Factors That May Influence Responses of the U.S. Transportation Sector to Policies for Reducing Greenhouse Gas Emissions

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Transportation vehicle operations in the United States contribute 32 percent of the nation's emissions of carbon dioxide and 7 percent of the world's emissions from energy use. Technical options to reduce emission rates exist, but policies to reduce emissions must recognize the fragmentation of responsibility for key transportation activities among diverse groups of decision makers and the need to coordinate their decision making. Policies to increase vehicle fuel efficiency affect decisions by vehicle suppliers, transportation service suppliers, and those who demand transportation services. Policies to shift to alternative transportation fuels affect decisions by these decision makers, by fuel suppliers, and possibly by infrastructure developers as well. Projected long-term increases in the demand for transportation services will offset emission reductions from these policies unless service can be delivered by modes with lower emissions or demand growth can be managed, as in other sectors of the economy. Additional research is needed to determine the most effective demand management strategies.

Recent international meetings and U.S. legislative proposals have recommended reducing annual emissions of carbon dioxide (CO_2) and perhaps other greenhouse gases by 20 to 50 percent over the next 10 to 50 years to forestall or reduce atmospheric warming and other changes in global climate. The institutional structure of decision making in the transportation sector, the nature of the sector's technologies, and the processes of technological change present opportunities for and constraints on reducing greenhouse gas emissions. They require careful consideration when designing policy options to implement an emissions reduction strategy. Some of the more important opportunities and constraints, their causes, and the implications they may have for policies that might reduce greenhouse gas emissions are identified.

TRANSPORTATION'S CONTRIBUTION TO GREENHOUSE GAS PRODUCTION

Vehicle operations in the U.S. transportation sector consume 28 percent of the nation's energy, 97 percent as petroleum fuels (*1*). It is estimated that this contributes 32 percent of the nation's emissions of CO_2 from energy use and 7 percent of the world's emissions of CO_2 from energy use (*2*). Highway transportation modes consume 73 percent of the energy used in vehicle operations (*1*) and will be the focus of any effort to reduce greenhouse gas emissions significantly.

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In addition to vehicle operations, transportation contributes to CO_2 emissions through

- The energy used to refine petroleum into fuels,
- The energy used to make and maintain transportation vehicles,
- The energy used to build transportation infrastructure,
- The energy used to make the materials from which vehicles and infrastructure are made, and
- The chemical processes of producing cement for infrastructure.

Transportation also contributes other gases that contribute to global warming: mobile air-conditioning equipment used in transportation is a significant emitter of chlorofluorocarbons (CFCs), and the natural gas pipeline system releases some methane (CH_4). Finally, motor vehicle operations release significant amounts of nitrogen oxides (NO_x), which may be precursors to nitrous oxide (N_2O), another greenhouse gas, and carbon monoxide (CO), which may retard removal of CH_4 from the atmosphere. CFCs, CH_4, and N_2O contribute more per molecule to warming than does CO_2, and together at present atmospheric concentrations these other greenhouse gases may contribute roughly as much to warming as CO_2 does now (*3*).

Efforts to reduce the transportation sector's emissions will require such potentially radical changes as fuel switching, rapid movement of new and cleaner vehicle technologies from prototype to production and marketing, and substantial modifications in the demand for transportation services. The speed at which such changes will occur depends largely on the speed with which the innovation process leads to technological breakthroughs in fuel and engine designs, the methods adopted for bringing such advanced technology to the marketplace, and the response of the marketplace (i.e., businesses and households) to both private-sector and public-policy initiatives to change the way we travel. Much has been written on the technical aspects of new fuels and engine designs (*4–6*). Relatively little analysis has been devoted to how the sector's processes for making decisions affect its ability to adapt to change and the choices it makes about the supply of, demand for, and use of these new technologies.

The transportation sector changes incrementally. Since World War II, the structure of the U.S. economy has changed slowly but dramatically through growth and major shifts from the Northeast to the South and West. The transportation sector has responded with new infrastructure, vehicle technologies, services, and demands. Change on this scale, at this pace, can apparently be accommodated. Considering the long lead times required for investments in relatively inflexible transportation infrastructure and plant and operating equipment and at the same time the major revisions in government regulation of transportation service supply, the transportation sector has demonstrated a remarkable capacity for institutional change during the past three decades. This flexibility will probably be tested to its limits if a concerted effort to bring about environmentally sound transportation systems becomes necessary because of global warming.

STRUCTURE OF DECISION MAKING IN THE TRANSPORTATION SECTOR

Although it is conventional to divide the transportation sector into modes, analysis of the sector's decision making is more meaningful if it is divided according to decisions made with respect to five major activities:

- Infrastructure supply,
- Vehicle supply,
- Fuel supply,
- Transportation services supply, and
- Demand for and consumption of services.

With a few exceptions (notably railroads and pipelines, which supply both services and their own infrastructure, and households or businesses that supply transportation services to meet their own demand), businesses that engage in one of these activities do not engage to any significant extent in the others. All the activities involve decisions about large, long-lived capital investments that require long lead times. Once made, these investments constrain subsequent decisions in the sector. The number, size, and influence of individual decision makers vary with the different activities.

Infrastructure Supply

Infrastructure developers are relatively few in number, and governments are the primary decision makers for several modes. Federal and state governments have primary responsibility for developing and building highways, and the federal government has this responsibility for inland navigation. Federal, state, and local governments develop port and airport facilities, but local governments are significant only in developing general aviation airports, which contribute relatively small quantities of greenhouse gases. Local governments are significant decision makers in providing streets and in determining associated spatial patterns of demand for services. Private-sector development of infrastructure is limited to (*a*) railroads, of which, following the mergers of the 1980s, fewer than 20 of the largest account for most of the track; (*b*) oil and gas pipeline companies, which number roughly 136 and 1,700, respectively; and (*c*) a dozen or so major airlines, whose investments in terminal facilities at hub airports affect airport capacity.

Each of these organizations typically contracts with much larger numbers of other businesses that build the infrastructure, but in general it is necessary to influence only the relatively small number of actors mentioned to effect change in the provision of infrastructure. Lead times to plan and build new infrastructure can range from a few years to a decade or more, depending on the mode and local circumstances.

Vehicle Supply

The same is true for vehicle suppliers. Worldwide, there are no more than 30 significant automobile suppliers (*7*). The U.S. market for automobiles and light trucks is supplied by the "big three" domestic automobile makers, a half dozen Japanese manufacturers operating or building plants in the United States, and imports from another dozen or so major manufacturers worldwide. Only seven major heavy-truck manufacturers and only two major diesel-electric railroad locomotive builders currently produce in the United States. A handful of companies dominate the world's production of commercial aircraft and engines.

Once again, these large companies contract with a much larger number of small enterprises to supply vehicle components. Significant change can be brought about by policies aimed at the major companies. However, lead times for new products are 3 to 5 years in most modes if a commercial prototype exists and longer if such a prototype must be developed. Production of successful designs may run for 6 years or longer and, once added to the fleet, a vehicle may operate for 7 to 20 years, depending on the mode. Therefore, major changes in the stock of vehicles can take 10 to 15 years or more to implement.

Fuel Supply

Petroleum supplies 97.4 percent of transportation fuel, and 74 percent is refined by the 16 largest oil companies. A much larger number of companies are involved in transporting, distributing, and selling the fuel to the final consumer. Again, investments tend to be long-lived, and lead times for fuel supply and transportation facilities tend to be long; those for fuel retailing can be much shorter.

Service Supply

Stephenson (*8*) categorized the nation's commercial transportation service suppliers in 1987. There were 856 Class I truckers (with $5 million or more in annual revenue), 1,266 Class II truckers, 35,500 smaller Class III truckers, and between 100,000 and 150,000 owner-operator trucking firms. There were 14 major airlines (with $1 billion or more in annual revenues), 80 smaller national and regional carriers of various sizes, and 169 commuter and cargo airlines. There were 18 Class I railroads (with $50 million or more in annual revenues) and 481 smaller Class II and local railroads, including many short-line operators. Waterborne transport consisted of a mixture of businesses, none of which dominated the mode. To these must be added bus and taxi companies and the vehicle fleets of governments, businesses, and households that supply their own transportation services. The transportation service supply activity thus contains a larger and more diverse group of decision makers than the activities described previously, especially in highway transportation.

During the past decade deregulation of transportation service supply industries has led suppliers to give greater attention to reducing the costs of providing services and, in some cases, to improving the match between service provision and service demand. Increased price competition coupled with the rather stagnant transportation market of the early 1980s led to declining revenues and a reduction in investment in more efficient equipment or in other, longer-range cost-cutting measures. The age of vehicle fleets in all major transportation modes has been increasing as a result.

The airline and trucking companies, in particular, appear to be on the verge of major investments to replace aging vehicles at a time when they are also seeking to expand their services. Airlines are seeking to reduce vehicle purchase and financial costs rather than fuel costs (*9*) and are concerned that reducing the latter would increase the former; the same appears to be true for trucking companies. Energy costs are roughly 10 to 20 percent of the total costs of supplying commercial transportation services; in comparison, labor typically accounts for 40 to 70 percent of total costs. Present concerns with vehicle purchase costs may reduce the rate of fleet turnover, as may the present backlog of orders at major aircraft suppliers. The recent trend of airline companies to lease rather than purchase vehicles requires additional study to determine its effects on fleet fuel efficiency.

Service Consumption

All individuals, households, firms, and public organizations consume transportation services. Travel as an activity continues to increase rapidly. Highway vehicle miles traveled (VMT) are projected to increase at an annual rate of 2 percent for the foreseeable future (*10,11*), doubling by 2020. Growth rates for highway freight, air freight, and commercial air transportation are also projected to remain high. As will be discussed, projected growth in demand is a major constraint on the ability to reduce emissions of greenhouse gases from present levels.

Much consumption of transportation is a consequence of demand for other activities that require transportation (commuting, movement of goods); some consumption results from a demand for the experience of travel itself in leisure or social activities or as a demand for variety and mobility. On the average, U.S. households spend about 21 percent of their income on transportation services, which is more than they spend on food and clothing (*11*). Although this percentage has been reasonably constant during the past 35 years, its makeup has changed. For example, between 1969 and 1983, commuting declined from 33.6 to 30.1 percent of household VMT, and other related business activities declined from 7.9 to 4.2 percent. During the same period, discretionary VMT, notably in shopping and personal business trips, increased from 19.3 to 30.4 percent of household travel (*11*).

Even the demand for and consumption of transportation involves long-term commitments of large amounts of capital, primarily in buildings, factories, and housing. Businesses and households may relocate, but they leave behind fixed investments that constrain development of infrastructure and aggregate demand for transportation services.

Implications of the Transportation Decision-Making Structure

This decision-making structure has several implications for any effort to introduce major changes into the sector. First, the fragmentation of decision making into these five functions means that many changes, especially fundamental ones, will require measures to coordinate decisions across functional groups. The long lifetimes and large sizes of investments in the sector's various activities increase the need for coordination, because the risk that changes in one activity may not be consistent with investments in the others discourages fundamental changes. Second, the variation in size and market dominance among businesses that perform these different functions means that different approaches will be required to influence decision making. Policy instruments geared to the few rarely apply with equal success to the many. It is easier to ensure that a small number of large businesses comply with regulations than it is to ensure that a large number of small businesses or individuals do so. On the other hand, providing new information or a tax credit may influence the decision making of households, but large businesses already may have all the information they need for their own decisions, and a tax credit large enough to influence their decisions may be too large to gain political support. Thus, efforts to change decisions in the transportation sector require that policy instruments be matched to the characteristics and needs of the decision makers.

Significant reductions in the sector's potential emissions will require a carefully tailored package of instruments aimed at different decision makers. If such reductions are to be realized in the next 15 to 20 years, the long lead times and lifetimes of investments in the sector require that such a package be assembled and implemented quickly.

STRATEGIES FOR REDUCING EMISSIONS

Five broad strategies could reduce greenhouse gas emissions from the transportation sector:

- Improve methods of infrastructure construction,
- Improve methods of vehicle manufacture,
- Improve vehicle fuel efficiency,
- Switch to nonpetroleum fuels with significantly reduced greenhouse gas emissions, and
- Modify demand for transportation either by encouraging the use of transportation modes with lower emissions levels or by reducing the rate of growth in demand for transportation services.

The first two strategies are oriented toward manufacturing and are not considered further. The last three seek to reduce emissions from transportation vehicle operations and are the focus of the remainder of this paper. The relationships between technological and decision-making processes within the sector and the options chosen to influence these processes will determine the success of the strategies.

Relationships Among the Strategies

These three strategies are themselves interrelated. Table 1 and Figure 1 present estimates of CO_2-equivalent emissions

TABLE 1 EMISSIONS OF CARBON DIOXIDE–EQUIVALENT GASES FROM ALTERNATIVE HIGHWAY VEHICULAR FUELS (*12*)

		Scenario 1		Scenario 2		Scenario 3	
		CO_2-equivalent emissions[1] from present fleet and VMT, or from a 29 mpg fleet in 2020 after 2% growth/year in VMT		CO_2-equivalent emissions[2] from 29 mpg fleet with present VMT, or from 58 mpg fleet in 2020 after 2% growth/year in VMT		CO_2-equivalent emissions[2] from 58 mpg fleet in 2020 after 1% growth/year in VMT	
Fuel	Feedstock	GT/year	% change relative to present petroleum fleet	GT/year	% change relative to present petroleum fleet	GT/year	% change relative to present petroleum fleet
Electricity	Solar	0	-100	0	-100	0	-100
Hydrogen	Solar	negligible	~-100	negligible	~-100	negligible	~-100
Natural Gas (CNG, LNG)	Biomass	0	~-100	0	~-100	0	~-100
Methanol	Biomass	0	~-100	0	~-100	0	~-100
Compressed Natural Gas	Natural Gas	1.081	-19	.541	-60	.383	-71
Electricity	Natural Gas	*	-18	*	-59	*	-71
Liquified Natural Gas	Natural Gas	1.135	-15	.568	-57	.402	-70
Methanol	Natural Gas	1.293	-3	.647	-51	.458	-66
Electricity	Present Power Mix[3]	*	-1	*	-51	*	-65
Gasoline	Crude Oil	1.336	-	.668	-50	.473	-65
Electricity	New Coal Plants	*	+26	*	-37	*	-55
Methanol (high-efficiency plant)	Coal	2.026	+52	1.013	-24	.718	-46
Methanol	Coal	2.639	+98	1.320	-2	.935	-30
Hydride	Coal	2.677	+100	1.335	-0	.948	-29
Liquid Hydrogen	Coal	3.240	+143	1.620	+21	1.148	-14

[1]See (12) for further details. Some emissions were omitted from the calculations.

[2]Calculated by authors from the estimates made by (12); some of their assumptions may not hold up under these additional calculations.

[3]The current plant mix generates electricity from coal, petroleum, natural gas, and from sources that do not emit greenhouse gases.

*Estimates of aggregate carbon emissions from electric vehicles depend upon level of penetration assumed in the fleet; such vehicles cannot be used in some applications. Calculations of percent change for electric vehicles are on a per vehicle basis which assumes that electric vehicles would be 3 times more efficient than the internal combustion vehicles they replace. This may be unrealistic in the 29 and 58 mpg scenarios.

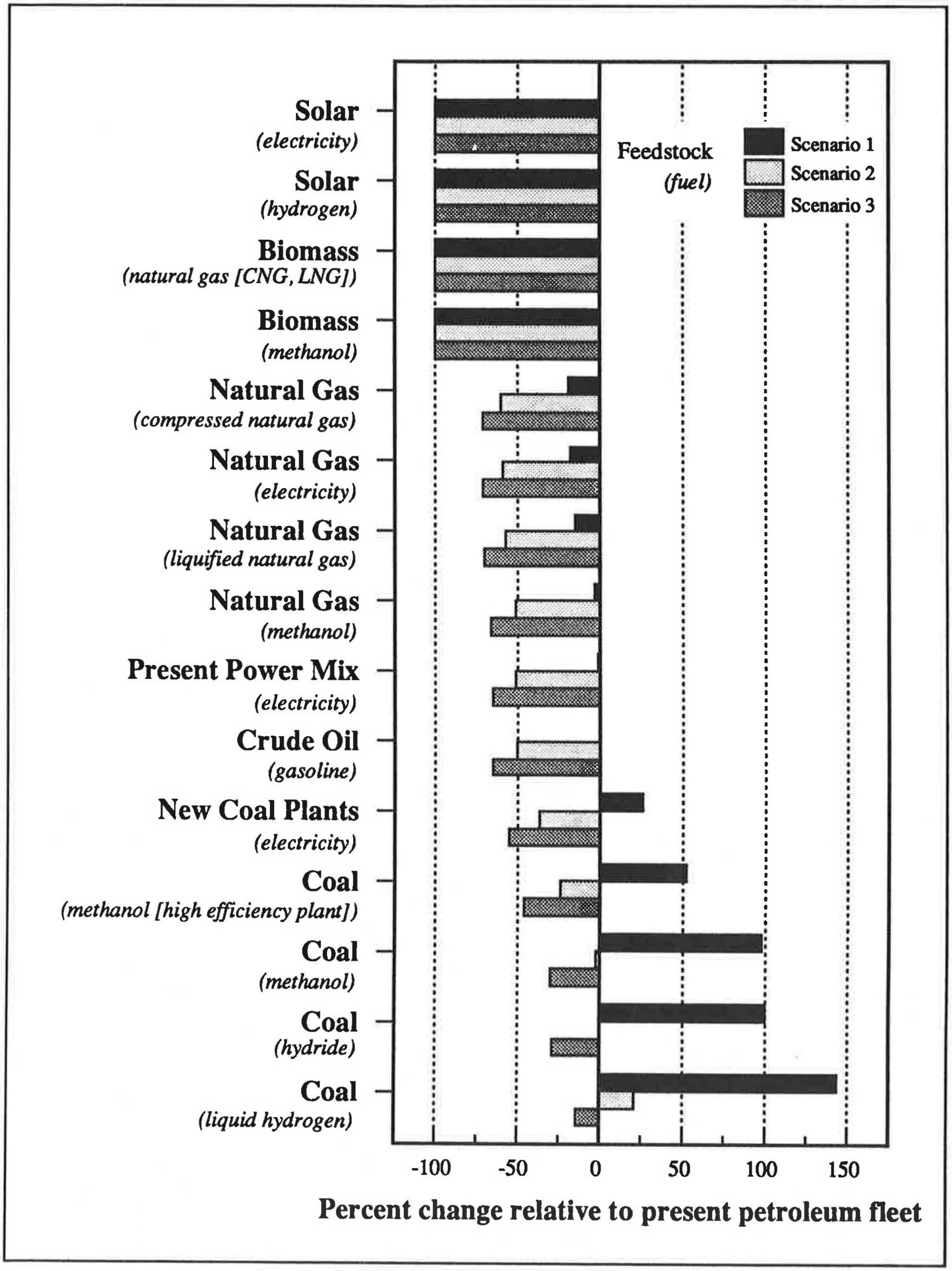

FIGURE 1 Percentage change in emissions of carbon dioxide–equivalent gases from alternative highway vehicular fuels.

(calculated on the basis of the warming effect of CO_2 and other gases) for some alternative automobile fuels and their supply systems in three fuel-efficiency–demand scenarios; the information relies heavily on work by DeLuchi et al. (*12*). The 2 percent annual growth rate in VMT assumed in the scenarios is within the range of growth projected by the Federal Highway Administration (*11*) and yields a near-doubling of VMT by 2020. Thus, a policy to double vehicle miles per gallon (mpg) for the petroleum-fueled fleet during the next 30 years would reduce *growth* in greenhouse gas emissions but would not reduce *emissions* from present levels.

Fuels from solar or renewable biomass feedstock would eliminate emissions in all three scenarios, assuming that biomass used to supply fuels was regrown. In the first scenario (present demand and mpg or doubled demand and mpg by 2020), replacing petroleum fuels with natural gas or with electricity from the present power plant stock would yield modest reductions in emissions—less than the 20 percent target that some have proposed. Although Table 1 does not present the effects of switching fuels when demand increases and fuel efficiency does not, it is clear that under such a scenario growth would more than offset the emission reductions that switching to natural gas would achieve. All coal-based fuels would increase emissions in the first scenario.

In the second scenario (present demand with doubled mpg or doubled demand with quadrupled mpg), all the fuels derived from natural gas would reduce emissions by at least 50 percent, and methanol from coal would reduce emissions by 24 percent from present levels. In the third scenario (halved demand growth rate with quadrupled mpg), VMT would increase nearly 35 percent by 2020. Increased fuel efficiency would allow all the coal-based alternative fuels to reduce emissions from present levels, but still by less than 50 percent, and still by less than what improved fuel efficiency would permit natural gas- or petroleum-based fuels to achieve.

Growth rates projected by the Federal Highway Administration for heavy-truck VMT are even higher than the 2 percent/year used in Table 1 and Figure 1, as are growth rates for commercial air traffic projected through 2000 (*13*). Thus, although the emission totals and reductions for these modes would differ from those for automobiles, a general problem remains of reducing emissions while demand increases.

Strategies to improve fuel efficiency, switch fuels, and reduce VMT are related in another fundamental way. Two obstacles to the use of alternative fuels are the large quantity of fuel that must be supplied to the vehicle fleet relative to the availability of some fuel feedstocks (biomass and some sources of natural gas) and the lower energy density and reduced vehicle operating range for a volume of alternative fuel. Improving vehicle fuel efficiency reduces the quantity of fuel needed to supply a vehicle fleet, as does reducing growth in demand for travel. In addition, improvements in drivetrain efficiency, vehicle weight, and aerodynamics are largely independent of fuel and engine technology and would allow a given volume of fuel to provide a greater operating range. Thus, doubling fuel efficiency and switching to methanol, a fuel with half the energy density of gasoline, would leave the range of the vehicle unchanged from present expectations and experience and might improve the attractiveness of methanol-fueled vehicles to potential purchasers.

Because of these interrelationships, a policy to reduce greenhouse gas emissions from present levels should view the strategies as complements rather than as substitutes for each other. For convenience, however, the three strategies will be discussed separately.

Improving Fuel Efficiency

Several trends may reduce CO_2 emissions slightly in the short term (less than 10 years) even without a change in policy. First, the average new vehicle being marketed is more fuel efficient than the average vehicle now in service for automobiles (30 percent), heavy trucks (15 to 20 percent), railroad locomotives (15 percent), and commercial aircraft (*1,8,14,15*). The process of vehicle replacement thus will cause some reduction in fuel consumption and emissions. Second, average new-car fuel efficiency has been improving slightly even in the absence of stricter efficiency standards, and the technology to improve fuel efficiency continues to develop for several reasons (*4*) unrelated to fuel efficiency (for example, to reduce passenger compartment noise, maintenance requirements, or manufacturing costs). The effectiveness of these trends in reducing CO_2 emissions is limited by the long time periods needed to replace entire vehicle fleets—on the order of 20 years for cars, longer for commercial aircraft—and by anticipated increases in the demand for transportation. In addition, preferences of vehicle purchasers for vehicle characteristics other than improved fuel efficiency will reduce the improvement in fleet fuel efficiency below what existing technology could achieve.

A technology base exists for increasing the rate of improvement in fuel efficiency for automobiles, which consume 44 percent of the energy used in vehicle operations, and probably for other modes as well. The U.S. Department of Energy has estimated that proven technology could substantially improve new-car fuel efficiency to 35 to 40 mpg and be cost-effective at gasoline prices of \$1.50 to \$2.00 per gallon (*14*). Bleviss (*4*) reports prototypes developed by European automobile makers that would average more than 60 mpg in city driving and 70 mpg in highway driving, in some cases with vehicle price, passenger space, and comfort comparable with cars now on the market. Although many of these prototypes use diesel engines that may be unable to meet restrictions on other pollutants, the prototypes also use technologies that would improve fuel efficiency regardless of engine type. It is likely that additional technologies to improve fuel efficiency exist but are not now cost-effective. Although some disagreement exists about the cost of achieving different levels of fuel efficiency, there appears to be agreement that the technology is available to improve fuel efficiency. Two factors limit its rapid introduction.

First, although "quick fixes" can be introduced into automobile product lines in 3 to 5 years, good solutions usually require more than one product generation (*7*). Quick fixes frequently sacrifice cost or performance of the vehicle in order to achieve the objective of the fix (improved fuel efficiency in this case), whereas good solutions require less sacrifice and sometimes yield improvements in cost or other performance characteristics as well as in the targeted objective (*4*). The normal process of technological change in vehicle design and manufacture is incremental, in large part because of the complexity of the vehicle and the manufacturing systems that produce it (*7*). Exceeding this pace increases technical risk for the manufacturer and the subsequent risk that vehicle purchasers will be dissatisfied and will purchase from a competitor.

Second, even if technological change entailed no technical risk in the product, the fragmented decision making in the sector would place a manufacturer or component supplier at financial risk. Decisions taken today to improve vehicle fuel efficiency might fail to match consumer demand for fuel efficiency once the new product reaches the market in 3 to 5 years. This could place the manufacturer at a disadvantage relative to other manufacturers who choose not to improve the fuel efficiency of their products. Thus, decisions of one manufacturer to produce vehicles need to be coordinated with those of other manufacturers and with the decisions of service suppliers who purchase vehicles.

One way to effect this coordination is through average fuel economy standards such as those imposed in the 1970s to improve automobile fuel efficiency. The corporate average fuel economy standards assured each vehicle manufacturer that its competitors would provide comparable levels of fuel efficiency even if future demand for fuel efficiency decreased (as in fact has occurred). This reduced a major source of uncertainty for the manufacturers (*4,5,7,15*). In addition, by requiring continual, gradual improvements in fuel efficiency to levels announced in advance, the standards reduced the technical risk of having to make major changes in vehicle design all at once in order to comply with the standards. A recent analysis by Greene (*16*) indicates that since the automotive fuel efficiency standards were imposed in 1975, they appear to have been at least twice as important as market trends in fuel prices in affecting automobile makers' planning for future products.

One suggested alternative to standards for coordinating decision making is to use higher fuel prices or fuel taxes to encourage the purchase of more fuel efficient vehicles and thus to encourage manufacturers to supply these vehicles. However, von Hippel (*17*) concludes that when automobiles reach a fuel efficiency of approximately 30 mpg, or slightly above the current new-car average fuel efficiency in the United States, the life-cycle cost of improving fuel efficiency offsets reductions in the life-cycle fuel cost from lower fuel consumption. As a result, purchasers become indifferent to further improvements in fuel efficiency, even for large increases in the price of fuel. In addition, households behave in the aggregate as though they use discount rates well above market rates to value future savings from lower fuel consumption. Von Hippel's analysis suggests that the point of indifference to higher fuel efficiency already has been reached in the domestic automobile market, and that higher fuel prices or taxes will have little direct effect on the fuel efficiency of new cars being purchased. The principal value of higher fuel taxes would be (*a*) as a signal to manufacturers and purchasers that the government considers fuel efficiency to be important and (*b*) as a source of revenue that could be used to fund other measures to reduce emissions of greenhouse gases from transportation.

Although highway vehicles with greater fuel efficiency could be marketed in 3 to 5 years, most of the vehicles they replace would continue in service with other owners instead of being removed from service. Half of the automobiles sold in a given year still will be in use 10 years later, and trucks remain in use for even longer periods (*1*). Thus, an additional decade would pass before the new vehicles begin to reduce fuel consumption significantly, and close to another decade would pass before the fleet turns over completely. Given the large market and long useful lifetimes for used vehicles, efforts to accelerate fleet turnover are likely to be very expensive. Therefore, if policy makers conclude that significant improvements in fuel economy are needed to reduce emissions in 15 to 20 years, policy instruments must be enacted quickly to meet such a schedule.

The recent emergence of global markets for vehicle manufacturers is a further and increasingly important factor in the sector's ability to change. It complicates the choice of options for implementing policy. In the case of automobiles, the United States is such an important portion of the global market and economies of scale are sufficiently important to competitiveness that setting standards for the performance of vehicles sold here can influence the performance of vehicles marketed elsewhere (*4*). On the other hand, requiring domestic commercial airframe and engine manufacturers to improve vehicle performance could place them at a disadvantage relative to foreign manufacturers, especially in foreign markets. In such a case international as well as national agreements on vehicle performance may be needed before implementing domestic policies.

Finally, the behavior of transportation service providers in operating and maintaining vehicles needs to be coordinated with vehicle designs that improve fuel efficiency. Unlike changes in vehicle technology, changes in operating and maintenance practices can be implemented in a few years and bring about immediate reductions in greenhouse gas emissions. For example, increasing automobile speed to 65 mi/hr from 55 mi/hr can reduce fuel efficiency from 5 to 30 percent, depending on the vehicle (*1*), and idling the engine of a heavy truck to keep fuel warm during prolonged cold-weather stops uses much more fuel than a fuel heater (*18*). Short-duration training programs for automobile drivers have been shown to reduce fuel consumption by 10 percent in the short term (*19*). However, additional research is needed to determine the most effective means of providing this information and, because little is known about how long changes in operator behavior persist after short-duration training, additional research is needed to determine how best to deliver information for long-term retention and use.

Similarly, poorly maintained vehicles consume more fuel than those in tune. Augmenting state and local automobile inspection programs so that they test fuel efficiency as well as other emission control and safety equipment could reduce fuel consumption. Trucking and airline companies are beginning to anticipate a shortage of skilled labor to maintain vehicles and are placing greater emphasis on the expected maintainability of what they buy (*20*). If inspection and maintenance programs for automobile fuel efficiency become widespread and stringent, these programs might cause automobile makers to design vehicles that require less cost and effort to maintain and perhaps also reduce the long-term cost of the inspection program.

An additional obstacle may arise if the federal government requires programs to encourage changes in operator behavior but leaves implementation to local or state governments, as has occurred in the past. Implementation of inspection and training programs at local or state levels promotes flexibility and tailoring of the programs to local circumstances. However, effective programs (especially requirements for inspection and maintenance) may not have the political and financial resources needed to realize their potential.

Switching to Cleaner Fuels

If greenhouse gas emissions are measured at the vehicle exhaust, then electricity, hydrogen, natural gas, methanol, and ethanol all yield fewer emissions than petroleum fuels (*21*). However, the production and supply systems for each of these cleaner alternatives require energy and can emit greenhouse gases. The net effect of switching from petroleum to other fuels depends on the combined production and consumption system. Any policy to reduce greenhouse gas emissions by switching from petroleum to other fuels should consider the feedstock, the processes to be used to convert it to fuel, the form of the fuel, and the level of demand anticipated (see Table 1 and Figure 1).

Vehicle technologies that use alternative fuels have been demonstrated commercially (*5,22*), although electricity cannot power all modes and the performance of presently available electric highway vehicles remains extremely limited compared with that of petroleum vehicles. Recommendation of a choice of alternative fuels is beyond the scope of this paper except to note that electricity from nonfossil sources or nonemitting solar or biomass fuel feedstocks are probably the only long-term solutions to prevent atmospheric concentrations of greenhouse gases from increasing. However, a policy to switch to an alternative will need to coordinate decision making across the five activities of the transportation sector.

As discussed at length by Sperling (*5*), the introduction of vehicles that use alternative fuels requires assurance to the vehicle suppliers and to the service suppliers who purchase vehicles that the alternative fuel will be available for the expected lifetimes of the vehicles, competitively priced, and reasonably convenient. Potential suppliers of alternative fuels, on the other hand, require assurance that there will be vehicles and demand for the fuel before they will invest in supplying it. Production of methane and electricity requires less coordination than production of alcohol fuels because they already have large end-use markets outside transportation and could absorb small, gradual increases in demand from transportation. However, electric vehicles that require an electrified right-of-way would require coordination with infrastructure suppliers to assure vehicle manufacturers and purchasers that the vehicles could be used. Without these assurances, the long lead time between a decision to invest in alternatives and a return on the investment makes switching fuels extremely risky.

A technical solution to some coordination problems is dual-fueled vehicles that can use either petroleum or an alternative fuel (*5*). Such vehicles have been demonstrated for methanol and compressed natural gas, but they usually incur penalties in cost, fuel efficiency, and performance relative to single-fueled vehicles. For example, dual-fueling might not incur any fuel efficiency penalty when petroleum fuels are used, but the vehicle would not be optimally efficient with the alternate fuel.

The need to coordinate decision makers would be greatest for highway modes for several reasons. First, this portion of the transportation sector contains the largest number of decision makers, primarily among service suppliers. Second, within a few broad categories (light trucks, heavy trucks, and cars), highway vehicles are functionally homogeneous. When combined with a slow turnover of the vehicle fleet and a relatively stagnant vehicle market, this homogeneity makes it difficult for alternatives to penetrate the market. Within each category, most vehicles are designed to be and are used as general-purpose vehicles under a wide range of conditions; the vehicles are not specialized for a specific trip purpose, driving range, geographic area, or time slot. The flexibility, mobility, and quality of service of these vehicles deteriorate rapidly if fuel supplies are uncertain or restricted in quantity or geographic range, as was evident during the oil supply interruptions of the 1970s. Finally, the relatively stagnant growth of the U.S. automobile market compounds the problems of market homogeneity, because an alternative must take market share from existing product lines instead of from growth in the market.

The exceptions to this generalization are commercial service suppliers who own their own fleets and operate within an urban area or between a small number of urban areas; they include airlines and railroads as well as some service suppliers who use highway vehicles. If these service suppliers have assurance that the fuel will be available, they can provide their own refueling facilities and schedule the operation of their vehicles to ensure that these facilities will be adequate. However, these suppliers account for only a small proportion of highway vehicles, which consume the most fuel.

Brazil, Canada, and New Zealand all have adopted policies to switch portions of their highway vehicle fleets from petroleum to alternative fuels (*5,22*). On the basis of this international experience, effecting a switch to alternative fuels requires a concerted, strong, well-funded package of government actions directed at a variety of concerns and various decision makers. Measures are needed to ensure the production of the alternative fuel; these are highly dependent on the alternative chosen (*5*). Measures are also needed to ensure

- The retail price competitiveness of the alternative fuel,
- The availability of the alternative at enough locations and in enough quantity to make refueling convenient,
- The conversion of existing vehicles and the production of new vehicles to use the alternative in sufficient quantity to provide a stable market for suppliers of the alternative, and
- The availability of personnel who are competent to convert existing vehicles and to maintain vehicles that have been converted or designed to use the alternative.

Modifying Demand

Demand for transportation services affects greenhouse gas emissions both in its size and in the choice of transportation modes used to provide the service.

Most of what is understood about individual transportation demand involves mode choice rather than the decision or need to travel. Most research on mode choice has emphasized the choices commuters make between the automobile and travel by rail transit, bus, carpooling, or vanpooling, in which high-occupancy vehicles (HOVs) deliver a service that is perceived to differ qualitatively from individual car use. Research on commuter mode choice and policies to influence it have been motivated by desires to reduce energy consumption, reduce traffic congestion, improve urban air quality, and plan investments in infrastructure. Each of these objectives should prompt continued interest in mode switching, even in the absence of concern over global climate change.

Options for influencing mode choice include

- Controls on parking and highway use (including provision of HOV lanes),
- Fiscal incentives and subsidies that increase the cost of solo commuting relative to HOV modes or that reduce costs for developers and business tenants who promote HOV use by their companies and employees; and
- Informational incentives such as advertising and moral suasion directed at businesses and individuals to promote or use HOV modes.

With the exception of a small (but growing) number of dedicated HOV bus-rideshare lanes, these options have had limited success in shifting commuting demand from private automobiles to HOV modes (*23*). People value highly the privacy and convenience of the automobile. However, the lack of success of many schemes may also be due in part to the local nature of the effort. As in the case of vehicle inspection programs, local implementation of mode-switching programs enables plans to draw on detailed local understanding of opportunities and constraints on various mode-switching options. However, even with support from the private sector, local governments often find it difficult to change people's preferred travel behavior. Federal funds to support local mode-switching efforts would reduce the vulnerability of these efforts to loss of local funding and might promote more effective local plans. In addition, these past efforts have been small in comparison with the federal expenditures, funded from user taxes, that support the provision of infrastructure for the modes from which switching is desired.

Approximately one in five commuters in 1983 was a ride-sharer (in a carpool or vanpool), which reduced the nation's transportation energy use by an estimated 4 percent (*23*). Only about 6 percent of commuters used public transportation (*11*). Even doubling the proportion of commuters who share rides would yield only a small reduction in the rate of greenhouse gas emissions, because commuting accounts only for 30 percent of annual highway VMT.

On the other hand, there is great potential to reduce future demand for transportation energy by reducing the growth rate in demand for transportation services, as the estimates in Table 1 indicate. Unfortunately, too little is understood about the determinants of demand for transportation service to permit the design of policies to reduce the projected growth rate in VMT by a significant percentage. National forecasts of demand still depend largely on projecting present trends into the future instead of on an understanding of how changes in the locations and behavior of individuals and businesses affect the number and lengths of trips demanded. Most transportation planning takes projected demand as something given and then attempts to satisfy it instead of taking a more integrated approach that asks whether it might be more cost-effective to reduce future VMT growth.

In this regard, although transportation planning has a rich literature, its approach to demand today is similar to the way electric power systems planning approached demand before the mid-1970s; since then, the electric utility industry has begun to recognize the potential to reduce service costs by modifying projected demand instead of accepting it (*24*). Analogous efforts in the transportation field can be found in the promotion of flexible work time and staggered work hours, opportunities to substitute telecommunications for physical movement, and land-use planning or other measures to reduce the number or length of vehicle trips for commuting and shopping.

Pursuing the comparison between sectors, efforts to manage electricity demand growth have occurred in a decision-making structure that is much less fragmented than that in the transportation sector. For example, the activities of supplying infrastructure, energy (fuel), and service are largely integrated within the electric utility, and many policies to manage demand can be directed at the utility through the public utility commission that already regulates it. In addition, the utility has a direct relationship with each customer, through metering and billing for service, which it can use to provide information and repackage its service to influence consumer demand for electricity. Research will be required to identify both alternative institutional arrangements that will better manage demand for transportation services and policy instruments to encourage these arrangements to develop. Deregulation and the increasing importance of vehicle leasing in several modes illustrate that the decision-making structure of the transportation sector can change.

A more fundamental obstacle to managing transportation demand is uncertainty about determinants of demand. For example, major uncertainties exist about how people and institutions will respond to changes in technologies and services that might permit (but not require) a reduction in physical movement, to the effective increase in leisure time that might result if the amount of time required for commuting to work were reduced substantially, and to the seemingly inevitable increase in urban traffic congestion during the next two decades. Plausible scenarios can be constructed that predict increased, steady, or reduced demand for travel in response to each of these conditions.

Similarly, major uncertainties exist about the effect of fuel prices on future demand. The oil price increases of the 1970s demonstrated that a significant, rapid increase in retail fuel prices can reduce demand in the short term (*25*). However, higher prices did not persist into the medium and long term to permit study of their effectiveness in these periods. In addition, improvements in vehicle fuel efficiency reduced the cost of driving despite high fuel prices. Finally, part of the decline in VMT observed following the fuel price increases may have been caused by the economic recessions induced by the higher fuel prices, not by direct consumer responses to the higher prices.

Demand for freight transportation involves similar issues of mode choice amid broad economic trends whose implications for future demand are uncertain. Railroads, heavy trucks, and inland waterways long have competed for certain types of business, but trends in the economy may change future mode choices. For example, manufacturers in many industries are switching from production strategies that rely on large inventories to strategies that maintain smaller inventories delivered more frequently in smaller lots (*26,27*). This shift toward "just-in-time" delivery favors modes with great flexibility and high fuel consumption (and emissions), such as truck and air, relative to rail and barge modes. Although railroads are successfully contesting some markets for high-value shipments, in general the potential to reduce greenhouse gas emissions by shifting freight to energy-efficient modes appears small given the continuing changes in manufacturing strategy. The long term implications of these changes in production strategy for transportation demand are unclear. In the short term, they are likely to increase demand for transportation. In the medium and long terms, relocation of some parts and materials suppliers to be near the final assembly plant will reduce demand, but it is uncertain how large the reduced demand will be relative to present demand.

In short, much more research is needed to understand the determinants of demand before policies can be formulated to reduce expected rates of VMT growth. Some large-scale experimentation or monitoring of household behavior before and after the introduction of flexible work schedules or telecommunications should be part of this effort, to determine the extent to which people use reductions in some forms of travel to increase other travel activities. The effects of land use patterns on transportation should be examined in addition to the historic emphasis on the effects of transportation access on land use. The microscale of land use planning needs more careful attention; for example, suburban office parks have the potential to reduce trip length, but their internal structure may discourage use of public transportation for commuting to them. The study of suburban "activity centers" (*28*) would complement this effort, as would the further development of combined public- and private-sector projects to encourage experimentation with such mutually designed controls on land development as traffic control warrants.

CONCLUSIONS

Aggressive intervention will be needed to reduce emissions of greenhouse gases from the operations of transportation vehicles. Much of this intervention can be directed at relatively small numbers of key decision makers, especially vehicle manufacturers and fuel suppliers, as well as at transportation service companies involved with air and rail. Such intervention, in the form of standards for vehicle fuel efficiency, requirements for the use or production of alternative fuels, and standards for vehicle operation and maintenance, could reduce substantially the expected growth rates in transportation energy consumption and the associated emissions. To achieve the maximum possible reduction from these interventions, they should be complemented by measures to encourage fuel-efficient decision making by the much larger number of people who purchase and operate highway vehicles. Unless this package of measures is complemented further, however, either by policies to reduce anticipated growth in demand or by significant improvements in the cost and performance of alternative vehicle-and-fuel systems that cause no net release of greenhouse gases, in the long term emissions will increase from present levels. These alternatives require additional research in the short term if they are to yield results that can be used to reduce greenhouse gas emission by the 20 to 50 percent levels that some have suggested may be desirable during the next 10 to 50 years.

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