Transportation Energy
Trends and Issues through 2030

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ABSTRACT

Controlling transportation energy use looms as a serious challenge for the United States in the 21st century. Demand for transportation services is steadily growing, driven by increasing population, economic activity, and incomes. Few forces presently constrain growth in travel by the energy-intensive modes of automobile, truck, and air transportation. In contrast to other sectors of the economy, transportation energy efficiency improvements are nearly stagnant. Efficiency increases are now absent in highway modes; aircraft efficiency is improving, but not enough to offset rising air travel. Transportation is also the most oil-dependent sector of the economy as well as the country's most rapidly growing source of greenhouse gas emissions. A conservative forecast indicates U.S. transportation energy consumption will rise from 23 Quads in 1990 to roughly 36 Quads by 2030. Less conservative assumptions would push the total to 43 Quads by 2030. From the sector's 1990 greenhouse gas emissions of 432 million metric tons of carbon (MT_C), the corresponding 2030 levels would be 682 MT_C – 815 MT_C.

Yet opportunities exist for efficiency improvements to counter a substantial portion of this growth. The most promising options are technological, with potential long-term efficiency improvements of threefold for cars and light trucks, twofold for aircraft, and 65% for heavy trucks. System efficiency can be enhanced through pricing reforms and improved planning to foster intermodalism and limit the growth of energy-intensive modes. Transportation energy use might then be cut nearly 50% by 2030, reducing the total to the range of 19 Quads – 22 Quads. Coupled with a shift to renewable fuels, the sector's greenhouse gas emissions could cut to 281 MT_C – 336 MT_C. Pursuing cost-effective strategies to move the system toward such reduced energy intensiveness would benefit both the economy and the environment. This paper examines these issues and identifies policies that would lead to reductions in transportation energy use and its associated problems such as greenhouse gas emissions and oil import dependence. The discussion draws largely on transportation analyses from the Energy Innovations (1997) study, which analyzed environmentally oriented energy policies for the United States (projections given here are based on that report unless otherwise noted).

INTRODUCTION

Transportation energy use raises a variety of public concerns, ranging from security issues associated with oil import dependence to environmental problems such as air pollution and greenhouse gas emissions. Until the energy crises of the 1970s, energy use in transportation, as in other sectors of the U.S. economy, essentially grew in step with population and economic activity. The oil shocks of 1973-74 and 1979-80 broke that link through market responses to fuel shortages, price hikes, and public policies such as automobile fuel economy standards established in response to the energy crises. From 1972-92, U.S. transportation energy use grew at an average rate of only 1.1%/yr, in spite of economic growth averaging 2.7%/yr over that period (Greene and Fan 1994). However, since 1992, the efficiency improvements induced over a decade ago have been played out and transportation energy use is again growing steadily with population and economy activity. As shown in Table 1, transportation accounts for 27% of U.S. primary energy consumption. The sector remains highly petroleum dependent and now accounts for 67% of U.S. petroleum use, up from a 51% share in 1973 (Davis 1997).

Transportation energy use also generates substantial amounts of air pollution, as also indicated in Table 1. Vehicles are the largest source of carbon monoxide (CO) emissions, but emissions controls have placed this pollutant on a declining trend (EPA 1993). The sector's volatile organic compound (VOC) emissions are also on a declining trend. Transportation now accounts for about 45% of nitrogen oxide (NO_X) emissions, but in this case, controls appear to have only limited emissions; a declining trend for NO_X is not yet clear. Transportation is a relatively minor source of sulfur dioxide (SO_2). Of greater concern is the sector's contribution to fine particulate matter ($PM_{2.5}$), a pollutant for which progress in control has been insufficient to date (Shprentz 1996). EPA recently proposed tighter standards for this pollutant. The fact that vehicle emissions occur at ground level in populated areas makes the transportation sector more important for addressing PM hazards than suggested by its 19% share of the inventory. Particulate emissions from a diesel vehicle are many times higher than those from a typical gasoline vehicle. However, because light duty gasoline-powered vehicles are so numerous, the total $PM_{2.5}$ caused by gasoline vehicles is nearly double the total $PM_{2.5}$ from diesels.

Nearly all transportation-related air pollution is due to fuel combustion in motor vehicles. For most vehicle pollutants, emissions regulations have clearly helped limit air pollution levels. However, real-world vehicle emissions are substantially higher than the nominal levels set by the emissions standards and in some cases, the controls have not been sufficient to offset growth in travel. Air pollution is not a primary focus of this paper; nevertheless, efforts to improve transportation energy efficiency generally will have a beneficial effect in reducing pollutants associated with transportation fuel use. Because emissions are closely related to energy consumption (although the relationships are complex), the ongoing need for control of air pollutants remains an important issue for transportation energy use.

Transportation directly accounts for 32% of U.S. carbon dioxide (CO_2) emissions from energy use. As shown in Table 2, CO_2 from transportation petroleum use exceeds that from coal use for electricity generation. The sector's responsibility would be even larger if the upstream emissions involved in producing transportation fuels were counted. In spite of its importance to the GHG emissions problem, transportation measures accounted for only 12% of energy sector

Table 1. Transportation Sector Shares of Energy Consumption and Energy-Related Emissions in the United States, 1992				
	Units	U.S. Total	Transport Amount	Transport Share
Primary Energy	10^{15} Btu/yr	82.4	22.5	27%
Petroleum	10^6 bbl/day	16	11	67%
Carbon Monoxide (CO)	10^6 T/yr	79	63	80%
Nitrogen Oxides (NO_X)	10^6 T/yr	21	9.4	45%
Volatile Organic Compounds (VOC)	10^6 T/yr	21	7.5	36%
Fine Particles ($PM_{2.5}$) and Precursors	10^6 T/yr	61	12	19%
Sulfur Dioxide (SO_2)	10^6 T/yr	21	1.0	5%
Carbon Dioxide (CO_2, as carbon)	10^6 T_C/yr	1338	432	32%

Units: Btu = British thermal units, bbl = barrels, T = metric tons.
Sources: Davis (1997); EPA (1993); Shprentz (1996); CO_2 estimates are for 1990, as in Table 2 below.

reductions called for by the first U.S. Climate Change Action Plan (CCAP 1993). The need to control greenhouse gas (GHG) emissions (which are mostly CO_2 from fossil fuel consumption) to allay risks of climate disruption poses an immense challenge to the U.S. transportation energy system. The GHG implications of transportation energy use are highlighted throughout this discussion.

Even though major problems are associated with transportation energy use, the economic motivations for addressing it are quite weak. Recent politics have been unsuited for strengthening existing policies (such as the CAFE standards) or developing new policies that might significantly alter the country's transportation energy picture. For those policies recently established, such as alternative fuel initiatives and the Partnership for a New Generation of Vehicles (PNGV), the expected effects on nationwide energy use and GHG emissions are likely to be negligible for the foreseeable future. Past experience suggests the need for a crisis, or at least the perception of one, to induce substantive action. The recently negotiated Kyoto Protocol, in which the United States and other developed nations agreed to significantly cut GHG emissions over the next 10–15 years, represents a step forward in terms of commitment to address the global warming problem. However, it is unclear that concerns about GHG emissions have yet reached the level needed to develop domestic policies sufficient to the task.

The public does have robust environmental concerns. This sensibility is reflected in the strengthening of air pollution control measures—one transportation energy-related arena where progress continues. Most existing pollution reduction targets are likely to be achieved through further refinement of the existing auto and oil-based system, valiant efforts to promote electric vehicles notwithstanding. On the other hand, controlling GHG emissions poses a more fundamental challenge to the existing transportation energy system. The auto and oil industries, among the

Table 2. U.S. Carbon Emissions by Sector and Primary Fuel, 1990								
	Million Metric Tons of Carbon per year						Electricity	
	Direct Fossil Fuel Use			Indirect	Totals	end-use	Consumption	
Sector	Gas	Oil	Coal	Electric		share	TWh/yr	share
Electricity	41.2	26.8	408.8	--	476.8	--		
Commercial	38.7	18.1	2.3	147.5	206.6	15.4%	839	30.9%
Residential	65.0	24.0	1.6	162.4	253.0	18.9%	924	34.1%
Transport	9.9	422.3	0.0	0.7	432.9	32.4%	4	0.1%
Industrial	119.6	91.9	67.8	166.3	445.6	33.3%	946	34.9%
Totals	274.4	583.1	480.5	--	**1338.0**	100.0%	2713	100.0%
fuel shares	20.5%	43.6%	35.9%					

Source: Derived from DOE/EIA Annual Energy Outlook 1994, Tables A8 and A17.

largest and most politically powerful in the country, appear quite content with the status quo, "letting the market work." Indeed, oil prices have been at historic lows, aside from fluctuations which, though they may attract much attention, are relatively small when viewed in a broader context. Risks of future oil supply disruptions surely exist, but are not reflected in prices and have largely faded from public awareness. A dilemma for the United States is how to prudently pursue options for improving transportation efficiency and diversifying its energy supply in the face of low oil prices.

The depth of the dilemma can be seen by examining the current structure of transportation energy use in the country. A look at the past twenty years of energy use, broken down by major transportation mode, reveals the inertia in the system—illustrating the time required for change—and shows where progress was made in the past—suggesting measures likely to succeed in the future. Ultimately, transforming the transportation energy system to ameliorate its problems (energy security concerns, economic risks, and environmental impacts) is a matter of making strategic investments leading to greater efficiencies, both of vehicles and for the system as a whole, and to more sustainable energy resources. The scale of the system is far too large for these to be public investments alone, although public investments in more efficient infrastructure are essential. Since market forces are incapable of addressing what are fundamentally non-market concerns, private investments will need public guidance.

TRANSPORTATION ENERGY USE TRENDS

Transportation energy consumption was 23 Quads as of 1992, a 27% share of the U.S. total. The sector's consumption is 97% petroleum products, amounting to 11 Mbd (million barrels per day). The U.S. transportation fuel consumption rate corresponds to two gallons per day of petroleum products per capita (Greene 1996). Figure 1 breaks down the sector's energy use by mode. Light vehicles (cars and light trucks) account for the largest portion, at 58%. Freight trucks (medium and heavy duty) account for 15% and aircraft for 9%. Other modes have smaller shares and—except for international shipping—smaller growth rates than the dominant modes of light duty vehicles, freight trucks, and aircraft. All of these modes rely nearly exclusively on petroleum fuels; the sector's relatively small amounts of natural gas and electricity are used mainly in pipelines.

A more revealing view is provided by the cross-tabulation in Table 2, which shows sources of energy-related carbon emissions by end-use sector and fuel type. Total emissions in 1990 amounted to 1338 million metric tonnes (MT_C) on a carbon-mass basis (corresponding to 4.9 billion tonnes of CO_2). As noted earlier, transport's share is 32% and it is concentrated in oil use. At 422 MT_C, transportation oil use is the single largest contributor to U.S. fossil carbon emissions, exceeding even the 409 MT_C from coal used for electricity generation. Transportation CO_2 emissions also exhibit one of the fastest rates of growth. Carbon emissions from transport appear to be growing at 1.3%/yr over 1990-2010, compared to 1.0%/yr growth in carbon emissions from industry; growth from the other end-use sectors is below 1%/yr.

The Energy Innovations (1997) analyses were performed using the DOE Energy Information Administration (EIA) National Energy Modeling System (NEMS). Projections through 2010 are based a 1995 version of NEMS, as used to prepare the 1995 Annual Energy Outlook (EIA 1995), but with lower oil and gas price assumptions. Oil prices are most relevant for transportation and only a modest price increase, averaging 0.9%/yr 1995-2010, is assumed. This rate implies gasoline rising from a 1995 price of $1.18/gal to just $1.35/gal (1995$) by 2010. Economic growth is assumed to average 2%/yr over the period. For extrapolations beyond 2010, various sources cited below were used to build spreadsheet models for light vehicles, freight trucks, and commercial aircraft; long-term trends for the other modes were drawn from EIA (1991). Figure 2 summarizes the resulting long-term projection. Overall, under the given assumptions, U.S. transportation energy use increases 60% over the 1990 level by 2030, reaching nearly 36 Quads compared to 22.5 Quads in 1990. U.S. transportation energy use grew at an average rate of 1.8%/yr over the two decades 1970-90, but this period included two oil shocks and the implementation of fuel economy standards. The projections shown imply average growth rates of 1.3%/yr for 1990-2010 and 1.1%/yr for 2010-2030, a distinct slow-down of recent growth.

DOE's past projections have tended to understate transportation energy use growth, largely due to assumptions of lower growth in highway travel and higher rates of efficiency improvement than recently observed (Alson 1996). Compared to the projections of Figure 2, assumptions more in line with recent trends (that is, assuming no market-driven increases in highway fuel efficiency) would imply roughly 11% higher growth by 2010 and 20% higher growth by 2030. In such a case, 2030 transportation energy use would reach about 43 Quads, 90% higher than the 1990 level, corresponding to an average compound growth rate of 1.6%/yr for 1990–2030. The sector's GHG emissions would also be proportionately higher. (Preliminary information available as this report was being finalized indicates that DOE has corrected some modeling problems and that the 1998 *Annual Energy Outlook* transportation energy use projections will be significantly higher than previous projections.)

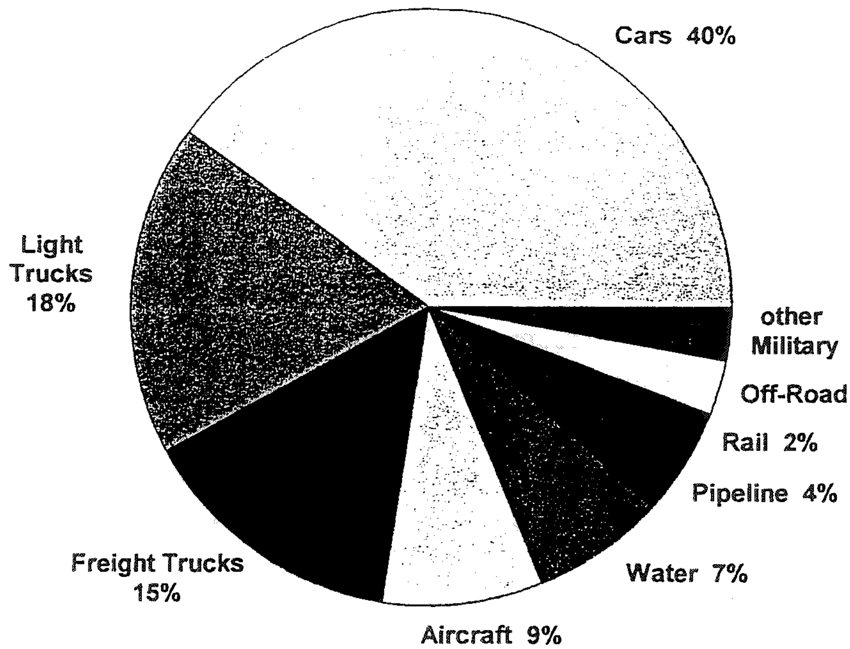

Figure 1. Shares of U.S. Transportation Energy Use by Mode, 1992

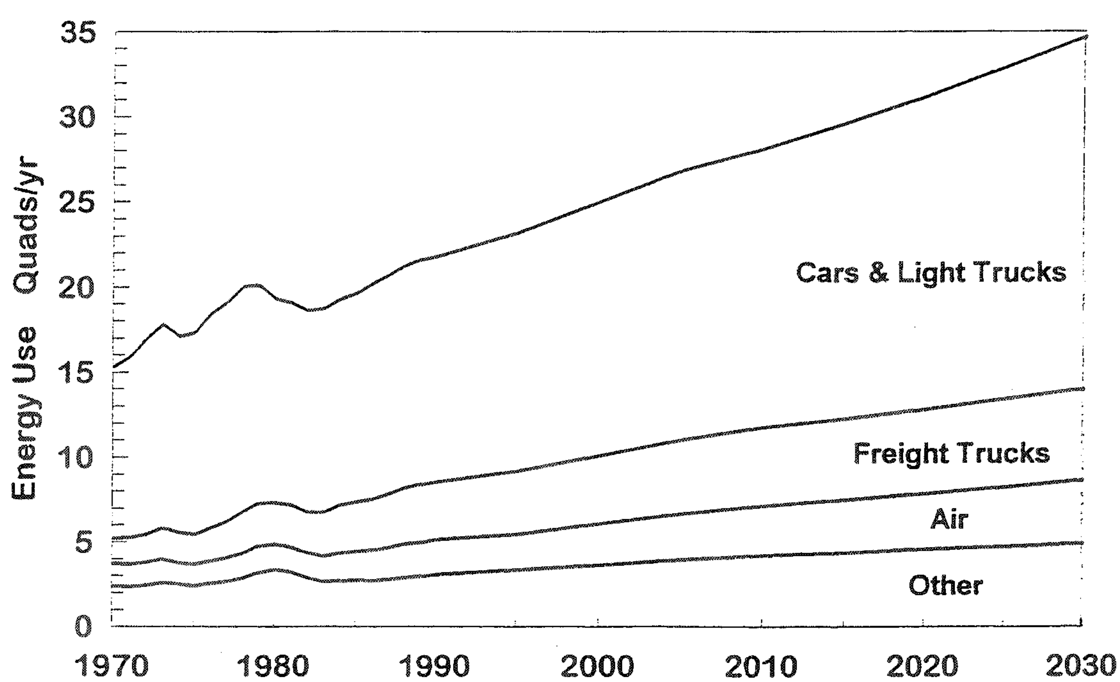

Figure 2. Trends in U.S. Transportation Energy Use by Mode, Historical Statistics through 1990 and Projections to 2030

OPPORTUNITIES FOR CHANGE

The projections given here indicate the enormous challenge associated with transportation energy use. The issue with respect to greenhouse gas emissions is particularly pronounced. The United States, like other nations, largely relies on fossil fuels for energy, and transportation relies nearly exclusively on oil. Nevertheless, advances in technology and alternative approaches infrastructure planning offer hope that the U.S. transportation system can evolve toward lower energy intensity and lower greenhouse gas emissions (DeCicco et al. 1993). The problems faced in attempting to transform transportation are collective problems—market failures, tragedies of the commons, inheritances of past public investments that poorly meet the needs of the future. Collective solutions would be required to guide the market toward investments in higher efficiency, renewable fuels, and a greater diversity of transportation choices. Identifying strategies to achieve such solutions is a major issue facing policy makers, who must reconcile diverse interests in crafting public policies that can be perceived as cost effective and win political support. The following discussion examines options for developing such strategies based on the dominant modes—light vehicles, freight trucks, and commercial aircraft. The analysis of potential energy savings is based on results from the Energy Innovations (1997) study.

Cars and Light Trucks

Cars and light trucks comprise the largest portion of transportation energy use and they have received the most attention to date. The principal policy that has had a measurable impact on the sector's energy use is Corporate Average Fuel Economy (CAFE) regulation, enacted in 1975. The CAFE standards are one of the major energy policy success stories of the past several decades. However, the standards have not been significantly strengthened since they reached their highest Congressionally mandated level in 1985. Nevertheless, they still constrain the fleet to an average fuel economy higher than what it likely would be in their absence. Greene (1990) estimates that the CAFE standards are responsible for at least three-quarters of the fuel savings obtained through light vehicle efficiency increases since 1978 when the standards first took effect.

The new light duty fleet average fuel economy in miles per gallon (mpg) has not significantly increased since 1982. As shown in Figure 3, the combined car and light truck average has been 25 ± 1 mpg for the past 14 model years (Heavenrich and Hellman 1996). In fact, due to the increased marketing of light trucks, the most recent new fleet average is over 1 mpg lower than it was 10 years ago. Thus, no further gains in on-road stock efficiency are to be had from the retirement of older vehicles. Ongoing increases in the amount of driving, which doubled in the past two decades, have now overtaken the vehicle efficiency increases. As a result, the past few years have seen record car and light truck gasoline consumption. Steadily increasing light vehicle fuel consumption and CO_2 emissions are expected for the foreseeable future unless new steps are taken to induce efficiency improvements.

Technology for improving vehicle efficiency has greatly advanced over the past decade and the feasibility of further improvements is well established (DeCicco and Ross 1993, 1994). Nevertheless, the subject has long been a contentious area of public policy. Disagreements involve how much improvement can be made over a given time frame. Many technologies that can improve fuel economy can also be applied to enhance other vehicle attributes, such as performance and luxury, as has been observed in recent years with the absence of market signals or regulatory direction pointing toward higher efficiency.

The general public prefers efficiency standards to higher gasoline taxes. The automobile industry stridently opposes stronger CAFE standards and takes the position that, if public concerns dictate control of fuel consumption, a modestly higher gasoline tax is their preferred approach. In fact, transportation fuel demand is relatively inelastic and the existing CAFE constraint implies that a certain tax hike threshold must be passed before the market is likely to be moved by higher fuel prices (DeCicco and Gordon 1995). Ideally, a combination of regulatory and incentive approaches is likely to be the best way to motivate higher fuel economy.

To estimate the energy savings from higher fuel economy if policies were enacted to pursue it, we drawn on DeCicco and Ross (1993), who estimated potential near-term (roughly 10-year lead time) improvements at three levels of technical certainty. The higher levels involve greater technical risk in the sense that widespread use of the technology improvements may be more difficult within a 10-year time horizon. As summarized in Table 3, these estimates are for new car fleet averages of 39 mpg to 51 mpg (41% to 82% higher than the 1990 average of 28 mpg). Proportional degrees of efficiency improvement are applicable to light trucks, which now average 21 mpg.

Estimating the cost of fuel economy improvement is difficult because of the limited information that is publicly available. The incremental cost estimates shown in Table 3 were based on a review of previously published information covering potential technology changes that are cost effective in terms of fuel saved over the life of a car. A cost-effectiveness index is the Cost of Conserved Energy (CCE), derived from the ratio of incremental technology cost to fuel savings over the life of an improved vehicle. An efficiency level is cost effective if its marginal CCE is less than the future cost of gasoline expected over the life of the improved vehicles. For example, achieving the mid-range (Level 2) estimate of 45 mpg is estimated to cost an average of $690 per car and be cost effective (from an aggregate consumer perspective) at an avoided fuel cost of $1.48/gal. This cost is higher than the DOE's expected gasoline price in 2005-2010. However, if even modest values of gasoline consumption externalities are added, this 45 mpg level would be cost effective.

For post-2010, potential efficiency improvements can be linked to attainment of the tripled fuel economy research goal adopted by the government/industry Partnership for a New Generation of Vehicles (PNGV 1994). This effort plans to have pre-production prototypes ready by 2003-2005. Allowing for 1-2 years of testing followed by 3-4 years to tool up for initial mass production suggests that super-efficient vehicles could be introduced into at least one market segment by roughly 2010. Allowing another 20 years for the technology to diffuse to all other car and light truck segments suggests that a tripled new fleet average—75 mpg vs. today's 25 mpg—could be attainable by 2030, as illustrated in Figure 3. Although the technologies needed for such high fuel economy levels appear costly at present (OTA 1995), the industry's R&D goals include affordability and cost effectiveness in terms of fuel savings. Other researchers project that fuel cell vehicles having such efficiency levels could be competitive with gasoline vehicles on a life-cycle cost basis early in the next century (DeLuchi 1992; Williams et al. 1995).

Table 3. Potential New Car Fleet Average Fuel Economy and Cost Estimates			
Technology Certainty:	Level 1	Level 2	Level 3
Achievable new car fuel economy (MPG)	39	45	51
Improvement over 1990 new fleet	41%	60%	82%
Average added cost per vehicle (1995$)	560	690	820
Average Cost of Conserved Energy ($/gal)	0.51	0.50	0.50
Marginal Cost of Conserved Energy ($/gal)	1.46	1.48	1.62

Source: DeCicco and Ross (1993), updated to 1995$ using 4% cumulative inflation from 1993-95. Fuel economy values are EPA composite 55% city, 45% highway unadjusted test ratings. Cost-effectiveness estimates are based on a 5% real discount rate and 12-year, 10,000 miles/year vehicle life.

Lovins (1995) identifies the possibility of dramatically higher efficiency levels through a radical "ultralight" approach to car design, which could yield tenfold or higher fuel economy levels. Clearly, such breakthroughs would greatly change the transportation energy picture and may well be necessary to achieve sharp curtailments of greenhouse gas emissions.

We adopt the PNGV goal as indicative of a long-term potential attainable over the next three decades. For the purpose of projecting energy savings, we adopt a linear fuel economy improvement trajectory starting at 25 mpg in 1997 and reaching 75 mpg by 2030. Such a path falls in the mid-range of the DeCicco and Ross estimates for the near-term and reaches the PNGV goal in the long-term. If the new fleet fuel economy triples by 2030, the on-road stock will have improved by a factor of 2.7 over the 1990 level. The result would be a 63% cut in light vehicle fuel consumption (other factors, such as the amount of driving, held equal). Thus, instead of light vehicles using roughly 20 Quads in 2030 (as indicated in Figure 2), their consumption could potentially be cut to 7.5 Quads. Even without shifting to renewable fuels, this energy savings would result in a substantial carbon emissions reduction compared to the trend we are already on. Combined with fuel diversification and measures to cut the amount of driving, we can be reasonably optimistic about greatly alleviating at least the light vehicle aspects of the U.S. transportation energy concerns.

Realizing even modest vehicle efficiency improvements will require concerted public policy guidance that is now lacking. Without market or regulatory incentives, there is no guarantee that R&D efforts such as PNGV will yield technological advances that are deployed so as to yield higher fleet average fuel economy. Strengthened CAFE standards would be a sensible and very cost-effective starting point. (Standards could also be converted to a marketable permit system for fleetwide fuel consumption or CO_2 emissions, which could provide greater flexibility as a "market-based" approach to regulation.) However, a standards-setting process is inherently conservative, so standards alone may not be extended high enough to bring advanced, technologies into production. Establishing a financial incentive, such as an extended gas-guzzler tax used to fund rebates for vehicles more efficient than average ("feebates"), would be a valuable complement

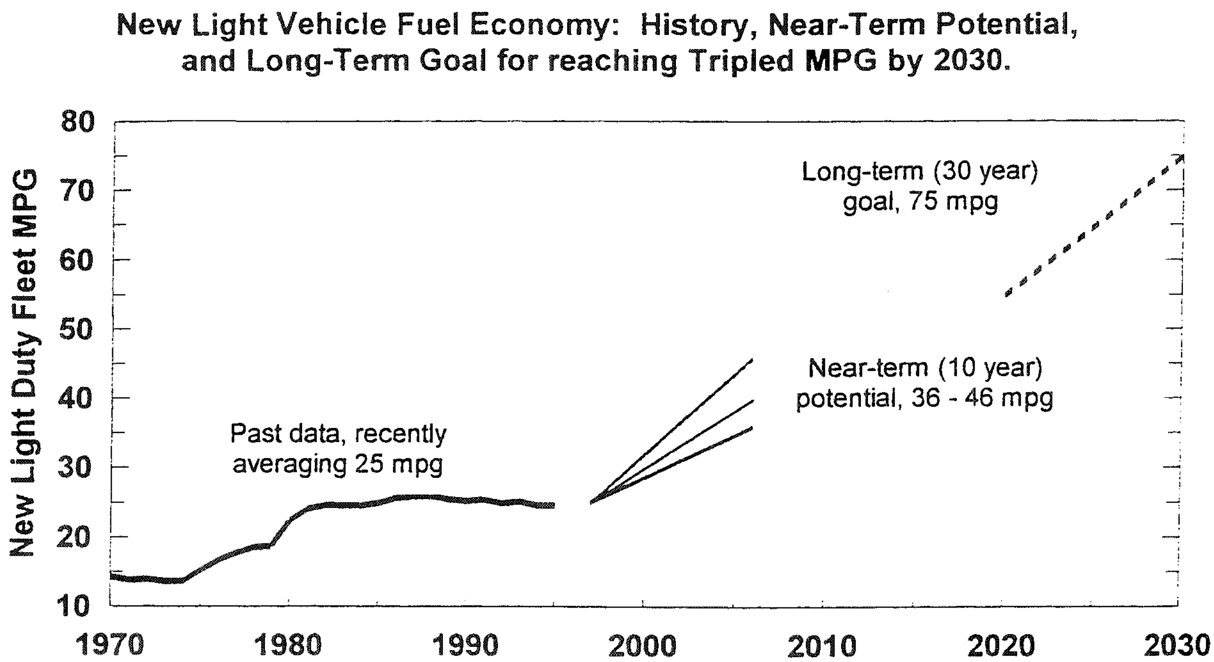

Figure 3. New Car and Light Truck Fuel Economy: Recent History, Near-Term Potential, and Long-Term Scenario

to CAFE standards and provide a long-term signal that could help spur greater technical advances. Extending initial market creation efforts, such as fleet programs, to coordinate bulk purchases of more efficient vehicles is another approach worth exploring. A policy package combining strengthened CAFE standards with incentives and market creation programs for efficient vehicles was recommended in Majority Report (1995), which this author endorsed.

Surface Freight

Trucking accounts for the second largest share of transportation energy use and shows steady growth. However, structural and operational changes in the trucking industry plus serious data limitations complicate the analysis of freight truck energy use. From 1960-1990, heavy truck energy use tripled, an increase rate only recently rivaled by air, and freight truck efficiency in ton-miles per Btu decreased over much of that period, even during the steep fuel price increases of 1973-82 (Mintz and Vyas 1993). NEMS-based projections are for freight truck energy use to increase at an average rate of 1.6%/yr through 2010, with truck efficiency improving slowly (0.4%/yr). Such an improvement rate would exceed what has been observed to date. EIA aggregates freight truck into three classes (small, medium, and large). Small trucks (up to 10,000 pounds gross vehicle weight) account for 29% of freight truck energy consumption. To estimate potential efficiency improvements, small trucks should be treated separately from medium and large trucks, since small freight trucks have engineering characteristics more similar to passenger vehicles than to heavy load-hauling vehicles.

Small freight trucks, such as those used in urban delivery applications, are likely to be able to incorporate many if not all of the technology improvements being developed for light duty passenger vehicles. However, a technology assessment particular to small freight trucks is not available, so we extrapolate from those used for light duty passenger vehicles. As noted above, PNGV technologies are intended to triple light vehicle fuel economy. We assume a more modest target of doubling the 1995 fuel economy for the small freight truck fleet by 2025. The long-term target is for new vehicles; using a stock turnover model implies a 70% improvement in small freight truck efficiency by 2025.

For large and medium freight trucks, the published assessments and research targets imply a more limited potential for efficiency improvement. Estimates of technical potential have only been made for the heavier classes of large trucks, but we will assume these provide a good guide to the potential for all medium and large trucks. Duleep (1997) projects, for optimistic assumptions and expected technology trends, that new heavy truck fuel economy can continue to improve at 1.2%/yr, yielding a 33% fuel economy improvement over current levels by 2015. Sachs et al. (1992) identified a higher fleetwide potential, for a 65% fuel economy improvement, from advanced technologies and higher penetrations of other technologies. We assume this level of improvement a long-term target achievable in new trucks by 2025. Accounting for stock turnover implies a 1.3%/yr improvement rate. Freight truck energy use would then be cut by about 34% by 2030, from a baseline projection of 5.3 Quads down to 3.5 Quads. In addition to steady support for R&D leading to engine improvements, an aggressive and well-marketed commercialization and technology incentive program would probably have to be established to realize improvements like these in the on-road truck stock. Further policy analysis and program development efforts are needed to identify what types of measures would be workable and effective for improving freight truck energy efficiency.

Intermodal Shipping. Efficiency can also be improved by increasing the use of intermodal freight shipping, in which a portion of truck highway travel is substituted with rail. Given goods and shipping routes for which it is suitable, rail is an inherently efficient mode of freight transport and, as noted below, the railroads have continued to improve their energy efficiency. Intermodal shipping has been a rapidly growing segment of the freight sector in recent years; it still covers only a small portion of total freight and considerable growth potential remains. America's Energy Choices (1991) projected a long-term potential shift of 12% based on estimates of the amounts of major commodity aggregations that could not be shifted from truck to rail. We also adopt this 12% as a 2030 estimate of the amount of baseline truck ton-miles that could be shifted to rail through either mode substitution or increased intermodalism. Adjusting for the increased rail traffic, including longer route circuity, yields an estimate of roughly 0.6 Quads of energy savings from greater use of intermodal shipping.

Other Freight Modes. In contrast to trucking, rail efficiency has shown steady increases in efficiency (measured in ton-miles per Btu) over the past several decades. Rail freight energy intensity dropped from 706 Btu per ton-mile in 1972 to 399 Btu per ton-mile in 1992, an average intensity decrease rate of 2.8%/yr (Greene and Fan 1994). According to Cataldi (1997), the railroad industry is actively modernizing and making technological improvements for competitive and economic reasons, and ongoing efficiency improvement is likely to occur as a side benefit. Lacking published assessments of future rail efficiency gains, we assume that progress continues at one-half the past rate of energy intensity reduction. The resulting projection is for a 1.4%/yr decline in rail freight energy intensity through 2030.

For waterborne and pipeline freight, potential efficiency improvements can be based on the "very high conservation" case projections of EIA (1991). Diesel technology improvements similar to those being pursued for heavy trucks and rails would also be applicable to ships. Improvements in other aspects of design and operation are also likely to be feasible. The EIA (1991) projections are for a 20% decrease in energy intensity by 2030 compared to the 1990 level, or an average rate of 0.64%/yr, for water and pipeline freight efficiency improvement.

Commercial Aircraft

Air travel is the third largest subsector of transportation energy use and it has been rapidly growing. U.S. air passenger miles travelled (PMT) grew at an average rate of 6.1%/yr from 1972-92 (Davis 1997). Because it is so energy intensive and the industry strives to reduce fuel costs, air travel has also shown the greatest efficiency improvements of any mode. Its energy intensity dropped by more than half, from 9.2 kBtu/PMT in 1972 to 4.3 kBtu/PMT by 1992 (Greene and Fan 1994). Thus, air travel energy use increased only 50% even though PMT more than tripled over this period. About 74% of this historical efficiency improvement came from technology changes and the rest came from operational changes (higher load factors). In the future, load factors can be increased somewhat further while the opportunities for ongoing technology improvements are substantial.

NEMS baseline projections of personal air travel show an average annual increase rate of 4%/yr for 1992-2010. The baseline efficiency increase rate is much slower, 0.7%/yr, for a 14% improvement by 2010; Energy Innovations (1997) assumes a continuation of this efficiency improvement rate through 2030. The implied net increase in baseline commercial air energy use and GHG emissions is 43% from 1990 to 2010. Steady growth is anticipated farther into the future, so that energy use for air travel in 2030 is 81% higher than the 1990 level. These projections pertain to domestic air traffic; international travel is expected to have even higher growth rates.

Because of the large growth in air travel, the resulting airport congestion, and anticipated limits in new airport construction, investments in high-speed rail (HSR) are attractive for a number of regions in the country. Options for HSR intercity passenger service include the now established technology for fast steel-wheel trains, such as the French *Train de Grande Vitesse* (TGV), and perhaps magnetic levitation (Maglev) vehicles in the future. HSR could be competitive with air (on both energy cost and travel time) for short trips of roughly 600 miles or less, which account for about one-third of domestic air travel. America's Energy Choices (1991, C-28) presented a scenario assuming a phase-in of HSR such that one-half of short trips are shifted from air to HSR by 2030. A public/private investment strategy leading to such a scenario would cut U.S. air travel by about 15% by 2030.

Greene (1997) identified significant opportunities for aircraft efficiency improvement, largely technological. Under an optimistic scenario, aircraft efficiency could increase from a 1995 level of 51 seat-miles per gallon (SM/gal) to 86 SM/gal by 2015 (accounting for stock turnover). Interpolating this 2.8%/yr increase rate for 2010, and assuming load factor increase to 67%, energy intensity could be reduced to 2.6 kBtu/PMT by 2010. This case entails a 57% efficiency improvement over the 1990 level by 2010, compared to 14% in the baseline. Since NEMS lacks a policy sensitive model of aircraft efficiency, we adjusted the NEMS results for a higher level of efficiency improvement. Combining operational improvements with Greene's optimistic technical efficiency improvements indicates that aircraft efficiency could essentially double by 2030. Incorporating shifts to high-speed rail, energy use for air travel could be cut by 38% compared to the baseline projection for 2030. As for freight trucking, further analysis is needed to determine what policies might be needed to accelerate air transport efficiency improvements beyond those likely to occur through market forces alone.

Intermodalism

While advances in vehicle design are surely necessary for a more sustainable system, they do not address many other public concerns. Moreover, such "tech fixes" may not suffice to achieve the large GHG emissions reductions likely to be needed in the long run. The past two decades reveal how failing to address system efficiency can greatly reduce energy savings. Vehicle efficiency improvements yielded a gross savings of 6.6 Quads in U.S. passenger surface transportation from 1972-92; however, decreases in vehicle occupancy had the effect of increasing consumption by 3.7 Quads, reducing the net savings by more than half (Greene and Fan 1994). Thus, while improving vehicle efficiency is crucial, system efficiency must also be improved. Approaches include providing a richer set of travel and accessibility choices, through smarter planning of land use and transportation infrastructure investments, and reforming price signals to avoid subsidizing energy intensive modes such as cars, trucks, and aircraft. A key to system efficiency is "intermodalism," that is, combining transportation modes in ways that provide better access than relying on a dominant mode such as highway travel. This approach was acknowledged in the title of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA), what was once known as the "highway bill."

This report is too brief to adequately cover the range of options and strategies for intermodalism. Energy Innovations (1997) reviews recent assessments of the scope for system efficiency improvements and synthesizes them into estimates of possible reductions in nationwide vehicle miles of travel (VMT). Concerted efforts to reduce VMT will probably occur only in areas facing air quality constraints. Based on 1993 status, 22 U.S. metropolitan regions fall into this category, accounting for 21% of national VMT. Examining the constrained areas' VMT reduction plans yields an average VMT reduction of 20% by 2010, which implies a nationwide reduction of 5.4% in 2010 due to such regional efforts. For the longer term, one can also incorporate effects from changes in land use as might be induced by location-efficient mortgages, transit-oriented development, and other measures to decrease auto dependence. Discussion of and impact estimates for such strategies were given in Majority Report (1995). Applying them to the VMT baseline based on NEMS yields combined effects (excluding fuel taxes or VMT fee-based pricing policies) amounting to a 18.6% cut of VMT by 2030.

Pricing Reforms

Changing the price signals, particularly for energy use and travel demand, will be an important part of a long-run strategy to improve transportation efficiency. From a climate protection perspective, a tax-shifting strategy to establish an economy-wide carbon tax is appropriate. The Energy Innovations (1997) study adopts a carbon tax of $25/ton ($CO_2$-mass basis, corresponding to $101 per metric ton of carbon) that would, for example, raise the price of gasoline by roughly $0.24/gal. Offsets for such a tax could involve shifting state and local road subsidies and other hidden, fixed, or indirectly paid costs of driving to fuel taxes or VMT-based fees. Such shifts are also justifiable as sector-specific pricing reforms that would improve the economic efficiency of the transportation system. Other approaches could involve raising the federal gasoline tax and then adjusting transportation trust fund allocations to provide appropriate state compensation. Another promising approach is "pay-at-the-pump" insurance, in which a portion of insurance premiums are shifted to a fuel price surcharge.

In terms of policy mechanics, user fee shifts and reforms involving motor fuel taxation have the advantage of existing mechanisms for revenue redistribution. Looking ahead, "smart" technologies might also be used to implement various innovative means of road use pricing or insurance premium charging. For example, vehicles could carry a device which reads an electronically encoded debit card that could be used for multiple purposes, from fuel purchase or toll collection to insurance collection. Any such tax shifting approach raises equity issues that must be addressed. It will not be possible to win broad political support unless the public can be convinced that they will see a true burden shift rather than a net tax increase.

Low-GHG Fuels

Shifting to fuels entailing lower GHG emissions, such as those produced from renewable feedstocks, is clearly critical for addressing greenhouse gas emissions concerns and also could help reduce oil dependence. Much research has been done on the topic of alternative transportation fuels, but no clear consensus has emerged about which fuels or combinations of fuels are most likely to succeed. Energy Innovations (1997) developed a trajectory of decreasing carbon intensity (e.g., in grams of carbon per Btu of fuel supplied) for delivered transportation fuel sectorwide, based on a review of studies of various low-carbon fuel options. Little fuel switching is expected to occur before 2010. The trajectory results in a carbon intensity decrease of roughly 3% by 2010 and 17% by 2030 relative to the 1990 level (which was essentially all petroleum, at 19.2 grams of carbon per kBtu). Such a shift could be accomplished by some combination of renewably produced biofuels (methanol or ethanol) or hydrogen, along with some natural gas. Inherently high costs suggest that significant use of plug-in electric vehicles may be unlikely beyond what is mandated in California, New York, and Massachusetts. Reducing the net GHG emissions associated with petroleum use may also be feasible through carbon sequestration.

Currently, extensive research, demonstration, and niche-market deployment efforts are being tried for alternative fuels, not all of which are that much less carbon-intensive than gasoline. A more concerted strategy, including specific incentives for low-carbon fuels, will be needed to achieve significant shifts away from petroleum fuels. Energy Innovations (1997) outlines a low-carbon transportation fuels strategy, but further policy analysis is needed on this topic.

CONCLUSION

Like other aspects of economies that affect natural resources and the environment, transportation energy use is confronting an issue of sustainability, namely, the extent to which current trends jeopardize the welfare of future generations. The U.S. transportation system is 97% dependent on petroleum, nearly half of which is imported. The sector is responsible for nearly a third of the country's carbon emissions and substantial shares of several serious air pollutants. The security, economic, and environmental risks associated with these energy-related impacts indicate that the current transportation system is unlikely to be sustainable. This examination of current trends indicates that energy use by each of the major transportation modes is growing steadily. Transportation energy use, which was 22.5 Quads in 1990, could reach 36–43 Quads by 2030. The sector's petroleum dependence remains persistent, so CO_2 emissions will essentially grow in step with energy use. Figure 4 summarizes the resulting projections of transportation sector CO_2 emissions. The range of baseline projections indicates growth by 2030 of 60%–90% above the 1990 level.

Many opportunities exist for efficiency improvements to offset growth in transportation energy use. The most promising options are technological. Potential long-term (circa 2030) efficiency improvements appear to be 200% for light vehicles, 100% for aircraft, and 65% for heavy trucks. Combined with system efficiency changes to help limit growth of the energy-intensive modes, transportation energy use might be cut by nearly 50% below the baseline for 2030, or as much as 20% below the 1990 level. The dramatic change in projected carbon emissions that would result from combining these technological and systems efficiency improvements is shown in the "Efficiency Only" curve in Figure 4. Shifts to renewable fuels would compound the efficiency effects to yield an overall 57% reduction below the 2030 baseline projection of transportation carbon emissions, as shown by the lowest curve in Figure 4.

Pursuing cost-effective strategies to move the system toward reduced energy intensity will be clearly valuable for the economy and environment. However, achieving such reductions in energy use and emissions will be a public policy challenge. It will require new efforts to increase passenger vehicle fuel economy as well as new initiatives to spur efficiency increases for freight and air transport. Further policy development and much stronger programs are needed to reduce the carbon intensity of transportation fuels. Complementary efforts to improve system efficiency through better planning and to orient the system to lower energy intensity through pricing reforms can also contribute. A crucial question is whether the political will can be mustered to proactively redirect the U.S. transportation energy system towards greater sustainability, or whether a new crisis must arise before serious steps are taken.

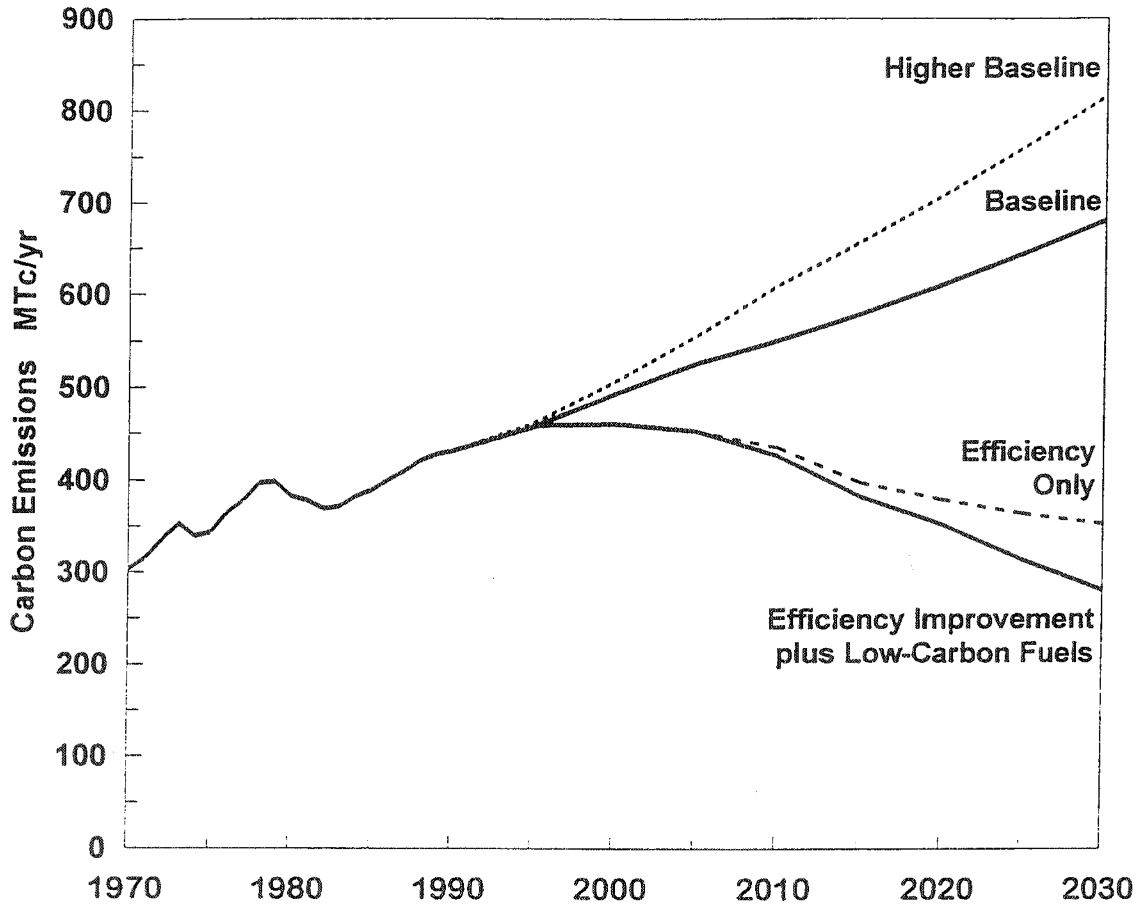

Figure 4. Carbon Emissions for U.S. Transportation Energy Consumption: Baseline Projections and Policy Scenarios

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