. Net Imports mmbd**	**Oil Expenditure B 1998$**
2000	$12.01	9.22	19.87	10.65	87
2005	$15.43	8.86	20.37	11.51	115
2010	$16.39	8.69	20.74	12.05	124
2015	$16.27	8.45	20.44	11.99	121
2020	$16.11	8.2	20.27	12.07	119
	Change in U.S. Demand mmbd	**Change in U.S. Imports mmbd**	**Change in Oil Expenditure B 1998 $**	**Change in Oil Price 1998 $/bbl**	
2000	0.01	0.02	3	-$0.39	
2005	0.17	0.24	11	-$1.65	
2010	0.40	0.57	16	-$2.51	
2015	0.68	0.97	19	-$3.17	
2020	0.94	1.33	23	-$4.06	

In the BAU case, U.S. petroleum consumption increases from 19.9 mmbd in 2000 to 24.6 mmbd in 2020, and imports increase from 10.7 mmbd in 2000 to 15.9 mmbd in 2020. In the Advanced scenario, consumption is actually lower in 2020 (19.3 mmbd) than in 2000 (19.9 mmbd), and imports increase from 10.6 in 2000 to only 10.7 mmbd in 2020 (for details, please see Table 6.16). However, if OPEC production is increased from the Advanced scenario level to match the BAU scenario level, the price of oil falls from $20.17/bbl in 2020 to $16.11/bbl., with smaller decreases in the years leading up to 2020 (Figure 6.22). As a result of the lower price of oil, U.S. consumption in 2020 increases from 19.3 mmbd to 20.3 mmbd. U.S. supply falls from 8.6 mmbd to 8.2 mmdb. The increase in U.S. consumption and decrease in U.S. supply combine to raise 2020 U.S. oil imports from 10.7 mmbd to 12.1 mmbd. Not surprisingly, this new level of imports falls between the BAU scenario (15.9 mmbd) and the unadjusted Advanced scenario (10.7 mmbd). While imports are higher than in the original Advanced scenario, the lower price of oil on all barrels consumed, domestic and imported, in the adjusted Advanced scenario saves the U.S. economy $23 billion in total oil expenditures in the year 2020.

The sum total of undiscounted oil expenditures savings for the adjusted versus original Advanced scenario from 2000 to 2020 is over $300 billion. This is despite the fact that the United States is consuming more oil in the adjusted (increased OPEC supply) Advanced scenario.

Several caveats should be noted. No representation is made that these illustrations are an accurate prediction of what OPEC and other countries would actually do. History suggests that price shocks are more likely than the smooth price paths used in all our scenarios. On the other hand, analyses by Greene, et al. (1998) and Schock et al. (1999) indicate that the kinds of reductions in oil demand and advances in energy technology reflected in the Advanced scenario would reduce the impact of any given supply reduction on the U.S. economy. Clearly, the results of this analysis depend on the accuracy of assumptions about world oil supply and demand functions made. While we have tried to choose elasticities consistent with the published literature, other choices of elasticities would lead to different results. The direction and nature of the conclusions would not change, however. Under any plausible assumptions, world oil prices would decrease, U.S. demand would increase, U.S. supply would decrease, U.S. imports would therefore increase, but U.S. expenditures on oil would be reduced.

6.5.6 Costs of Light-Duty Vehicle Fuel Economy Improvements

The benefits of fuel savings, reduced GHG emissions, lower levels of air pollution, improved energy security, and so on, should be weighed against the full costs of achieving these benefits, discounted over the forecast period. Unfortunately, not only are the full benefits difficult to measure, but estimating costs are also problematic for two reasons. First, as we have noted above, estimates of the future costs of technologies are rare and always uncertain. Second, the CEF-NEMS model outputs do not provide sufficient information to estimate costs for modes other than light-duty highway vehicles, and even in that case only a partial estimate can be made. As we suggest below, enhancing the model's ability to produce cost estimates should be a high priority.

Estimates of the costs of fuel economy improvement can be made for light-duty gasoline vehicles only. This is unfortunate, because a significant fraction of the MPG gains achieved by light-duty vehicles in the Advanced scenario can be attributed to what the CEF-NEMS classifies as Alternative Fuel Vehicle technologies: the TDI Diesel, fuel cell vehicles, etc. No way has been found to compute the incremental costs of increased AFV market success using existing CEF-NEMS outputs. (In theory, the value to consumers of these technologies exceeds their costs or they would not have purchased them.) Costs for gasoline vehicles, however, can be calculated by combining outputs describing the market shares of fuel economy technologies by vehicle class with the input data on their costs and fuel economy improvement potentials. A spreadsheet was constructed to make these computations and the results are presented here for the Advanced scenario, and the CAFE sensitivity case. Assumptions about vehicle use, discount rates, etc. match those used in the CEF-NEMS model for the Advanced scenario. These spreadsheet calculations do not account for synergies among technologies as the NEMS model does. This should produce a very small overestimate of the overall fuel economy benefit.

Given that the CEF-NEMS model explicitly trades off the price of technologies against the value of their fuel savings in estimating market shares, it should not be a surprise to find that, overall, the value of fuel savings exceeds the costs of achieving it in both 2010 and 2020 for both passenger cars and light trucks. As shown in Table 6.13, the passenger car MPG increases from 27.6 in 2000 to 38.1 in 2010 is worth $1,285 to consumers in present value, but cost them only $811. By 2020, however, the difference is reduced: $1,780 in present value benefits versus $1,548 in initial costs. For light trucks, the cost comparisons are even more favorable. For $1,028 in vehicle price, light truck owners receive $1,921 present value worth of fuel savings in 2010. In 2020, $2,040 in initial expenditure returns $2,625 present value savings.

The vehicle lifetime carbon emissions reductions attributable to fuel economy improvements are also shown in Table 6.13. Key assumptions are constant miles driven and no discounting of future carbon emissions. Since the value of fuel savings to consumers exceeds the cost in every case, the average cost per metric ton of carbon reductions is always negative. The marginal costs of C savings achieved in 2020 versus 2010, on the other hand, are considerable, $174/MtC for cars and $156/MtC for light trucks. However, the cost to consumers includes taxes and PATP insurance, which together adds some $0.70 to the price per gallon. The value to society of fuel savings would not include these components but should include other societal costs of gasoline use, which we have discussed above.

Table 6.14 shows the same calculations for the CAFE Sensitivity Case. These results were discussed above.

6.5.7 Fuel Cell Sensitivity Cases

Of all the technologies considered for the transportation sector, fuel cell vehicles combine the most promise for increasing energy efficiency and reducing greenhouse gas emissions with the greatest uncertainty with respect to their cost and performance. Recent dramatic improvements in both areas may explain why several manufacturers have announced commercial introduction of fuel cell vehicles in the 2003-2005 period. When the “5-Lab” study was conducted just two years ago, such a prediction seemed to us too unlikely to be included even in our High-Efficiency, technologically optimistic scenario. Yet fuel cell technology still has a long way to go before it can compete with conventional internal combustion engines. In the sensitivity cases presented here we measure the impacts of fuel cell system costs, and particularly the rate of reduction in costs, on predicted market success.

For fuel cells to be cost-competitive with ICE powerplants, their costs will have to be dramatically reduced from current levels. In principle, we see no reason why this cannot be accomplished given continued research advances, experience and learning in production, and economies of scale. The key components of a fuel cell system are: (1) the fuel cell stack, (2) the electric motor and associated controllers, etc., (3) the reformer and hydrogen storage buffer in the case of a methanol or gasoline-powered system, and (4) the hydrogen storage tank in the case of a hydrogen FCV. Since these components will make the internal combustion engine drivetrain unnecessary, there will also be a credit for the elimination of these components.

Our cost estimates are based on a study by Directed Technologies, Inc. (Thomas et al., 1998) for the U.S. Department of Energy based on a bottom-up design and costing methodology (details of the equations used may be found in Appendix A-3). For each component, they analyzed the least costly materials and processes, emphasizing the reduction of the parts count and the minimization of manufacturing costs. They intended their cost estimates to apply in the vicinity of the year 2004. We assume a learning curve, according to which fuel cell costs begin in 2005 at two times the levels estimated by Thomas et al. (1998), and in the Advanced scenario decline rapidly to those levels in 2011, then continue decreasing at a decreasing rate, reaching about 70 percent of the Thomas et al. (1998) estimates in 2020. The value of the internal combustion engine credit, however, is assumed to remain constant over time, except that it varies with the weight of the vehicle. We apply a 75 percent overhead mark-up to the net cost, the sum of the fuel cell system cost and the ICE credit.

All system components and their costs depend on the weight of the vehicle. We illustrate these costs in Table 6.15 for passenger cars with weights typical of the years 2010 and 2020 in the Advanced scenario. The learning curve cost factor is 112 percent in 2010 and 69 percent in 2020. In 2010, the heavier fuel cell vehicle requires 67 kW if powered by hydrogen, 76 kW if powered by gasoline. The additional stack size primarily reflects a loss of fuel cell efficiency when operating on reformer gas versus pure hydrogen, but also some increase in weight. The stack cost alone ranges from $2,840 to $3,060. The gasoline and methanol versions also require reformers, while the hydrogen version requires an expensive fuel tank to store the hydrogen. In 2010, the incremental cost of the fuel cell system, including overhead, ranges from $4,190 to $4,390. When the cost factor falls to 69 percent in 2020, costs drop dramatically, for two reasons. First, as the costs of the fuel cell unit approach that of the ICE powerplant, the net cost approaches zero. The 75 percent overhead multiplier magnifies the benefit each $1 fuel cell system cost reduction. Second, the fuel cell system costs are more sensitive to weight than the cost of the ICE powerplant. As a result, while fuel cell system costs are cut in half between 2010 and 2010, the net cost of the fuel cell systems falls by 75-80 percent.

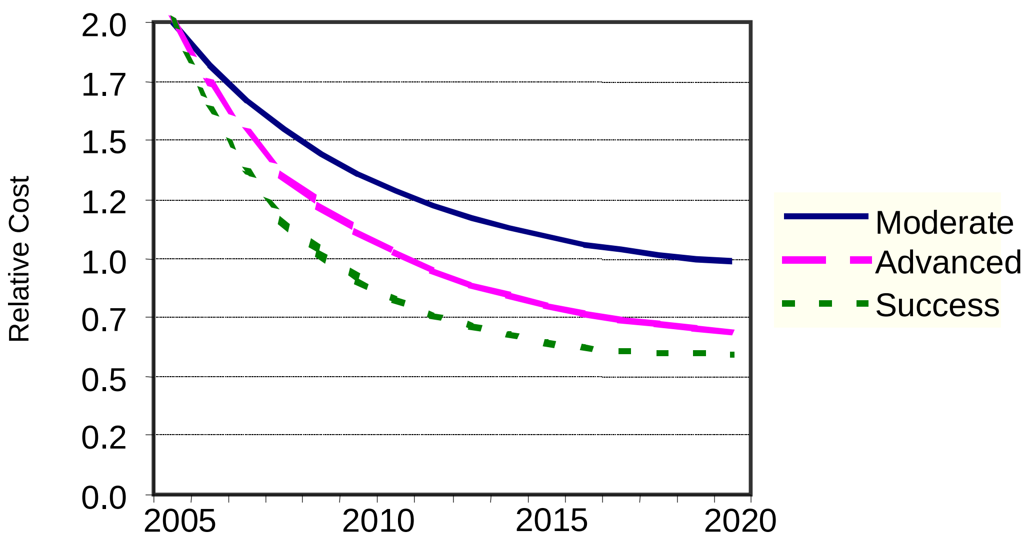
Table 6.17 Case Fuel Cell Vehicle Costs and Fuel Economy

	Gasoline		Methanol		Hydrogen	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Cost Factor	112%	69%	112%	69%	112%	69%
Vehicle Weight (pounds)	2790	2195	2790	2195	2790	2195
Stack Size (kW)	76.1	59.9	73.6	57.9	67.2	52.9
Stack Cost (1998 $)	$3,061	$1,650	$2,999	$1,620	$2,843	$1,544
$/kW	$40	$28	$41	$28	$42	$29
Motor Cost (1998 $)	$99	$521	$968	$510	$909	$481
Reformer Cost (1998 $)	$960	$483	$932	$469		
Hydrogen Tank (1998 $)					$1,147	$559
Fuel Cell System Cost (1998 $)	$5,012	$2,654	$4,898	$2,599	$4,899	$2,585
ICE Credit (1998 $)	-$2,502	-$2,097	-$2,502	-$2,097	-$2,502	-$2,097
Net Cost + Overhead (1998 $)	$4,392	$976	$4,193	$879	$4,195	$854
Fuel Economy (GE MPG)	48.8	62.1	56.0	71.2	75.3	95.7

Fuel cell vehicles costing several thousand dollars more than conventional vehicles have negligible impacts in our BAU and Moderate scenarios. But when costs approach those of gasoline ICE vehicles in the Advanced scenario, sales levels rise to 2.2 million units per year in 2020. Beginning with the "stand-alone" Advanced case, we estimated impacts on fuel cell sales of two alternative assumptions, both based on the fuel cell cost analysis of Directed Technologies, Inc. (1998), described in Appendix A-3.

Three alternative learning curves were assumed: (1) the Moderate scenario curve in which costs decline to 1.0 times the 2005 mass-production cost levels, (2) the Advanced scenario curve in which costs decline to 0.7 times the 2005 mass-production level by 2020, and (3) a "Fuel Cell Success" curve in which costs decline to 0.6 times the 2005 mass-production level (Fig. 6.23). In the Fuel Cell Success case, a gasoline fuel cell vehicle costs $1,000 less than a conventional gasoline ICE vehicle in 2020, a hydrogen or methanol fuel cell vehicle costs $1,100 less. In addition, in the Fuel Cell Success case we assume that fuel cell vehicles have equivalent passenger and cargo space to gasoline ICE vehicles, full availability of hydrogen by 2020, and equivalent maintenance costs for gasoline and methanol fuel cells, 25% lower maintenance costs for hydrogen fuel cell vehicles.

Fig. 6.23 Assumed Fuel Cell Learning Curves



The results of these changes are striking. Assuming Moderate scenario fuel cell costs but all other Advanced scenario policies results in negligible fuel cell vehicle sales (180,000 units) even by 2020 (Fig. 6.24). The Fuel Cell Success case assumptions increase annual sales to close to over 2 million units in 2015 and almost 4 million units in 2020, a 25 percent market share that is still headed upward in 2020. In the Advanced case, 15 percent of the fuel cell vehicles sold in 2010 are powered by hydrogen.

By 2020 hydrogen's share increases to 49 percent. In the Fuel Cell Success case, two-thirds of the fuel cell vehicles sold in 2020 are powered by hydrogen.

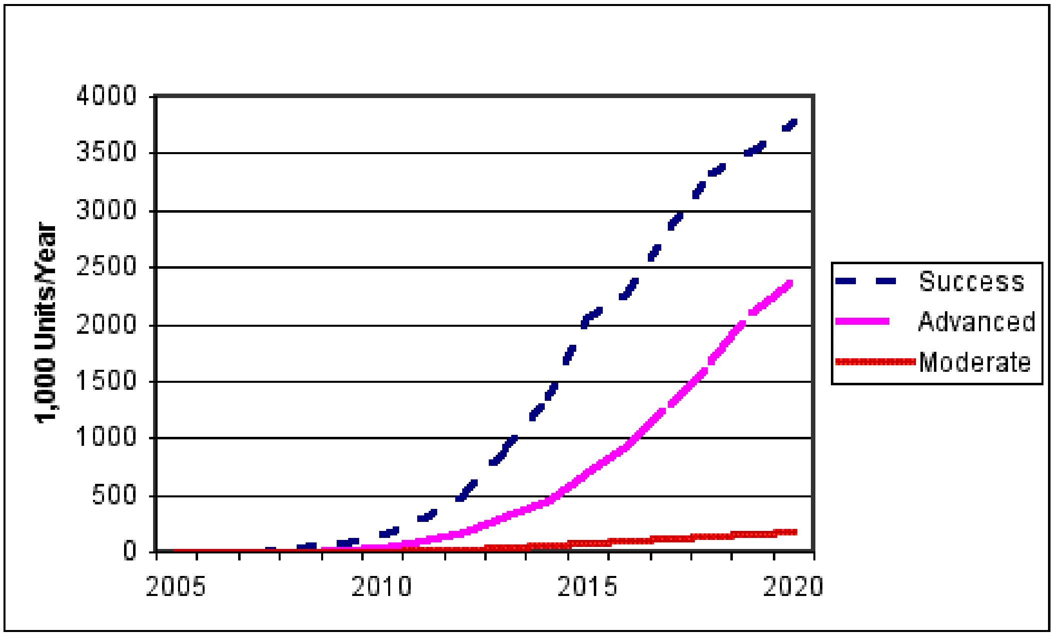
Clearly, the success of fuel cell vehicles is highly uncertain at the present time. Despite dramatic progress in the past five years, automotive fuel cell technology still has a long way to go before it will be competitive with conventional gasoline vehicles in terms of both cost and performance. These sensitivity cases illustrate just how sensitive market success is likely to be to cost. Much will also depend on how consumers react to the less readily quantified differences between fuel cell and conventional vehicles, such as noise, vibration, reliability, and so on.

6.6 REMAINING ANALYSIS NEEDS

The transportation sector analysis would benefit by three types of improvements:

- Additional CEF-NEMS runs that explore the sensitivity of results to changed technology assumptions and that "tease out" the individual effects of new policies from the effects of a changed "state of society" reflected in the scenario descriptions, and the specific effects of individual policies;
- Enhancing certain CEF-NEMS reporting capabilities; and
- Development of new methodologies to evaluate the impacts of new technologies and policies.

Fig. 6.24 Fuel Cell Sensitivity Cases



6.6.1 Additional Model Runs

Time and resource constraints prevented us from conducting a number of useful CEF-NEMS runs for the transportation sector. Among the more important runs are:

1. "Changed baseline" runs that maintain the EIA Reference Case's "no new policies" assumption but that include modifications made in the CEF-NEMS model, such as those to the Alternative Fuels Model coefficients, and allow for a higher growth rate for vehicle travel. The new baseline run would: (1) clarify what portion of the reductions in greenhouse gases and other effects are caused by the alterations made to the CEF-NEMS model, and (2) allow policies to be evaluated against a more widely accepted view of future vehicle travel growth.
2. Runs that selectively remove key policies one at a time, to ascertain their individual impacts.
3. Additional sensitivity runs, similar to the "no diesel" run, to test the sensitivity of GHG reductions and costs thereof to the success or failure of the set of technologies considered. These will measure

the effects of different technology assumptions, e.g. lower or higher costs for key technologies, changes in the portfolio of successful technologies, changes in the dates of introduction, etc., on the outcomes.

6.6.2 Add to CEF-NEMS Bookkeeping Capabilities

The NEMS model provides an impressive amount of output, describing a vast array of the model's calculations. However, for the purposes of the CEF Study, several additional outputs are needed. The most important of these are:

Calculation of the costs of fuel economy improvements for *both* Fuel Economy Model and Alternative Fuel Model calculations. Most but not all of the data necessary to make these calculations is available from existing NEMS outputs as standards tables or as options. In addition, several assumptions must be made and the calculations are complex and time consuming.

- Modifications to the CEF-NEMS model code could provide precise, automated computation of the costs for passenger cars and trucks.
- Reporting of renewable ethanol use in the transportation sector tables. At present, use of ethanol as a blending stock is reported in the "Motor Gasoline" totals in transportation sector tables. It would also be desirable to identify renewable ethanol as coming from corn versus cellulosic feedstocks.
- Accounting for transportation use of hydrogen and for the processes used to produce the hydrogen. At present, hydrogen used by motor vehicles is reported as "liquid hydrogen," which is not the only form in which it may be used. Also, the production of hydrogen for use in the transport sector is not accounted for in the CEF-NEMS.
- Although the NEMS model documentation implies that emissions of criteria pollutants are estimated for transportation, that capability is currently not implemented due to difficulties in maintaining its currency. Given the changing state of knowledge in this field, as well as the continuously evolving status and outlook for emissions regulations, maintaining an up-to-date capability to forecast transportation emissions is a major effort. Fortunately, there are on-going research programs on this subject, most notably at Argonne National Laboratory and at the University of California, Davis, that could be drawn upon for annual updating of emissions factors. As the CEF Study works to fulfill its goal of considering the full range of environmental benefits of clean energy technologies, this issue must be addressed.

6.6.3 Development of New Methods

The Clean Energy Futures Study could benefit from the development or implementation of improved analytical methods in several areas, especially:

- More rigorous and explicit methods of harmonizing assumptions about technological advances and policy contexts across the sectors. Over the past 25 years, analysts of different sectors of the economy have developed sometimes surprisingly different methods for forecasting technological change and assessing its impacts. This often leads to striking differences across sectors in key areas such as the degree of optimism about technological progress or the political will to impose binding policies.
- More rigorous methods for assessing the impacts of multiple technologies based on fundamental technological breakthroughs. Methods are need that will allow for the connections among alternative technologies to be taken into account. For example, an advance in storage

technologies for compressed hydrogen might also have implications for other vehicles using gaseous fuels; advances in electrochemical energy storage would have implications for both hybrid and battery electric vehicles. Improved methods for deriving the implications of technological advances on a range of alternative vehicle technologies are needed.

- More explicit methods for linking R&D effort to technological change should be implemented. Admittedly, this linkage is not well understood and would be difficult to predict in any case. Nonetheless, more rigorous, explicit linkages should be developed, with the goal of making assumptions clearer and more readily comparable to historical experience.
- Technology adoption for gasoline versus alternative fuel vehicles is handled differently in the current CEF-NEMS model. A few of the differences have been addressed in changes made to the CEF-NEMS Alternative Fuels Model, described in appendix A-3. An improved methodology is needed to treat technological changes for light-duty vehicles in an integrated framework, so that policies such as feebates or fuel economy standards can be effectively addressed, and so that technological potentials can be consistently assessed.
- Technology adoption algorithms for freight trucks and aircraft should be enhanced to follow the methods used for light-duty vehicles. Within the CEF-NEMS Transportation Sector Model, technology adoption is handled very differently across modes of transport. In general, mechanistic technology penetration curves for freight trucks and aircraft are triggered when fuel prices exceed a target level (this statement is an oversimplification, but captures the essence of the method). For light-duty vehicles, the trade-off between initial cost and future fuel costs is explicitly represented (other attribute trade-offs are also represented to varying degrees), and differences among consumers' evaluations of these trade-offs are recognized. The method used for light-duty vehicles is not only believed to be theoretically superior, but also allows for more rigorous policy analysis.

6.7 SUMMARY AND CONCLUSIONS

Energy use and carbon emissions from transportation have grown steadily over time and appear likely to continue to grow without new policies or sharp changes in fuel prices and availability. The direct physical causes of this growth have been:

- Travel demand has continued to grow strongly as incomes and population have risen; for example, personal vehicle vmt grew by 2.8 percent/yr during 1974-1995.
- Light-duty fuel economy has stagnated over the past decade (and perhaps would have fallen without the presence of fuel economy standards).
- Vehicle technology has changed over time, but much of the technology has been used for purposes other than higher efficiency.

Several factors will strongly influence future levels of transportation energy use and GHG emissions. On the favorable side, a variety of technology options currently are available to reduce energy use and emissions, and a substantial portfolio of advanced technologies is under development. Obtaining large emissions reductions will require counteracting a number of factors, however:

- Inexpensive fuel and consequent disinterest in fuel economy among light-duty vehicle purchasers
- Fuel efficiency tradeoffs with vehicle characteristics that *are* of interest to vehicle purchasers – acceleration performance, vehicle size, consumer features such as 4-wheel drive, and so forth.

- Time required for redesign, retooling, and fleet turnover; the full benefits of new technologies take years to develop.
- High costs and/or important technological and market risks associated with some of the most promising fuel economy technologies.

In other words, both market factors and the status of technology options are crucial to reducing transportation energy use and greenhouse emissions. Policies that change market incentives for consumers and vehicle manufacturers, and policies that can boost technology development are both crucial to reducing CO_2 emissions.

We have examined the impacts of a number of transportation policy changes on future transportation energy use and greenhouse emissions. The accuracy of the forecasts presented here is dependent on the assumptions we have made about future potentials for technology change across a range of future transportation technologies currently under development, and about the effectiveness of various policies. Although we have chosen these assumptions with care, we admit readily that technology forecasting is a highly uncertain art, and further that the outcomes of some of the chosen policies, particularly increased R&D funding, should be interpreted more as educated guesses than as precisely calculated results. Nevertheless, we note that the types of improvements we project are in line with historical improvements in transportation technology. Further, our sensitivity results show that the results are robust in the face of failure of a key technology; this is a critical result because we cannot claim that our choice of technological “winners” is necessarily the correct one.

The results show that transportation energy use and greenhouse emissions will continue to grow at a rapid rate without substantive policy changes. For the Baseline scenario, energy use rises from 25 Quads in 1997 to 36.8 Quads in 2020, and carbon emissions rise from 478 MtC to 700 MtC during the same period – increases of over 45 percent. In the Moderate scenario, which focuses primarily on advancing technology development and does not attempt to strongly influence markets, transportation energy use still grows to 34.1 Quads in 2020, and carbon emissions to 646 MtC in 2020, in both cases growth of more than one third from 1997 levels. Only in the Advanced scenario, where policies focus on *both* developing technology and influencing markets, does growth in energy use and greenhouse emissions slow markedly. In that scenario, transportation energy use rises only 16 percent by 2020, to 28.9 Quads, and carbon emissions rise only 12 percent, to 545 MtC. As noted, these results are not affected markedly by the elimination of an important technology, the direct injected diesel, because other technologies increase their market share when the diesel is eliminated.

Significant emissions reductions from transportation will take time. This is partly because technological adoption and fleet turnover are slow processes in this sector, and partly because even the higher fuel prices associated with the carbon permits and “pay at the pump” insurance have not curbed the steady growth of transport demand. Understanding how demand for mobility is likely to evolve and how it can be influenced without sacrificing accessibility is an important area that needs further investigation. Even in the Advanced scenario in the year 2020, key technologies such as hybrid vehicles, fuel cell vehicles, blended wing-body aircraft, and more, are a minority of new vehicle sales and a far smaller minority of vehicle populations. If these technologies are the beginning of a revolution in transportation technology, that revolution will have only just begun by 2020.

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